Effects of outdoor air supply rates on subjective factors in three call centers in the tropics (a principal component analysis approach)

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5 authors, including:

K. W. Tham
National University of Singapore

Pawel Wargocki
Technical University of Denmark

David P Wyon
Technical University of Denmark

HB 2006
healthy buildings
Creating a healthy indoor environment for people
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PROCEEDINGS

VOL. I - Indoor Air Quality (IAQ), building related diseases and human response

EDITORS
E. de Oliveira Fernandes
M. Gameiro da Silva
J. Rosado Pinto

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FOREWORD

Healthy Buildings 2006 inscribes itself on the path of a series of Conferences that, since 1988 are being organized around the world focused on the issue of the quality of the indoor environment seen from a holistic perspective. The subject of the conference is ‘Indoor Air Quality and Climate’ as reflected in the acronym of the Society that organizes these conferences (ISIAQ). The theme of the conference relates to indoor environment. However, among the determinants of the indoor air quality in a particular building it is also importance to address those that may be associated with strategies or options referring to urbanism, architecture and construction technologies.

Consequently, the ‘Healthy Buildings’ series aims to reach a ‘two in one’ accomplishment: first, to follow the progress in the advancement of knowledge regarding indoor environment themes and, second, to cross information, experiences and perspectives from the different disciplines concerned with creating a better built environment. In that sense, HB2006 is not only of a scientific character but aims also at debating and clarifying strategies and good practices to define the best policies for the benefit of people.

With this in mind the conference objectives were clearly stated:

- To describe the state-of-the-art in the field of healthy buildings.
- To create a multi-disciplinary forum for scientists working in the field of indoor air quality and healthy buildings.
- To contribute to the development of methods for the assessment of environmental health hazards and their effects on health.
- To allow interactions among scientists, policy makers, medical, legal and building professionals.
- To support health and environmental policy-making and to provide public information on links between buildings, environment and health.

A main feature of HB2006 that makes it unique among the conferences of this series is the attempt to bring to the same platform of exchange of experiences and share of concerns, an uncommonly large number of professionals from the health side representing both research and practice. In organizing the conference it proved to be quite a task to accommodate the different “cultures” of the various disciplines, which all have developed their own meeting practices including the way results are presented. In some disciplines it is good use to present abstracts only while in others full papers are the only accepted format. This is why in this conference we have about 200 contributions being “just” abstracts and over 400 full papers.

The growing rate of some chronic illnesses such as allergies and asthma is a well-known fact. These illnesses which represent an important economic factor are being thought to relate to the quality of indoor environment. To avoid them requires new strategies which will depend very much on the way the construction activity is organized and qualified. This is the rationale to bring together building physicists, architects and engineers and medicine doctors together with educators and policy makers.

Policies to control pollutants in the indoor environment need to be backed by knowledge regarding their effects on health and those who deal with the effects of indoor pollution need to know what may be the causes. There is no risk assessment without knowledge of the effects of the substances, there are no standards without good risk assessment and there is no prevention without identification of sources, either due to the activities conducted indoors or determined by the building itself including HVAC systems.

To provide a healthy living in healthy buildings we have to focus not only on indoor air. Rather, we should also look at the building in the context of its interactions with its neighborhood. Our target should always be to consider the building as a whole if it comes to speaking about its quality. It is the performance of the entire building that is “responsible”, inter alia, for the quality of the indoor air and climate. In short, nothing that relates to the building , be it safety, noise, hygiene, comfort, productivity or energy performance will be strange to the final overarching “health” of the building which guarantees the well-being of the occupants.

Buildings are products of intelligence, knowledge and inspiration of a number of actors interacting hopefully in an integrated way. The performance based approach is a *conditio sine qua non* for the modern pre-requisites of quality. It is also an essential pathway to reach the condition of ‘healthy building’. That is why the different professions, mainly architects and engineers, need to get together around the concept of building under the environmental perspective and explore the potential of stating and guaranteeing the quality of the building to make it healthy from the very early stage of its conception on: efficient use of energy, use of clean materials, rational management of activities indoors, proper controlling systems and devices.

Over 600 contributions were received coming from over 50 countries. That shows not only the interest given to this subject worldwide but rather the fact that the issue is not anymore an exclusive preoccupation for the developed countries but is becoming a matter of concern for more and more countries and communities.

To create an event like HB2006 requires a great deal of effort of many people. I would like to thank all those that gave their support all in different ways, the authors, the reviewers, the sponsors, the partners, the staff and my colleagues in the Organizing Committee. The driving force was the genuine desire of contributing to the advancement of the scientific knowledge in our field but also to facilitate the progress in what regards the policies at the level of both the design, construction and management of buildings, and environmental health. I do hope that all participants will benefit from this conference which represents another stone towards a better built environment for people.

Eduardo de Oliveira Fernandes
Universidade do Porto, June 2006

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PLENARY LECTURES

TOPIC 1 - INDOOR AIR QUALITY (IAQ), BUILDING RELATED DISEASES AND HUMAN RESPONSE

Sustainability and Health are Integral Goals for the Built Environment

Vivian Loftness, FAIA; Volker Hartkopf, PhD; Lam Khee Poh, PhD
PhD students: Megan Snyder, Ying Hua, Yun Gu, Joonho Choi, Xiaodi Yang

Carnegie Mellon University Center for Building Performance

Summary; *The importance of proving that sustainable design and engineering improves health, productivity, and quality of life has never been more important. To this end, the Center for Building Performance and Diagnostics (CBPD) at Carnegie Mellon University, in collaboration with the Advanced Building Systems Integration Consortium*, have been actively developing sustainable design guidelines and a database of laboratory, field, and simulation case studies that reveal the substantial environmental, health and productivity benefits of a range of advanced and innovative building systems. Captured in the Building Investment Decision Support tool (BIDS™), the cost-benefits of investing in a better built environment should drive measurable changes in building design, construction and management. This presentation will explore the health-related benefits of high performance buildings - designed to deliver the highest quality air, thermal control, light, ergonomics, privacy and interaction, as well as access to the natural environment.*

Keywords: *Sustainability and Health, Sustainable Design for Health, Healthy Building Systems*

1. Definitions of sustainability

Many decisionmakers assume that sustainable design is about resource conservation – energy, water, and material resources. The last ten years, however, has seen a dramatic broadening of the definition of sustainability to include assurances for mobility and access as affected by land use and transportation, for health and productivity as affected by indoor environmental quality, and for the protection of regional strengths as we pursue a more globally shared quality of life. In the US, this broader definition of sustainability is most often ensured through the voluntary LEED™ (Leadership in Energy and Environmental Design) standard of the US Green Building Council. The 69 credits in the LEED for New Construction standard extend beyond the conservation goals of energy, water and materials to include sustainable sites and transportation, outdoor atmosphere, indoor environmental quality and waste.

The Center for Building Performance and Diagnostics at Carnegie Mellon University would argue for expanding this definition even further, to give greater emphasis to contextual and regional design goals, to natural conditioning, and to flexible infrastructures that support change and deconstruction. *

Seven CBPD Principles for the Design of Sustainable Built Environments

1. Sustainable design depends on an integrative, human-ecological design approach.
2. Sustainable design depends on changing approaches to land-use and community fabric.
3. Sustainable design depends on the effective use of natural, local and global resources to reduce infrastructure loading and maximize infrastructure use.
4. Sustainable design depends on the design of flexible, plug and play systems.
5. Sustainable design depends on the use of sustainable materials and assemblies.
6. Sustainable design depends on design for life-cycle instead of first cost.
7. Sustainable design depends on the promotion of infrastructures to neighborhood amenities.

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[*] ABSIC members 2000 to present: Armstrong World Industries, BP Solar, Carnegie Mellon University, US Department of Energy, US Department of Defense, Electricité de France, US Environmental Protection Agency, Gale Foundation, US General Services Administration, Northwest Energy Efficiency Alliance, Public Works and Government Services Canada, Somfy, Siemens Energy and Automation, Inc., Steelcase Inc., Teknion Inc., Tyco Electronics, United Technologies/ Carrier, National Science Foundation.

The CBPD defines sustainable design as "a Tran disciplinary, collective design process driven to ensure that the built environment achieves greater levels of ecological balance in new and retrofit construction, towards the long term viability and humanization of architecture. Focusing on environmental context, sustainable design merges the natural, minimum resource conditioning solutions of the past (daylight, solar heat and natural ventilation) with the innovative technologies of the present, into an integrated "intelligent" system that supports individual control with expert negotiation for environmental quality and resource consciousness. Sustainable design rediscovers the social, environmental and technical values of pedestrian, mixed-use communities, fully using existing infrastructures, including "main streets" and small town planning principles, and recapturing indoor-outdoor relationships. Sustainable design avoids the further thinning out of land use, and the dislocated placement of buildings and functions caused by single use zoning. Sustainable design introduces benign, non-polluting materials and assemblies with lower embodied and operating energy requirements, and higher durability and recyclability. Finally, sustainable design offers architecture of long term value through 'forgiving' and modifiable building systems, through life-cycle instead of least-cost investments, and through timeless delight and craftsmanship" [1].

The clarity of the definition of sustainability matters, especially when assessing the relevance of sustainable design, construction, and operations of buildings to long term human and environmental health.

2. A Definition of Health to be Integral with Sustainable Design

Building on the Cornell Medical Index of 1949 [2], the Center for Building Performance at Carnegie Mellon is using the following ten indices for evaluating the importance of design, construction and operation decisions on human health:

Definition of health integral with sustainable design

1. Respiratory system
2. Digestive system
3. Eyes, vision, irritation, circadian system
4. Ears, hearing damage, concentration
5. Skin
6. Musculo-skeletal
7. Circulatory system
8. Nervous system
9. Genitourinary system
10. Mental health, stress, biophilia

Alternatively, evidence from the research suggests six primary clusters of health issues related to the built environment: respiratory (chest, wheeze, allergies, asthma, colds, flu); mucosal (eye, nose, throat); dermal (face, hand skin); neuro-physiological (headache, migraine, dizziness, heavy-headedness); musculoskeletal; and psychological (SAD, bipolar disorder).

3. Linking Health and the Built Environment

By setting CBPD's definition of the attributes of sustainable design against the characteristics of human health, even intuitive judgment would illuminate the importance of building design decision making and building operation to human health, as shown in figure 1.

With over 5 years of intense study by faculty, researchers and graduate students, the Center for Building Performance and Diagnostics at Carnegie Mellon and the Advanced Building Systems Integration Consortium have been collecting building case studies as well as laboratory and simulation study results in an effort to statistically link the quality of buildings – system by system – to productivity, health and life cycle sustainability. Amassed in the BIDS™ (Building Investment Decision Support) tool, these case studies enable building decision makers to calculate returns on investments in high performance building systems, and will lead to greater understandings of the importance of land use and buildings to health (see http://cbpd.arc.cmu.edu/ebids).

The following six sections will explore design innovations and life cycle benefits of changes in land use, building massing and enclosure, HVAC engineering, daylight and lighting system design, interior systems, and long-term building maintenance and operations.

4. Sustainable Land Use and Health

One of the most significant design shifts needed for the long-term health of humans is a shift away from automobile-based land use planning and single use zoning. In industrialized nations, dramatic reductions in transportation by walking and biking may contribute to increasing rates of obesity, while increased reliance upon automobiles has resulted in ever-increasing levels of particulate and ozone that are respiratory hazards. Numerous studies have revealed the seriousness of particulate related health concerns. Wordley et al. [3] identified a 2.4% increase in respiratory admissions and a 2.1% increase in cerebro-vascular admissions associated with a 10 μg/m^3 increase PM10 in the air. According to Dockery & Pope [4] a 10 μg/m^3 increase in PM10 in the air increases respiratory admissions by 0.8 ~ 3.4%. Tenias et al. [5] found that a 10 μg/m^3 increase of NO2 and O3 in the air causes increases in the number of emergency visits for asthma by 7.6% and 6.3%, respectively.

Moreover, automobile-based design is “paving” the countryside, with the elimination of natural landscapes that act as natural lungs for our air and with salting, oils, and storm-sewer overflows resulting in toxic runoff into our drinking water. As a result, it is imperative that sustainable design ensure: live-work-walk lifestyles with mixed-use communities; multi-generational mobility with mixed mode transportation; and the preservation and celebration of natural landscapes and sustainable infrastructures.

Guidelines for Sustainable Land Use for Health

- Design live-work-walk communities to reduce car pollution – particulates and ozone – that trigger asthma
- Design for pedestrian, bicycle, transit mobility to reduce obesity
- Minimize paving for roads and parking, salting and oil runoff, as well as standing water concerns.
- Design landscape dominant environments to reduce thermal heat islands, heat stress, and rebuild natures lungs for air quality

5. Sustainable building massing/ enclosure and Health

After land use design, the second most critical decision for human health may be the design of building massing and its enclosure. Humans need access to the abundances in nature - daylight, natural ventilation, thermal diversity, physical access and views; at the same time, humans need protection from natural stresses – overheating, excessive cold, rain. The design of the building enclosure is critical for both of these.

The CBPD has identified 16 international case studies linking access to the natural environment to improved health outcomes, including reductions in headaches, colds, SBS (Sick Building Syndrome), and patient length of stay (see figure 2). Beyond the health benefits, ten international case studies demonstrate that access to the natural environment increases individual productivity between 3-18% and reduce absenteeism between 9-71%, while 8 studies indicate over 50% (each) lighting and HVAC energy savings [6].

While the debate continues as to the mechanisms whereby daylight improves health, research continues to reveal that sunlight, especially morning sunlight, reduces length of stay for patients recovering from surgery, bipolar and SAD treatment [7-10]. The work of the Lighting Research Institute at RPI has begun to reveal the relationship of exposure to ultraviolet light and our melatonin production that controls circadian rhythms, sleep cycles and may even slow cancer cell development [23]. The confounding variables of glare and overheating that might accompany uncontrolled sunlight must also be studied.

The importance of views of nature and proximity to windows to human health is equally debated, with the work of Ulrich [11], Mendell [13], and now Kellert [24] identifying a link to reduced length of stay after surgery, sick building syndrome, and overall emotional health and the importance of biophilia. In addition to confirming the importance of seated views for all building occupants, research is critically needed to understand the importance of the content of a window view to health (eg., landscape vs. sky vs. building walls), as well as the benefits of direct access to the outdoors that could accompany views through windows and doors.

The value of increasing outside air delivery rates is becoming increasingly evident, as will be described in HVAC design. It is not clear, however, whether increased levels of outside air are more effectively delivered through operable windows or through mechanical systems that incorporate filtration, dehumidification and thermal conditioning of that outside air. There are over a dozen studies that reveal the benefits of natural ventilation in existing buildings, as compared to mechanical ventilated buildings, in reduced headaches, mucosal symptoms, colds, coughs, circulatory problems, and SBS symptoms. While operable windows can bring in higher quantities of outside air, however, they can also bring in unwanted outdoor pollution, humidity, rain, and noise. The pros and cons of increasing outside air rates through natural versus mechanical means are outlined in figure 3, with a definite emphasis on the value of natural ventilation, especially given the long term field performance of HVAC systems and controls.

The design implications for increasing daylight, view and natural ventilation are first to increase surface area with thinner floor plates, and second to resolve glare, overheating, heat loss, and rain penetration through appropriate enclosure design. In some respects, sustainable, healthy buildings have many of the characteristics of sustainable, healthy humans – they are physically fit rather than obese (thin floor plans, finger plans and courtyard buildings); they have circulatory systems that take the heat from the core out to the surface (eg. air flow windows); they absorb sunlight and breathe fresh air. At the same time, sustainable buildings are designed to reduce climate stresses – rain, cold and hot temperatures, diurnal temperature swings, excessive sun, freeze-thaw – with completely regional design solutions.

	Respiratory system	Digestive system	Eyes, vision, irritation, circadian system	Ears, hearing damage, concentration,	Skin	Muschulo-skeletal	Circulatory system	Nervous system	Genitourinary system	Mental health, stress, biophilia
Land Use										
Design live-work-walk communities		λ				λ	λ			
Design mixed mode mobility	λ	λ				λ	λ			
Increase landscape/ reduce paving	λ					λ		λ		λ
Distributed,/renewable power sources	λ									
Building Massing and Enclosure										
Design for Daylighting / View / Passive Solar			λ					λ		λ
Design for Natural Ventilation	λ									λ
Engineer Thermal Load Balancing							λ			
Design Enclosure Integrity	λ			λ			λ			
Lighting and HVAC Systems										
Separate ambient and task lighting			λ							
Specify high performance lighting & controls			λ							
Separate ventilation and thermal conditioning	λ						λ			λ
Increase outside air & ventilation effectiveness	λ									
Engineer moisture/humidity management	λ				λ					
Engineer individual control of temperature							λ			
Interior Systems										
Specify ergonomic furniture						λ	λ			
Design spatial layout/density for health/safety						λ				
Specify acoustic quality				λ						
Specify materials vs. outgassing/ degradation	λ							λ		
Specify materials vs. irritation/ re-infection	λ	λ			λ					
Specify materials vs. mold	λ									
Operations										
Continuously Commission Systems	λ									
Eliminate standing water, dampness and mold	λ									
Design for non-toxic pest/ plant management	λ	λ						λ		
Design for environmentally benign cleaning	λ				λ			λ		
Improve food//vending quality for health		λ								
Improve water quality for health		λ								
Reduce waste/ manage waste vs pests	λ									λ

Fig. 1. Linking Design Decision making and Health

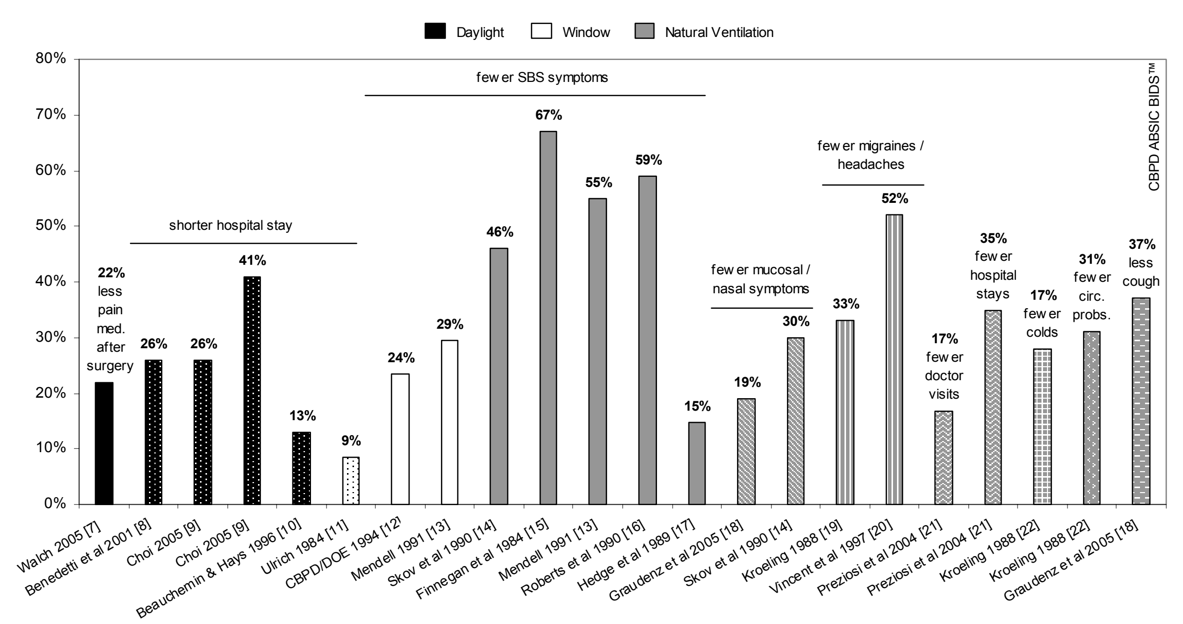

Fig. 2. Health Benefits of Access to Nature [7-22]

No	**Yes**
Avoid outdoor pollution	Dilute indoor pollution – HVAC
	Dilute indoor pollution – materials/ activities diffuse
Avoid outdoor humidity	indoor humidity build up
Avoid outdoor noise (traffic, HVAC, mowers)	Connect to nature – air, sounds
Well designed/maintained HVAC provides control	Increase local ventilation rates w/o heat recovery
Avoid rain penetration	Increase local thermal control in cool periods
	Design windows to shed rain

Fig. 3. Should Windows Open?

Guidelines for Sustainable Building Massing and Enclosure for Health

- Design for daylighting without glare to support visual acuity, reduce headaches
- Design for natural ventilation without drafts and rain penetration to reduce respiratory/flu symptoms
- Engineer thermal load balancing to eliminate radiant asymmetry - arthritis, circulatory disorders,
- Design for passive solar heating where climate appropriate for thermal comfort and UV benefits
- Design enclosure integrity to eliminate mold affecting SBS, respiratory/allergy and asthma

6. Sustainable HVAC and Health

The design of heating, ventilation and air conditioning systems for human health are based on at least three improvements in individual occupant conditions: increased outside air rates and filtration; improved moisture/humidity control; and improved thermal comfort control.

Healthy, sustainable air, for example, is dependent on a commitment to improving the quality and quantity of outside air. Increasing outside ventilation rates has substantial research justification: a doubling or tripling of code requirements for outside air measurably reduces headaches, colds, flues, nasal symptoms, coughs, and SBS symptoms [26-35]. This may be achieved by maximizing natural ventilation with mixed-mode HVAC systems, and/or designing the HVAC system with separate ventilation air and thermal conditioning systems (thermal conditioning can be water or air based). To ensure ventilation effectiveness, the ventilation system must be designed to provide air to the individual with task air systems with some level of individual control to address local pollutant buildup. At the same time, a healthy HVAC system will guarantee pollution source control through design configuration and maintenance and for effective filtration. Beyond the studies of natural ventilation/mixed mode conditioning previously discussed, the CBPD has identified seven international case studies demonstrating that high performance ventilation strategies reduce respiratory illnesses including asthma and allergies by 10-90%, as well as ten studies that demonstrate reductions in SBS, headaches, flus and colds (see figure 4). Specifically, the critical HVAC improvements are increasing outside air rates, mold/moisture control, air stream management and filtration. In addition to health benefits, thirteen studies also suggest individual productivity gains of 1.7-11% due to high performance ventilation strategies, with a small energy penalty for increasing outside air rates with heat recovery, or 50-80% energy savings for natural ventilation combined with mixed mode conditioning [25]. In addition to providing healthy breathing air, it is critical for the HVAC system to provide individual thermal controls. While a majority of laboratory and field experiments in this arena relate to productivity and task performance, the CBPD has identified two international case studies that link thermal comfort to reduced headache and SBS symptoms [40, 41]. Clearly, extreme temperatures have measurable health consequences such as heat stroke and frost bite, but it is unclear whether long term exposure to moderately warm or cold thermal conditions have any health impacts. The health consequences of radiant asymmetry (the literal cold shoulder) and conductive losses through the feet to uninsulated floors, should be quantifiable, but no studies have been identified. However, the CBPD has identified 14 studies that link temperature control to individual productivity gains between 0.2-7%, while one study identified 15% percent savings in energy through task thermal conditioning, given consistent vacancy rates in office environments [45]. The challenges for HVAC design for thermal comfort are to: design for dynamic thermal zone sizes (changing use patterns); provide individual thermal controls (eg under floor air distribution system); design for building load balancing and radiant comfort; and finally, to engineer prototyped, robust systems that provide air quality and thermal comfort consistently as installed in the field, over time.

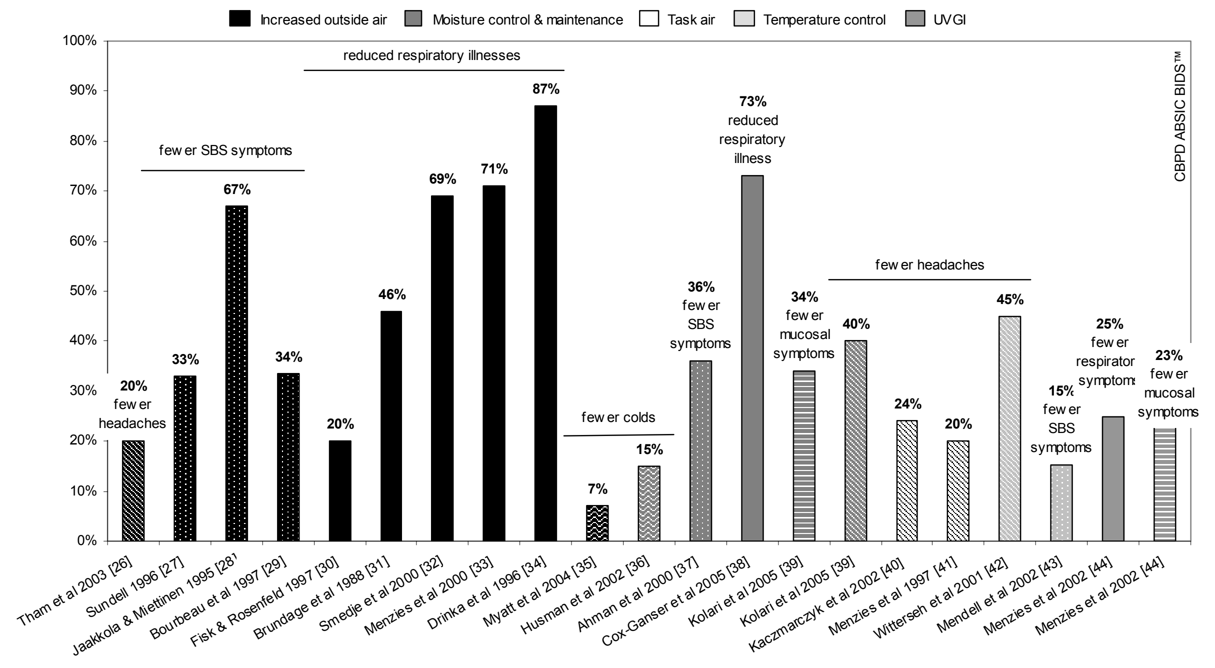

Fig. 4. Health Benefits of High Performance HVAC [26-44]

Sustainable HVAC for Health

- Increase outside air rates, through natural ventilation or HVAC with heat recovery – to reduce respiratory, allergy, asthma, colds, headaches, SBS
- Engineer ventilation effectiveness, including air path and filtration management – to reduce respiratory, throat and mucosal symptoms
- Engineer moisture/humidity management - to reduce mold affecting respiratory illnesses, colds, SBS
- Separate ventilation and thermal conditioning systems for individual thermal control – to reduce headaches and SBS symptoms

7. Sustainable Lighting and Health

Light levels and the control of glare and brightness contrast can dramatically impact performance at task. These variables can also impact health, with the most frequent symptoms being vision related headaches. In addition, the spectral distribution of the light source, as well as time of day variations in light, may have a measurable impact on circadian rhythms, as previously discussed. Finally, views that may be associated with daylight sources may have a measurable impact on depression, recovery rates, and SBS symptoms.

The CBPD argues for maximizing the use of daylight for both sustainability and health, so long as it can be provided without glare and excessive heat loss or heat gain. Daylight can provide the higher light levels needed for fine work, improve color rendition and sculptural definition, give the full spectrum and ultraviolet content that might be critical to circadian rhythms, and provide access to views of nature.

Electric lighting systems then have the responsibility to interface effectively with daylight to meet the needs of specific tasks, and provide the appropriate quantity and quality of light when daylight is not available. To this end, sustainable lighting is dependent on selecting the highest quality lighting quality fixtures, lamps, ballasts, reflectors, lenses and controls to light each specific task or task surface. These actions can also have health benefits. For example, replacing magnetic ballasts, with both audible buzzing and PCBs, with electronic ballasts in fluorescent lamps has resulted in a 74% reduction in the incidence of headaches in a study by Wilkins et al [47]. The separation of task and ambient lighting, to enable lower overall ambient light levels at 20-30 fc (supportive of computer work and face to face discussions) to be augmented by higher task light levels at 50-100fc (for fine print work), has resulted in 19% reduction in headaches in a study by Cakir and Cakir [48]. A third study revealed the benefits of reducing direct and reflected glare and shadowing that can occur with direct 'downlighting' from the ceiling: a 27% reduction in headaches resulting from a shift to indirect/direct lighting [46].

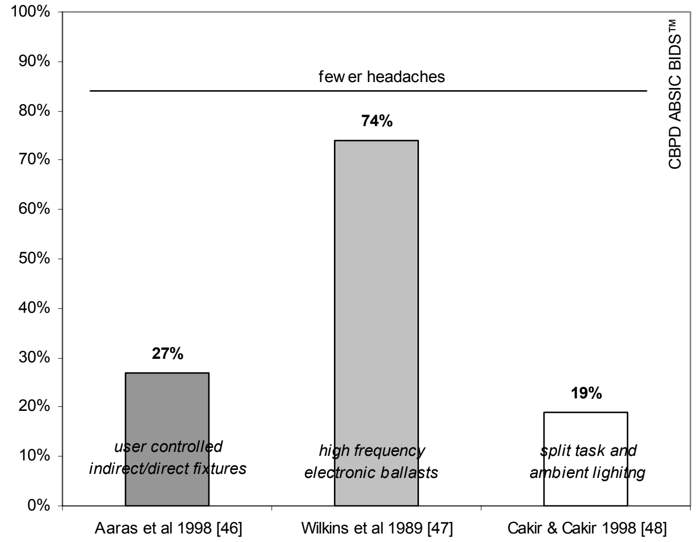

Fig. 5. Health Benefits of High Performance Lighting [46-48]

In addition to these three international case studies that demonstrate that improved lighting design reduces headache symptoms, the CBPD has identified twelve international case studies that indicate that improved lighting design increases individual productivity between 0.7-23% while reducing annual energy loads by 27-88% [49].

Guidelines for Sustainable Lighting for Health

- Design for daylighting without glare to support visual acuity, color rendition, circadian rhythms, view content – reduced length of stay, headaches
- Specify high performance fixtures for maximum lumens/watt, reduced glare, shadowing and noise - reduce headaches
- Separate ambient and task lighting delivery to match light levels to task, provide control

8. Sustainable Interior Systems and Health: materials and ergonomics

Among a range of interior design decisions that affect sustainability and productivity, at least two design decisions also have measurable health impacts – material selection and the ergonomics of furniture and space layout.

Interior material selection is critical in relation to thermal performance, air quality (outgassing), toxicity in fires, cancer causing fibers, and mold growth, which in turn impact respiratory and digestive systems, eyes and skin. The CBPD has identified six studies linking materials selection to health outcomes including SBS, mucosal irritation, allergies and asthma (see figure 6). While sustainable design depends on the use of materials and assemblies that support healthy indoor environments, it also mandates the selection of materials with low embodied and transportation energy, since these environmental costs carry secondary health concerns.

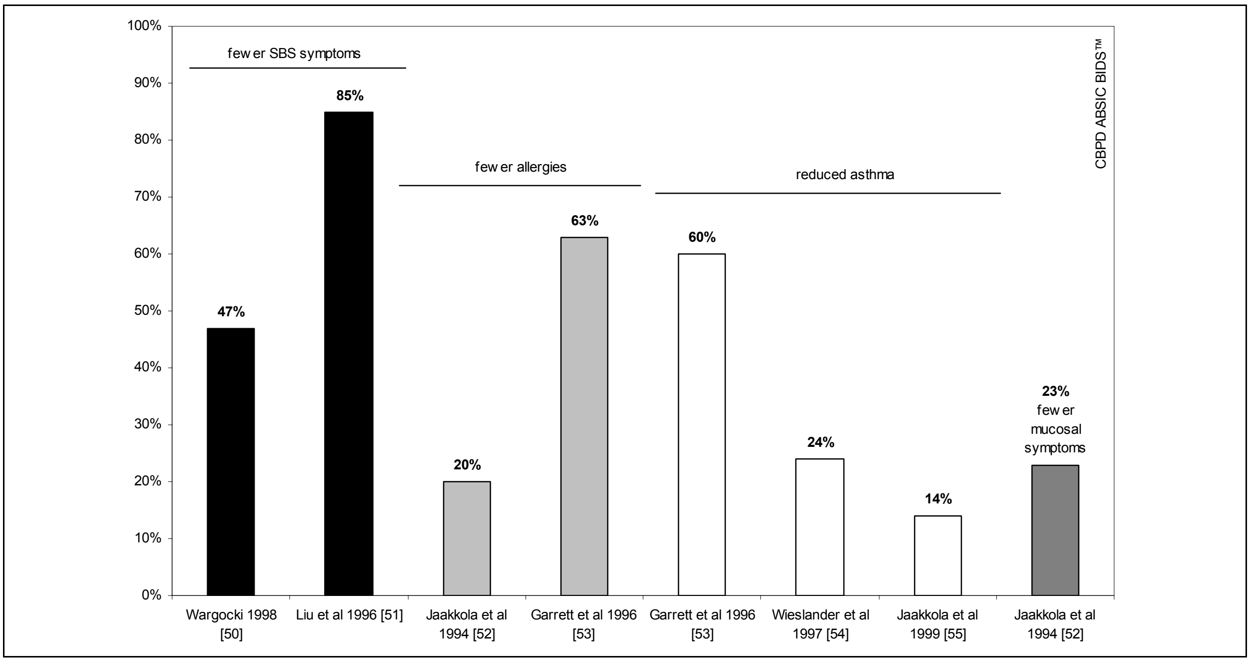

Fig. 6. Health Benefits of High Quality Interior Materials [50-55]

Guidelines for Sustainable Material Selection for Health

- Specify materials that do not irritate the skin with contact to avoid dermatological conditions
- Specify materials that do not outgas toxins to avoid respiratory/allergy and asthma
- Specify materials that do not degenerate into respirable fibers or emit radon to avoid cancers
- Specify materials that are not fire hazards causing respiratory illness or death
- Specify materials that do not foster mold or mildew leading to respiratory symptoms
- Specify materials with low embodied energy and low transportation costs to reduce outdoor air pollution

In addition to indoor surface materials, design decisionmakers must address the anthropometric and ergonomic needs of building occupants. Given the growing preponderance of computer-based work today, work surfaces, chairs, keyboards and mouse design must be ergonomically designed to reduce musculoskeletal disorders (MSD). According to a Washington State study, 1.7 to 3.2% of MSD complaints result in medical costs averaging $22,000 per affected occupant, and in many cases permanent consequences for the employee [56]. The CBPD has identified 7 international case studies that demonstrate that ergonomic workstations reduce MSD symptoms between 48 – 84% (figure 7). Ergonomic design goes beyond anthropometric concerns, however, to also address building layout and densities that support human health and productivity. Seneviratne and Phoon [57] identified over 40% reductions in nose, throat and mouth symptoms with greater workspace and improved maintenance. Jaakkola and Heinonen [58] identified a 35% lower rate of colds among occupants of individual offices, compared to those in shared offices. Hendrich et al [59] identified a 70% reduction in medication errors and a 60% reduction in patient falls through the design of acuity adaptable hospital rooms.

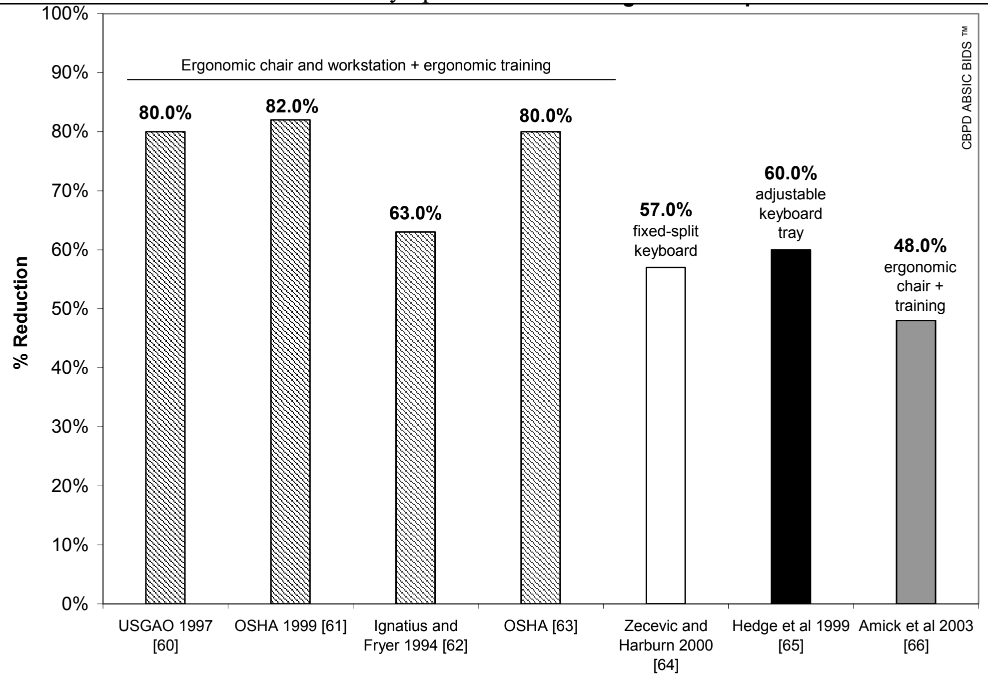

Fig. 7. Musculoskeletal Disorder Reductions due to Ergonomic Improvements [60-66]

The most substantive body of research, as captured in the work of John Templer [67], may be the effective design of stairs, ramps, curbs and surfaces to reduce the frequency of falls, with measurable health consequences. The most rapidly emerging body of research may be related to the infections transferred by contact with door handles, faucets, even elevator buttons, and the importance of hands-free design and frequent hand washing. Each of these studies emphasizes the importance of space layout, finishes and furnishings to human health.

Guidelines for Sustainable Interior Design and Furnishings for Health

- Specify furniture ergonomics to reduce musculoskeletal disorders (MSD)
- Design spatial layout/density to reduce transmission of contagious illnesses (flus, colds)
- Design spatial layout to reduce falls, tripping
- Design layout and specify surfaces to reduce infections transferred by contact with hands free design

9. Sustainable Maintenance and Operations and Health

Needless to say, each of these design decisions will become obsolete if there is no commitment to long-term maintenance and operational standards. The building enclosure, HVAC and lighting systems must be continuously commissioned to maintain the healthy conditions intended. Standing water, dampness and mold must be prevented. Occupant densities must be managed, and furniture and finishes must continue to meet the health standards set.

In addition, human activities in buildings and the products they bring in must also be selected for health. Art supplies, cleaning supplies, plants, fertilizers and herbicides must all be environmentally benign. In addition, the food and water quality should be monitored for health, including guidelines for vending machines. Waste should also be effectively managed since it is a natural breeding ground for roaches, rodents and other pests. While this research team has not evaluated the studies that may link poor maintenance and operation practices to health concerns, it is clear that any degradation in as-built performance will result in health consequences equally serious as those of poor design, engineering and construction.

10. Calculating the Life Cycle Benefits of Sustainable Design and Health

The work of the faculty, researchers and graduate students of the Center for Building Performance and Diagnostics at Carnegie Mellon and the Advanced Building Systems Integration Consortium extends beyond the pursuit of building case studies that link the quality of buildings to productivity, health and life cycle sustainability. The development of the BIDS™ tool has necessitated the identification of "soft" and hard life cycle costs in building ownership in order to calculate the return on investment of high performance building systems (see http://cbpd.arc.cmu.edu/ebids). Figure 8 helps to reveal the diverse building-related costs of doing business in US offices, including salaries and health benefits, technological and spatial churn, rent, energy and maintenance costs. This cost is normalized in dollars per person per year, rather than cost per square foot, since the employee represents both the greatest cost and the greatest asset to an organization.

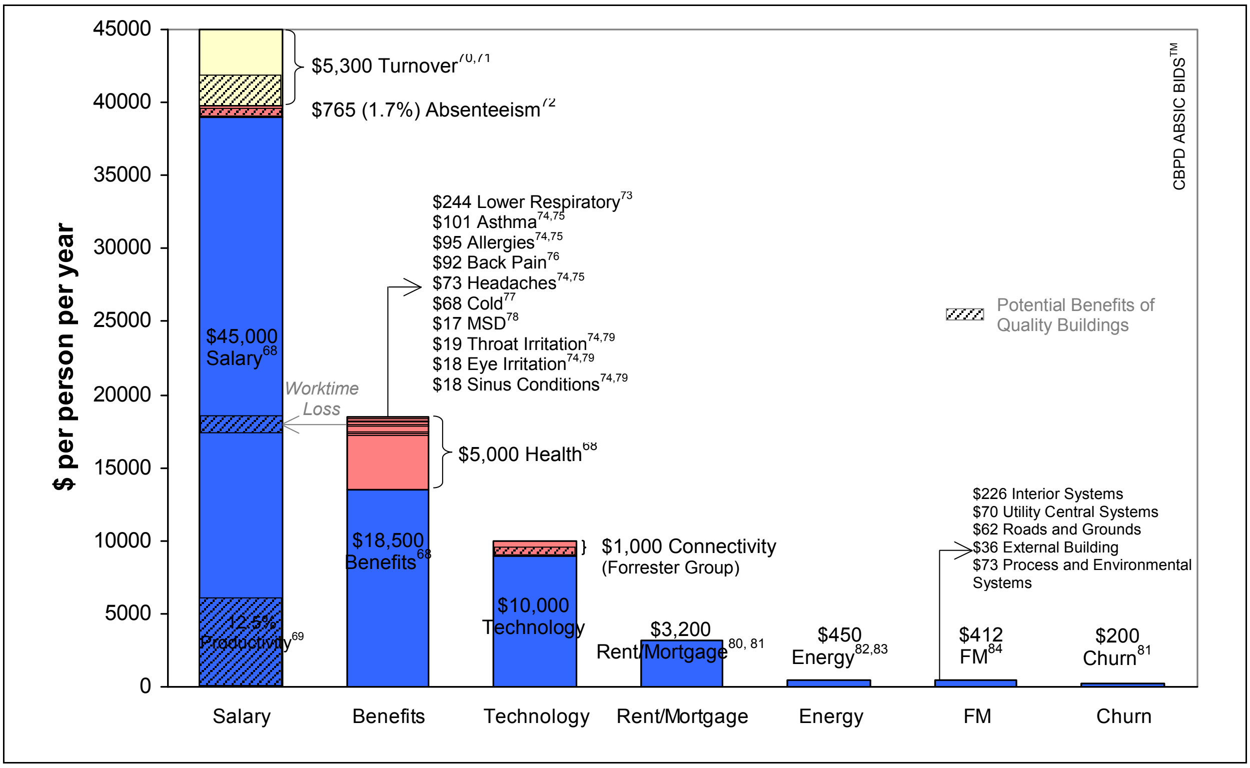

Fig. 8. Improving the Quality of the Built Environment will Reduce the Life Cycle Costs of Business [68-84]

According to independent non-profit organizations, human resource research firms, and the U.S. government, the average employer cost for health insurance was approximately $5,000 per employee per year in 2003 [85-89]. The CBPD has been able to identify the cost of several specific health conditions and illnesses that can be linked to the quality of the indoor environment, including colds, headaches, respiratory illnesses, musculoskeletal disorders, back pain (see figure 8), which account for roughly $750 of the $5000 annually spent per employee, or 14% of all annual health insurance expenditures. These direct costs for medical attention and pharmaceuticals would be multiplied with the indirect costs of reduced speed and accuracy on task, lost work time and absenteeism, among other secondary consequences of health concerns.

While the focus of the BIDS™ effort to date has been to improve the quality of workplaces in office buildings, there is growing interest in identifying case studies for other facility types, such as schools and hospitals. This inclusion broadens the opportunity to find case studies linking building quality to performance outcome, but requires research to customize the life-cycle factors and calculations to that building type, and to develop new design recommendations that might emerge from these data sets.

Example Measures of Cost-Benefit Performance for Different Building Types

Offices	Schools	Hospitals
O&M, Energy & Water	O&M, Energy & Water	O&M, Energy & Water
Worker Health	Teacher Health	Length of Stay/Recovery Rates
	Student Health	Nosocomial Infections
		Patient Falls
		Staff Health
Attraction-Retention	Teacher Turnover	Staff Turnover
Individual Productivity	Student Test Scores	
	College Placement	
Absenteeism/Presenteeism	Absenteeism/Presenteeism	Absenteeism/Presenteeism
Organizational Productivity		Bed Vacancies
Market Share/ Customer	Drop-out rates	Cost/Bed
Speed to Market	No Child Left Behind	Profit/Bed
Waste Cost/Benefits	Waste Cost/Benefits	Waste Cost/Benefits
Litigation/Insurance/Tax		
SBS		Medication Errors

For example, the calculation of life cycle benefits of better design, engineering and management of hospitals would include variables such as: the average length of stay per illness, averaged at 4.6 days per patient in US hospitals [90]; average cost of hospital stay, set at $1217 per day in US hospitals [91]]; patient reinfection rates, estimated at 2.16/10,000 patient days in US hospitals [92]; average of cost of these nosocomial infections, estimated at $27,000 plus 12 day increase in hospital stay [93]]; and the average cost of nurse turnover, at $13,800 per nurse per year [94-96]. The magnitude of these costs would clearly justify significant investment and reinvestment in the quality of buildings to ensure long-term health and productivity.

11. Health and the Built Environment: A major research Mandate

Sustainability is in truth all about health. Energy/material extraction and use and atmospheric, water and land pollution are as significantly health-related issues as they are environmental conservation issues. Certainly the design and maintenance of building enclosures, HVAC, lighting, and interior systems are directly linked to our short and long term health, as the evidence collected in this paper has begun to prove. Human health in the built environment is one of the most critically needed research efforts, requiring both extensive experimental and field research efforts. Controlled laboratory experiments need to be carried out simultaneously with experiments in the field – to map chains of consequence, and identify possibly building related causes for respiratory, digestive, circadian, musculo-skeletal, circulatory, and nervous system illnesses, as well as other health related concerns. Yet in the United States, at least, there is remarkably little federal investment in defining and valuing healthy buildings and communities (see figure 9).

One cannot overstress the importance of defining key national and international research directions for addressing the impact of the built environment on health. Bringing together emerging knowledge about the importance of land use, building enclosure, HVAC, lighting and interior design decisions, with the life cycle justifications to ensure their implementation, is critically needed. Sustainable buildings and communities have the potential to deliver the highest quality air, thermal control, light, ergonomics and acoustic quality, as well as regionally appropriate access to the natural environment, which are integral to human health

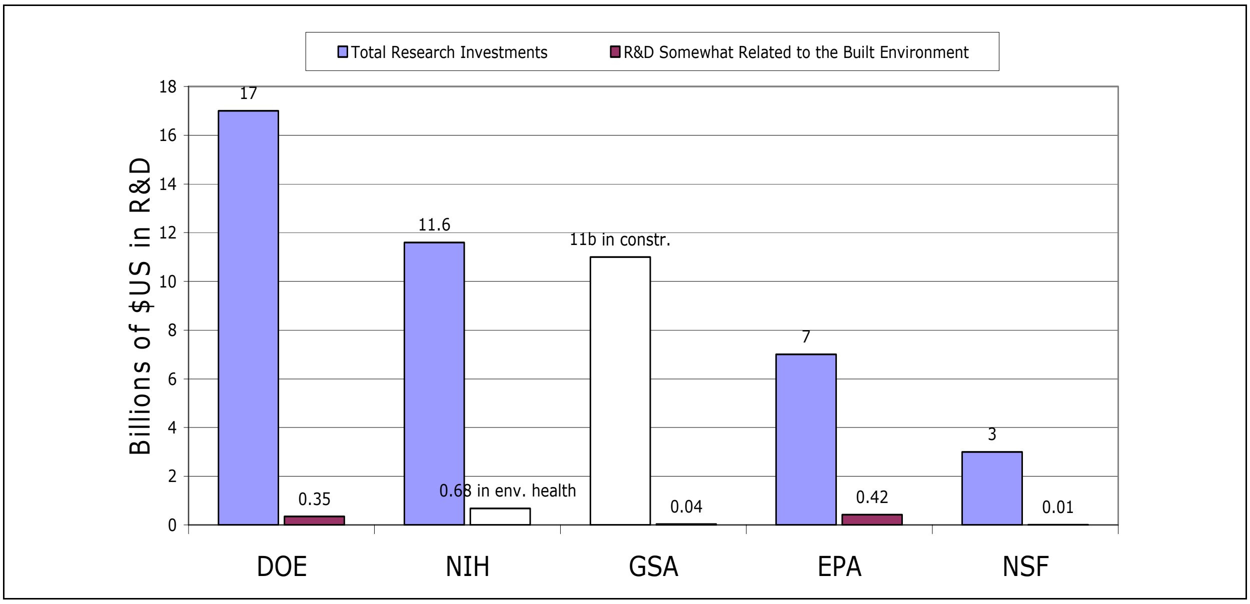

Fig. 9. Yet Marginal Research Investments in the Built Environment [97]

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Policies For Indoor Air Pollutants

R L Maynard

Health Protection Agency, England, UK

More work has been done to discover and control the effects of outdoor air pollution than indoor air pollution. In some ways, this is natural as great outdoor air pollution episodes claim many lives, but it should be recalled that more exposure to air pollutants occurs indoors: even during the London smog of 1952 people spent far longer indoors than out in the fog! Of course, pollutants generated outdoors spread to the indoor environment. The converse also applies though indoor pollution (not indoor sources of pollutants) tends to have a small effect on outdoor concentrations. It should be noted that key indoor sources, for example, fires and cooking equipment tend to be vented to the outdoors to prevent indoor concentrations rising to dangerous levels. The outdoor environment is thus used as a disposal site for gaseous and particulate air pollutants generated indoors. In the UK in the mid 1990's domestic combustion generated 14% of the total production of primary PM_{10}*; in the coal burning era the contribution was much larger than this.*

Studying the effects of indoor exposure to air pollutants is more difficult than studying the effects of outdoor concentrations. Recent time-series and cohort studies have revealed effects at low concentrations of particulate matter, ozone, nitrogen and sulphur dioxide, and carbon monoxide. With the exception of ozone, it is fair to assume that these studies reflect indoor exposure to a significant extent. This is an important point. We know a good deal about outdoor concentration-response relationships. It is known, from studies including monitoring of personal exposure, that variations in average exposure correlate well with variations in background outdoor (ambient) concentrations of particulate matter: if this were not known the results of studies relating effects on health to outdoor concentrations would be more difficult to accept.

Studies using outdoor concentrations have been used as a basis for setting standards for outdoor concentrations of air pollutants. In recent years, a move away from simple standards that assume a safe level (threshold) of exposure has occurred in some countries and a policy of progressive, cost-benefit tested, reduction in concentrations has been adopted. This is the case in the UK and, increasingly, in EC Directives on Air Quality standards are being replaced by objectives and targets. But this is not the case in all countries and problems of interpretation of legal wording specifying margins of safety are being found. In these the legal requirements lag behind the scientific evidence.

If standards (or targets and objectives) can be set for outdoor pollutants it might be thought that they could be set for indoor pollutants. Indoor, it has been asked why the outdoor standards cannot simply be applied indoors. This is an important and difficult question. The answer lies in the nature of the studies used as a basis for controlling outdoor concentrations. Take, for example, the time-series studies. These tell us about the response in a population to changing outdoor (usually background outdoor) concentrations. For example, when the outdoor concentration of particles less than 10 µm in diameter (PM_{10}) increases by 10 $\mu g/m^3$ the daily death rate increases by about 0.6%. But this does not mean that if the population's average exposure over a 24 hour period increased by 10 $\mu g/m^3$ the population's daily death rate would increase by 0.6%. Exposure is a function of outdoor concentration and this function will vary from country to country. The point is that we can develop a policy based on background outdoor concentrations because we know how they are linked to effects on health but we do not know how indoor concentrations are linked to effects on health. Let us assume for a moment that only particles generated outdoors and which stayed outdoors affected health. It would clearly be foolish to set a standard for indoor concentrations of particles on the basis of studies using outdoor concentrations as their independent variable. This is an extreme example and is, of course, not completely true. But it is likely to be partly true. We know that a significant proportion of the indoor concentration of particles less than 10 µm in diameter is contributed by dust generated by people moving about and this component of PM_{10} is thought to be less injurious to health than the fine particles (< 2.5 µm diameter) produced outdoors, for example by motor vehicles. To summarise: standards and policies can only be satisfactorily applied and developed for the environment in which the studies being used as a basis for those standards and policies have been conducted. This means that the great wealth of recent epidemiological evidence that has so significantly changed our thinking about the effects of air pollutants on health cannot be applied to setting standards or developing cost-benefit tested policies for indoor concentrations of air pollutants.

This should lead those concerned about indoor exposure to air pollutants to ask whether epidemiological studies that do focus on indoor concentrations could be done. Some epidemiological approaches are certainly applicable indoors, for example, panel studies have been undertaken. But the two methods that have produced such exciting new results in the outdoor field are not applicable indoors. Consider, firstly, the time-series approach. In these studies the researcher depends on variations in meteorological conditions to produce changes in outdoor concentrations and thus of exposure. The varying meteorological conditions affect the rate at which pollutants generated outdoors (or passing from indoors to outdoors) disperse. But variations in meteorological conditions play a smaller part in controlling indoor concentrations of air pollutants: in the outdoor environment sources tend to vary little from day-to-day (allowing for weekends and holidays) but weather conditions do vary; indoors the sources vary from building to building, are affected by seasonal conditions but are probably less affected by day-to-day changes in meteorological conditions.

The problem is no easier with regard to studies of the effects of long-term exposure to air pollutants. Cohort studies undertaken in cities with long-term differences in annual average concentrations of pollutants have shown that people living in cities characterised by comparatively high levels of pollutants have, at all adult ages, an increased risk of death. This produces, unsurprisingly, a reduction in life expectancy in the polluted cities. In these studies the unit of study in the city: the approach is not applicable to individual houses though in principle, it might be applicable to groups of different types of house though it is unlikely that sufficient numbers could be studied to provide the necessary statistically power to detect effects. Such studies have not been attempted though further thinking about their possible feasibility would be useful.

The above discussion has focused upon epidemiological studies but other sources of data are available. These include chamber studies involving volunteers and studies conducted in occupational settings. In both of these more information on personal exposure is available and their findings can be applied with some confidence to the indoor environment. Much information about the effects of exposure to carbon monoxide, for example, has been acquired from studies of volunteers and the findings of such studies can certainly be applied indoors. In fact, these studies are also used as a basis for guidelines and standards for concentrations of pollutants measured outdoors. To the toxicologist these studies are perhaps more appealing than are epidemiological studies: much more precise information on the exposure of individuals is provided and an exposure-response relationship can be constructed with confidence. But, of course, only limited numbers of individuals can be studied and, in general, exposure of children and unwell subjects is regarded as ethically dubious though some such work has been done. Perhaps the greatest problem is posed by the poor agreement between volunteer studies and epidemiological studies at low concentrations: the former tend to show thresholds of effect, the latter do not. In the outdoor air pollution field, this has led to epidemiological studies being regarded as the Gold Standard with volunteer and toxicological studies being relegated to a supporting role and being seen as of most use in explaining, when they can, the mechanisms underlying the epidemiological findings. This is an important, if secondary, role and recent work in animals using concentrated ambient particles has greatly strengthened confidence in epidemiological findings of effects of low concentrations of particles on the cardiovascular system.

One problem that is common to both the indoor and outdoor environments is that of exposure to mixtures of air pollutants. Workers who focus on single pollutants tend to ignore this and fashion dictates, to some extent, the pollutants most thoroughly studied. In the outdoor air field particles have been studied much more intensively than gaseous pollutants in the past ten or so years. This is shown by the great emphasis placed on fine particles ($PM_{2.5}$) and the much lesser emphasis placed on NO_2 and co-pollutants produced by the same sources as fine particles and which thus vary in concentration in much the same way as fine particles. Distinguishing the effects of such co-pollutants is difficult and conclusions about which component of a mixture is actually producing a given effect are sometimes less soundly based than could be wished. This point was stressed by several speakers at the 2006 Annual Conference of the US Health Effects Institute in San Francisco. The point is especially important in considering the indoor mixture of air pollutants – especially as this mixture may be very different from that found outdoors. Consider, for example, the recent finding from studies of the effects of outdoor air pollutants that show that NO_2 is an effect-modifier of the effects of particles. It seems that where concentrations of NO_2 are comparatively high particles have a greater than expected effect on health. This may be important indoors when concentrations of NO_2 frequently exceed those found outdoors. The mechanistic basis for this effect modification is, as yet, unknown.

A final and important point regarding standards for indoor pollutants involves the practicality of such standards – assuming they could be set. It is accepted that an outdoor air quality standard involves much more than a specified concentration and averaging time. A method for monitoring, a specified location for the monitors, a policy on acceptable levels of compliance with the standard, methods of quality assurance and quality control and a reporting structure are all required. Clearly these demands would be difficult to meet indoors – at least in private properties. It might be asked, how could adherence to an indoor standard be monitored and how could such a standard be enforced? These difficult questions have led to attention being focused on control of sources of indoor air pollutants and on the removal of such pollutants as are produced from the indoor environment. Thus, product standards and standards for ventilation and for venting via chimneys and exhaust systems have been widely developed. Ensuring that potentially dangerous devices such as gas fires or coke-fired boilers are properly fitted and maintained and function to product standards demands qualified engineers and technicians and qualification standards for such workers are set in many countries. This is the case in the UK. In addition, in the UK, guidance on maintaining good indoor air quality characterised by low levels of air pollutants is provided. Details of this advice can be found on the website of the UK's Committee on the Medical Effects of Air Pollutants (see: http://www.advisorybodies.doh.gov.uk/comeap/PDFs/guidanceindoorairqualitydec04.pdf).

Good indoor air quality is essential to health: exposure to raised levels of air pollutants damages health and in some cases, for example carbon monoxide, can cause death and significant lasting disability. Controlling levels of indoor air pollutants is therefore important. Setting standards for indoor concentrations of air pollutants is, however, difficult and emphasis on product standards, standards for ventilation, standards for servicing and installation of potential sources on the provision of guidance may be more effective.

Note: The views expressed here are those of the author and should not be regarded as representative of those of the Health Protection Agency

Indoor Air Exposure

M. J. Jantunen

KTL (National Public Health Institute), Dept. Environmental Health, POBox 95, FI-70701 Kuopio, Finland
email: matti.jantunen@ktl.fi http://www.KTL.fi/Expolis, .../ExpoFacts

***Summary**: The term **indoor air exposure** is used to mean different concepts, ranging from exposure to air contaminants originating from indoor sources to exposure to all air contaminants in indoor environments from both indoor and outdoor sources. Epidemiological associations between the mortality and morbidity of urban populations and ambient air pollution monitoring data are routinely called health effects of outdoor air exposure, which has created false interpretations: that the same air pollutants when originating from indoor sources are of lesser health importance, or that the observed health effects are due to exposure the while outdoors.*

Further confusion has been created by counterarguments that outdoor air pollution matters little, because we spend over 90% of our times indoors. True, but misleading because much - for some contaminants most - of the indoor air pollution comes from outdoor air.

*A pragmatic approach to indoor air exposure focuses on air pollution exposure and risk management: **The overall impact of buildings, building equipment and management, indoor materials and activities on exposure to air pollution.** Managing of the risks from indoor air exposure should therefore focus both on elimination and dilution of the contaminants from indoor sources, and protection from outdoor air pollution. The latter can be advanced by isolating indoor microenvironments from outdoor air pollution, but also by reducing outdoor air pollution. Buildings do not only protect from outdoor air, they also contaminate it - directly and indirectly. The direct impacts come from the energy efficiency, heating system of and fuel selection for the buildings. Built urban environments, however, modify their environments also by other means than exhausting flue gases and wastewater. For the same effective residence and work space, different urban plans require vastly different land areas and generate different forms and quantities of traffic. These environmental effects of the entire building stock and consequent urban infrastructure may, overwhelm all the direct and obvious impacts that an individual building has for the air pollution exposure of its occupants.*

***Keywords**: Exposure, indoor air pollution, indoor sources, ventilation and infiltration, urban infrastructure*

1. Introduction

The term *indoor air exposure* is used - often without the necessary clarification - to mean different concepts, ranging from exposure to air contaminants originating from indoor sources up to exposure to all air contaminants in indoor environments. The former definition excludes exposure indoors to air contaminants originating from outdoor air and entering the indoor spaces via ventilation system or open windows and doors. The latter engulfs the former definition, but also most of our exposure to outdoor air contaminants, because we spend in average so little time outdoors that exposure to air contaminants outdoors forms only a minor fraction of the total exposure - with the possible exception of ozone.

Air pollution epidemiologists have - with remarkable success - studied the statistical associations of mortality and morbidity of urban populations and cohorts with outdoor (ambient) air pollution monitoring data. Based on this study design feature, epidemiologists often talk about the health effects of outdoor air exposure, which has created two false interpretations. The first: that exposure to air pollutants - even the same air pollutants - arising from indoor sources is of lesser health importance, and the second: that the observed health effects are due to the exposure that the population acquires while outdoors (as literally interpreted from 'outdoor air exposure'). To avoid the confusion, some USEPA documents use the terms 'air pollution from outdoor origin' and 'air pollution from indoor origin' [1,2].

Confusion has been amplified by indoor air experts, who have testified that outdoor air pollution matters little, because we spend over 90% of our times indoors. This is a misleading truth. It is true for the sheer time allocation percentage and the health importance of indoor air quality, but misleading because much - for some air contaminants most - of the indoor air pollution comes from, and reflects the quality of outdoor air.

1.1 Time-activity

The significance of indoor sources and indoor air pollution on human health is due to two facts. (I) Indoor sources are much closer to people than outdoor sources, and dilution of air contaminants from indoor sources is only 1/100 - 1/1000 of the respective outdoor pollution dilution. (II) Most people in the industrialised societies spend a very high portion of their total time indoors. One of the objectives of the *EXPOLIS* study [3,4], was to determine the time - average hours per workday - spent indoors at home by active adult European urban populations in different microenvironments and activities. Grand average time spent indoors was 22.3 h/d or 93%, which does not include time spent in transit - also mostly indoors. [5]

Table 1. Time allocations for indoor Environments in European cities, h/d (city)

Indoor	min	max
home	13.5 (Milan)	15.8 (Oxford)
work	6.1 (Athens)	7.5 (Milan, Prague)
other	1.3 (Oxford)	2.2 (Grenoble)

1.2 Indoor Air Exposure

How should we then deal with *indoor air exposure*? Only considering exposure originating from indoor sources, or the total exposure while indoors. My own solution is pragmatic, aimed at being helpful for risk management: *The overall impact of buildings, building equipment and management, indoor materials and activities on exposure to air pollution (while indoors).* Certainly all exposure to air pollutants from indoor sources is included, but one should also consider the protective capabilities of the buildings, which, in fact, is exactly what buildings are designed, built and maintained for, to provide shelter from outdoor weather air pollution.

Because the whole stock of buildings and the activities in and between them are the two most important urban ambient air pollution sources, one should also consider their direct (heating and ventilation effluents), and indirect (land use and traffic) effects on urban ambient air and consequently also indoor air exposure.

2. Air Pollution Exposure from Indoor Sources

Enemy N:o 1 - tobacco: The most important indoor source of air pollution exposure is tobacco smoke. When present tobacco smoking is usually the leading source of indoor combustion particles, numerous VOC:s and CO, as well as a significant source for NO_2 [e.g. 6,7,8,9].

Because the role of tobacco smoke is so dominating for most indoor air contaminants and exposures to them, all results and discussions presented are derived from data, which has been cleaned from the impacts of ETS, unless otherwise mentioned.

In the absence of environmental tobacco smoke (ETS), the other contributions of indoor sources to the exposures to air pollutants vary greatly, (i) between the different pollutant croups (different VOCs, particulate matter, bioaerosols, CO and NOx), (ii) between building categories, buildings and indoor spaces within them, and (iii) between different regions, e.g., in Europe.

2.1 Carbon monoxide (CO), and nitrogen dioxide NO_2

The indoor sources of CO and NO_2 are the same, unflued or leaking combustion devices. Incomplete combustion due to low quality fuel, poor mixing or insufficient quantity of combustion air and/or low combustion temperature generate CO. The opposite conditions, well mixed excess air and high combustion temperature produce NO, which is rapidly oxidised to NO_2. The fundamental difference, however, is that NO formation even in the most ideal residential combustion conditions is limited to a few hundred ppm:s, while unfavourable combustion can generate percent level concentrations in the flue gas.

The most abundant indoor (and outdoor) air pollutant, CO is usually present in concentrations ranging from a few hundred up to a several thousand $\mu g/m^3$. Although indoor CO sources are mostly nonexistent or weak, acutely dangerous CO concentrations come almost exclusively from indoor sources and these are responsible for thousands of lethal and many more non-lethal poisonings annually in Europe. Aside of such dangerously high CO exposures, people are routinely exposed to CO from indoor sources, which add to the background exposure from ambient air. The average contributions of indoor sources to total personal CO exposures of those individuals who were exposed to these sources in Milan, Italy, were ETS (15%), and gas cooking (10%) [6].

The common indoor sources of NO_2 in Europe are tobacco smoke and gas appliances [10]. When integrated over a full day or longer, indoor concentrations of NO_2 are usually, even in the presence of indoor sources, lower than respective ambient air concentrations, because of the reactivity of NO_2 with co-pollutants and indoor surfaces as can be seen from table 2.

Table 2. 48 h. average outdoor and indoor NO_2 concentrations ($\mu g/m^3$) in three EXPOLIS cities [11]

City	outdoor	indoor	workplace
Helsinki	24 ± 12	18 ± 11	27 ± 15
Basel	36 ± 13	27 ± 13	36 ± 24
Prague	61 ± 20	43 ± 23	39 ± 18

Short term concentrations in kitchens with gas stoves and (bath)rooms with gas fired unflued hot water heaters, short term NO2 levels may exceed 1000 $\mu g/m^3$, far above the levels observed in outdoor air [12].

2.2 Volatile organic compounds (VOC)

After CO, VOCs are found in *highest indoor air concentrations*, and are consequently also responsible for the highest long-term population exposures. VOC:s are no doubt the most studied indoor air contaminants. In a review of 68 American and European indoor air studies, Brown [13] lists ethanol, 1,1,1-trichloroethane, toluene, limonene, acetone and xylenes as the indoor air VOC:s with the highest average concentrations. In Helsinki, Finland, indoor concentrations of acetone, formaldehyde, toluene, xylenes and limonene were the highest [14,15]. In a study of 3 German cities, the highest average indoor air concentrations were observed for limonene, toluene and pinene [16]. The top rank lists in these different studies are similar, acknowledging that ethanol was only considered by Brown and formaldehyde - not a VOC - was only considered in the Helsinki list.

In the German Environmental Survey (GerES II) [17] 74 VOC:s were analysed in the personal air (7 days) in a sub-sample of 108 participants representing 36 study locations in GerES IIa. The mean exposure to total VOC:s was 901 μg/m^3, with 95th percentile as high as 2810 μg/m^3. Mean personal exposure concentrations for the different VOC classes were highest for oxygenated VOC:s (308 μg/m^3), followed by aromatics (286 μg/m^3), alkanes (187 μg/m^3), terpenes (98 μg/m^3) and aliphatics (21 μg/m^3) [18].

Contributions of indoor sources to indoor exposures

The highest personal exposures to VOC:s are often due to high residential indoor concentrations. In the *EXPOLIS* study, e.g., in the sub-sample of high Naphthalene exposures in Athens, all were due to high home indoor concentrations (100 - 1000 μg/m^3), and home - but not workplace - naphthalene concentrations were also the determining factors in the Naphthalene exposures of 2/3 of the other study subjects. In Prague, where the levels were much lower, home or workplace indoor concentrations were the determining factors in only 3/21 cases. In Oxford, high workplace concentrations were the leading causes to higher than average hexane exposures. In Helsinki, Workplace and home indoor concentrations were the leading factors for 1/3 of the higher than average benzene exposures. [19]

The simplest and quite useful approach for assessing the relative contributions of indoor sources to indoor exposures, is to look at the indoor/outdoor (I/O) concentration ratios, which have been extensively reported since the late '70's. Ratios close to 1.0 indicate outdoor air as the main contributor to indoor exposure. High ratios up to 10 and above indicate that indoor sources dominate the indoor concentrations. This approach is, however, not reliable for compounds with high reactivity or absorbance to indoor surfaces. In the *EXPOLIS* study in Helsinki, the mean I/O ratios were highest for acetone (145) followed by formaldehyde (13), propionaldehyde (11), and 4 other aldehydes (7-8) [20, 21].

According to Brown [13] the contribution of indoor sources is highest (>90% in average) to indoor concentrations of, and respectively indoor exposures to limonene, isopropanol, α-pinene, camphene, undecane, dodecane and decane (aldehydes were not included). In the other end indoor sources contribute the least (½ or less) to e.g. benzene, butanal and carbon tetrachloride.

In Helsinki the contributions of residential and occupational indoor sources to total personal exposures were highest for aldehydes, terpenes and xylenes, lowest for benzene, toluene and nonane [15].

In the GerES II -study multivariate analysis was carried out to determine and quantify the major sources of personal exposure to various VOC:s, with main focus on aromatics. The only significant indoor source for benzene was ETS. For C-8 aromatics (ethylbenzene and xylenes) the main indoor sources were occupational, the presence of paints and lacquers in the workplace (24 % of variation) and daily time in workshops (20%). Interestingly, daily time reading newspapers and magazines explained 10% of the exposure variation. For C-9 aromatics (propylbenzenes, ethyltoluene, trimethylbenzenes) similar indoor determinants were found, and renovation or painting within the living environment explained another 13 % of the population exposure variation. [18]

In another recent German survey of the exposures to and sources of the aromatics, benzene, toluene, ethylbenzene and xylenes (BTEX), indoor sources - in urban area and absence of smoking and attached garages - contributed significantly only to Toluene exposure [22].

Indoor sources for VOCs have been identified in statistical *source attribution analyses* using principal components analysis (PCA) on the *EXPOLIS*-Helsinki data. The most influential indoor sources identified were cleaning products (Acetone, Terpenes, Aldehydes, 1-Butanol, Hexanal), building products (Octanal, Formaldehyde, Acetaldehyde and Benzaldehyde) and air refreshers (Limonene) [21, 23].

Indoor VOC differences between buildings

In the *EXPOLIS* study the variation of VOC concentrations between residential buildings in 7 European cities was in most or all cities greatest for alcohols, alkanes, esters and halogenated VOCs (standard deviation > arithmetic mean and max> 10 x mean). Variations were less pronounced or consistent for aldehydes and aromatics. Variation between the VOC concentrations in workplaces was similar, except for aromatics, which showed the highest and most consistent variation. Both indoor and outdoor sources contribute to this variation. [14]

Differences between regions and seasons:

Between cities: According to the *EXPOLIS* study differences between the average residential indoor air VOC concentrations in 7 European cities were remarkable.

Table 3. Average VOC concentration differences between 6 European cities (EXPOLIS) ($\mu g/m^3$) [14]

VOC Group	Lowest avg.	Avg	Highest avg.
Alcohols	2 (Basel)	25	60 (Milan)
Aldehydes	10 (Basel)	25	63 (Milan)
Alkanes	18 (Helsinki)	48	127 (Milan)
Aromatics	43 (Helsinki)	163	463 (Milan)
Esters	3 (Bas.&Hel.)	16	70 (Milan)
Halogens	2 (Bas.&Hel.)	28	130 (Milan)
Miscell.	21 (Basel)	59	98 (Mil.& Ath.)

The high average indoor concentrations in Milan in particular were due to a small number of very high levels. The indoor levels reflected the respective outdoor air VOC levels, but were in average 50% (alkanes, aromatics, exters) ... 150 % (alcohols, halogenated VOCs) higher.

Urban - rural: In the previously quoted German study outdoor and indoor concentration differences for BTEX-concentrations between urban (High traffic area in the city of Hannover) and rural (in Wedemark, no major traffic nearby) areas were also assessed [24, 25]. Although the average outdoor air concentration were about 10 times higher in the urban vs. rural area, the respective indoor air concentrations of benzene were only about 50% higher in the city. For the other aromatics the average indoor concentrations in the urban and rural areas were even closer. I.e. for BTEX compounds indoor sources all but eliminated the urban-rural indoor exposure differences. Because the indoor source contributions are generally lower for BTEX than for other VOCs, urban-rural indoor exposure differences for the other VOC:s - terpenes in particular - are likely to be even smaller and only weakly reflect the respective outdoor air concentration differences.

Seasonal: Residential indoor VOC concentrations also exhibit systematic seasonal differences, with 2.2 - 2.3 (aromatics) ... 2.5 - 2.8 (terpenes and alkanes) times higher average concentrations in winter vs. summer in three German cities [16]. The phenomenon obviously reflects the high relative contributions of indoor sources and reduced ventilation rates in winter.

2.3 Particulate matter

Particulate air pollution is (in sampling, regulation and research) usually divided according to particle size into coarse (2.5 - 10 µm aerodynamic diameter), fine ($PM_{2.5}$ < 2.5 µm) and ultrafine (< 0.1 µm) fractions.

In a Western urban context, the most important source of indoor air particles - in the absence of smoking - is usually outdoor air. Compared to VOC:s, indoor sources play a smaller relative role in the exposure to particulate matter. Penetration of particles from outdoor air into indoor spaces is therefore a matter of great interest for indoor air exposure, and it will be dealt here after assessing the indoor sources.

Indoor sources of PM exposure:

Outdoor and indoor air concentrations of and personal exposures to $PM_{2.5}$ in Helsinki, Finland, were attributed to sources in the *EXPOLIS* study using both statistical (PCA) and deterministic source reconstruction techniques [26]. Indoor concentrations were in average 10% lower than the respective outdoor concentrations. The dominating indoor source was human activity, which significantly elevated the average levels of indoor air mineral dust (2.5 $\mu g/m^3$) compared to outdoor air (1.6 $\mu g/m^3$). Another distinct indoor source was detergent particles from poorly rinsed clothes, marked by phosphorus, which was not detected in outdoor air, but was quite high - up to 2 $\mu g/m^3$ - in some residential environments. Phosphorus levels were quite low in most other cases.

In a multiple regression modelling study, using *EXPOLIS* data from six European cities, the indoor determinants identified for the 48 h indoor concentrations were smoking (16% of the var.) and gas stove (1.4%) for $PM_{2.5}$, smoking, building type and gas stove (all < 4%) for BS, and gas stove (11%), heating fuel (7%), building type (5%), smoking and cooking for NO_2 [8]. In a French regression modelling study of the determinants of $PM_{2.5}$ exposures of asthmatic children, the statistically significant variables were indoor smoking (36% of variation), ambient air PM_{10} (24%), pets (particularly rodents, 21%) and traffic exposure (12%) [9].

In a study focused on the short-term impacts of indoor PM sources various means of cooking contributed drastically to indoor PM concentrations (with peak concentrations of 30 - 60 $\mu g/m^3$ for $PM_{0.02\text{-}0.5}$ and 10 - 300 $\mu g/m^3$ for $PM_{0.7\text{-}10}$. Cleaning activities (8 $\mu g/m^3$ for $PM_{0.02\text{-}0.5}$ and 30 $\mu g/m^3$ for $PM_{0.7\text{-}10}$) and mobility of the occupants (4 $\mu g/m^3$ for $PM_{0.02\text{-}0.5}$ and 20 $\mu g/m^3$ for $PM_{0.7\text{-}10}$) contributed much less. Oven cooking was the strongest source for indoor $PM_{0.5}$, sautéing for PM_{10}. [27]

Infiltration of ambient particles into indoor spaces

Of the commonly monitored particle size fractions, $PM_{2.5}$ infiltrates best (30 - 90%) from outdoor to indoor air. Indoor infiltrations of ambient coarse ($PM_{2.5\text{-}10}$) and ultrafine (# particles smaller than 0.1 µm) are lower.

In non-smoking homes in Boston, MA, minimum infiltrations were observed for ultrafine and coarse, maximum for 0.1 - 0.5 μm particles. Infiltration efficiency depends also on the season (higher in the summer, if no air conditioning (AC) and high AER) and home characteristics (low in summer, if equipped with AC and low AER). [28]

In studies made in two very different climate zones and building types, namely residences in Brisbane, Australia [29], and offices in Helsinki, Finland [30], indoor concentrations in both followed the outdoor concentration changes in a smoothed and delayed pattern. In the former, however, the I/O ratios were 0.8 - 1.0 for both particle number and PM2.5 mass concentrations, in the latter the I/O ratios fell within a much broader range, 0.05 - 0.75. In another Finnish office building with a mechanical ventilation system equipped with EU7 class filters, infiltration of outdoor air particles was highest (0.25 - 0.3) for 0.2 - 0.5 um particles, lower (0.15 - 0.2) for 0.1 um, and lowest (0.02 - 0.06) for 0.01 um particles. [31]

In an American study of two retirement homes (in Baltimore, DE, and in Fresno, CA), residential HVAC filter efficiencies were 30 - 65 % for coarse particles, lowest 10 - 20 % for 0.06 - 1.0 μm particles but again over 25 % for particles smaller than 0.01 μm. Indoor $PM_{2.5}$ concentrations in air conditioned apartments were, in average, only 45% of outdoor concentrations, but reached 80 % when AC was turned off and homes were ventilated through open windows (April - May in Fresno, CA). Personal exposures of the residents followed closely the indoor air concentrations with a mean 3 $\mu g/m^3$ increase from personal cloud [32].

3. Risk Assessment and Management

The first exposure and risk management option for indoor air pollution should always be indoor source elimination or isolation. The indoor sources of CO, NO2, VOCs and PM have been identified earlier in this presentation. The second option is dilution by ventilation.

Keeping these facts in mind, I will now explore some additional aspects of indoor exposure control.

Infiltration - Exposure - Health

According to epidemiological studies the most harmful ambient urban air particle size fraction for health is $PM_{2.5}$, which - in non-smoking indoor spaces - comes mostly from outdoor air, much of it after having been transported over long distances. Most of the population exposure to and therefore - logically – also mortality and morbidity from outdoor air $PM_{2.5}$ is, however, caused by indoor exposure to $PM_{2.5}$ of outdoor origin. An interesting epidemiological study [33] pointed out that, indeed, increased fraction of buildings with central air conditioning within the community significantly reduces the association between ambient air PM and serious health effects (CVD, COPD, Pneumonia). These facts open a significant reduction potential for urban $PM_{2.5}$ mortality risk in buildings.

In more recently built buildings with advanced filtered mechanical ventilation and air conditioning systems, the infiltration of outdoor air $PM_{2.5}$ is significantly lower than in older buildings with natural ventilation via open windows and vents [34]. A probabilistic exposure modelling exercise demonstrated that reducing the distribution of $PM_{2.5}$ infiltration into all buildings in the city of Helsinki to the level of the office buildings built after 1990, would reduce the population exposure to $PM_{2.5}$ from outdoor origin as well as its adverse health effects by 27%, in fact almost as much as total elimination of all traffic sources from within the metropolitan area limits.

O_3 is another air pollutant with significant public health risks, against which buildings and ventilation & AC systems can provide a significant level of protection. Ozone levels in sealed and centrally air conditioned buildings are only in the order of 1/10 of the ambient air levels. Also *nitrogen dioxide* is sufficiently reactive to be significantly reduced indoors vs. outdoors.

IAQ risk management strategies

Indoor exposures to the coarse, fine and ultrafine PM, to O_3 and NO_2 can, therefore be managed not only by avoiding and managing indoor sources, but also by restricting the infiltration of outdoor pollution to indoor environments, i.e. by enhancing and expanding the protective function of the building and its ventilation system.

Urban air pollution risk management applying building technologies should not be seen as alternative, but rather as complementary to urban ambient air pollution reduction measures. This is highlighted by interesting differences between the two strategies. Reduction of local air pollution sources has no impact on exposure to the air pollution load from extra-urban sources, while building technologies reduce pollution exposure from intra- and extra-urban sources equally. Reduction of local air pollution sources has only limited potential for protection of vulnerable population groups or individuals, while building, ventilation and filtration technologies can be targeted for efficient individual or building level protection.

4. Buildings as direct sources of urban ambient air pollution - consequently indoor air exposure

Buildings do not only contaminate their own indoor air and protect more or less from outdoor air pollution, they also contaminate outdoor air. The most obvious sources are ventilation, and flue gases from heating. The former depends on the quantity of indoor air contaminants that are exhausted, i.e. pollutants from indoor sources, the latter on the energy requirements, system and fuel used for heating the building. In the case of a single building, its impact on its own external air quality usually remains marginal. In the case of the entire building stock of the city, its contribution to urban ambient air quality may range from moderate to critical. By collectively polluting the urban ambient air, buildings also pollute the indoor air, and thus increase the indoor air exposures, equally in neighbourhood buildings with low or high pollution output. In the case of e.g. London in 1952, heating of buildings by coal fed fireplaces was the biggest source of the air pollution catastrophe, which caused thousands of excess acute deaths. Heating of the buildings has since improved in London and other cities in the developed world, and yet many of the world's megacities are not better off today than London was in 1952. After all previous improvements Irish legislation completely eliminated the use of coal for domestic heating in Dublin in 1990. The public health consequences were dramatic; a 12% step reduction in cardiovascular mortality and 30% reduction in respiratory mortality, which truly highlighted the cumulative impact of the pollution from the whole urban building stock to air pollution exposure and health [35].

5 Buildings as indirect sources of urban ambient air pollution - consequently indoor air exposure

Two examples will highlight this issue better than a theoretical discussion. WHO provided me an opportunity in the autumn of 1998 to visit Kuala Lumpur, capital city of Malaysia, in the context of a training course in indoor air quality management for local authorities. Kuala Lumpur is a rapidly growing, developing and modernising city, typical for this tropical region, where economies grow with double digit annual percentages and buildings need to be cooled, not heated, year around. With raw simplification, two schools of architecture were building the city for the 21st century there:

The first applies traditional local experience and understanding about the natural forces of convective air currents and wind guidance in open unrestrictive spaces, night-time cooling of the building mass and shadowing by trees to create a comfortable indoor climate with a minimal external energy need.

The second uses more technical indoor climate management, based on sealed high rise buildings, mechanical ventilation and central air-conditioning, resulting in high electric power consumption, in particular for forced forced air circulation and refrigerative cooling. Air pollution load from the energy generation needs for a building of this second school is obviously much higher than for one of the first school.

This is, in fact, a comparison between 2-dimensional and 3-dimensional urban plans.

The most striking difference in comparing these alternatives is that in the first alternative creates an order of magnitude larger city for the same people and activities compared to the second. This has fundamental impacts on the required traffic network, system and exhausted pollution.

In the 2-dimensional city the transportation needs will most likely be served by an arterial highway network connecting housing areas to office parks and shopping malls with large parking areas. In the latter, rail transit is perfectly suited to handle the high passenger volumes over relatively short distances, and much of the horizontal street traffic of the first alternative is in fact replaced by vertical traffic by escalators and elevators in the second - 3-dimensional - urban structure.

There is on obvious trade-off particularly in urban planning in the warm and hot climate zones between high electric power needs for air conditioning of the 3-dimensional city and high street traffic for transporting in the 2-dimensional city.

Similar alternatives may also apply in the design and location of a single building, particularly if it generates more than average volumes of traffic. An example is the future concert hall of the city of Helsinki. After years of fierce political debate, it will be located right in the heart of the city within short walking distances of all major transport terminals certainly in the noisiest and most polluted location of the city, which will set expensive requirements for the building. The few thousand daily visitors of the building, however, will generate only a minimum amount of extra traffic, traffic pollution and noise.

The alternative locations were much less central, would have allowed a simpler, 'greener' and cheaper building, but would have also generated significant new traffic volumes with pollution, noise and parking needs. Oddly, these alternatives were favoured by most green politicians of the city and environmental activists.

Locating a new office building, concert hall, etc., may, during the service life of the building be much more important for urban ambient air quality – and consequently for the collective indoor air exposure – than all its other indoor, outdoor environmental and energy characteristics. Location can add or reduce hundreds of millions of passenger kilometres, the respective energy inputs and pollution and noise outputs, as well as determine the means of transport for these kilometres.

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Adaptive Thermal Comfort in Building Management and Performance

R. J. de Dear

Macquarie University, Division of Environmental and Life Sciences, Sydney, NSW 2109 Australia
email: rdedear@laurel.ocs.mq.edu.au

Summary: *Conventional thermal comfort theory (PMV) regards building occupants as if they were thermometers; expose them to any indoor climate and they will register an appropriate level of thermal discomfort. A corollary of this view is that people the world over have had their internal "comfort thermometers" calibrated to a universal standard, as represented in ISO-7730. The alternative, known as adaptive comfort theory, recognises that the human thermal comfort sensor is somewhat more complicated than a thermometer. First of all the calibration reference or "comfort set-point" is not universal at all. Instead, it drifts in the direction of the climate to which the person has been exposed. Secondly, there appears to be some hysteresis built into the human comfort "sensor" because the comfort response to a given indoor climatic regime depends partly on the outdoor climatic context of the building from which the occupants entered the building. Since provision of thermal comfort to its occupants is one of the most important functions of a building, it is logical that building quality or performance should be quantified in thermal comfort terms. Any given building is likely to receive different ratings, depending on whether conventional (PMV) or adaptive comfort theory is used in the rating scheme. This paper explores recent developments in quantitative expressions of human thermal comfort criteria in the context of building performance rating schemes currently undergoing revision in Australia (National Housing Energy Rating Scheme) and the Netherlands (ATG).*

Keywords: *thermal comfort, adaptive comfort model, climate, natural ventilation, energy rating*

1 Introduction

Given recent mainstream acceptance of adaptive thermal comfort concepts in international standards [1] it seems appropriate to start considering in which contexts and precisely how, adaptive concepts can be applied. The assessment of building performance, either simulated or actual, entails the quantification of how closely indoor climatic conditions track some theoretical optimum. The conventional approach has been to regard a range of comfort index values [2] to be acceptable (e.g. $-0.5 < \text{PMV} < +0.5$ which is assumed to correspond with 90% acceptability). The magnitude and duration of excursions outside that range are inversely proportional to the indoor environmental quality of the building. By logical extension, the time-weighted magnitude of deviations outside the acceptable range is also an indicator of the amount of energy required to restore comfort.

Clearly the choice of thermal environmental index used to define the optimum or benchmark condition has a major influence over the outcomes of the performance assessment tool. For example, benchmarking in terms of a static indoor air temperature, as was common a few decades ago, unfairly penalizes indoor environments that achieve comfort through the other environmental parameters in the human thermal comfort equation, such as air speed. Benchmarking comfort in purely environmental terms unfairly penalizes buildings in which occupant comfort can be maintained by behavioral thermoregulation (e.g. adjustment of clothing insulation levels). To the extent that it incorporates a combination of indoor environmental and behavioral parameters, the PMV comfort index [2] represents a logical choice in building performance assessment tools, and has been useful in that context for many years. A typical example is the index developed in the 1980s and 90s by the Netherlands' Government Building Agency [10]. In that approach a building's thermal performance (either prospectively during the design stage, or post occupancy) was calculated by weighting the number of hours during which conditions go outside the desired PMV range by the Predicted Percentage Dissatisfied (PPD) calculated in each hour of exceedence ; in effect the Dutch index was the sum of "weighted excess hours" using the PMV/PPD comfort methods [10].

Recognition that the comfort setpoint within building occupants themselves is not static, but rather adaptive, introduces a whole new dimension to the task of defining building performance benchmarks. Adaptive comfort theory [3, 4] emphasizes the *temporal* variability of building occupants' comfort setpoint, particularly as it responds to changes in the atmospheric environment outside the building. Our thermal comfort optimum seems drifts in the direction of the climate to which we have been exposed; as winter turns to summer, so does our comfort optimum move from cool to warm. Given the importance of the temporal dimension in adaptive comfort theory, it is surprising that there has been relatively little work on defining the precise temporal characteristics of the comfort system. In the adaptive comfort model [6] incorporated into ASHRAE Standard 55 [1] the external atmospheric parameter is represented as either an actual or climatological monthly air temperature for the specific city in question. Here the term 'climatological' refers to a long-term, typically 30 year average. The choice of a monthly average was based less on detailed knowledge of the workings of our adaptive mechanisms, and more on the practicalities of climatic data availability. A climatological average can be criticized on several grounds. For example, what if the month in question is climatically anomalous? An exceptionally hot December may lift the population's comfort set point a bit higher than would be the case in a more "normal" summer (southern hemisphere). This is the same criticism that we sometimes hear in relation to using Typical Reference Year (or Typical Mean Year) meteorological records for thermal performance simulations and energy/HVAC load calculations. And why such a long integration period for the external climatic stimulus to thermal adaptation? Weather fluctuations occur on a synoptic timescale, for example, between four to seven days in Sydney, these dynamics are filtered out by the monthly averaging process. The rebuttal to these perfectly valid criticisms points to the practical issue of data availability. Monthly climatic averages (or norms) can be readily obtained for virtually *every* location on the planet [e.g. 5]. Whether or not a month represents the optimal timescale of our adaptive comfort processes has yet to be critically examined, but the strength of statistical correlation between indoor comfort optima and outdoor monthly climatic data [6] suggest that a month represents a useful solution.

Be that as it may, some comfort problems or applications have access to a much richer set of outdoor weather data that more fully captures dynamics. As noted above, weather/climate varies on a complex spectrum of time-scales; from minutes up to geological time-scales. The relevant domain for thermal comfort falls somewhere between diurnal (daily), and seasonal scales. But the *precise* location within this continuum remains unknown to date. If we accept that thermal expectation is driven primarily by thermal experience;

> *How long does it take to adapt to the variations in the outdoor climatic stimulus?*

or to put it another way;

> *What is the half-life of our comfort perceptual system's "thermal memory"?*

2 Representing outdoor temperature in the adaptive comfort problem

In their summary of new building performance assessment procedures in The Netherlands, Van der Linden *et al.* [9] described a four-day, weighted running mean of outdoor temperature as the driver for adaptive comfort setpoints, although the justification of that choice was not addressed. Their weights went as follows: today's temperature was weighted 41.7% in the four day running mean, yesterday's temperature contributed 33.3%, the day before yesterday's temperature 16.7%, and the day before the day before yesterday's temperature was weighted 8.4%

While The Netherlands' [9] representation of outdoor weather in the adaptive comfort system sounds intuitively plausible, an empirically justified answer to this question is yet to be presented. But before such an answer can be found one first has to decide which indicator or response parameter in the human comfort system is most relevant to the problem (and also accessible to the comfort researcher). Comfort can be diagnosed simply as a sensory response ("*warm*", "*cool*", "*neutral*" etc.), or one can look at behavioral indicators (e.g. clothing choices). Yet another option, particularly in the workplace, could be productivity-based, although the difficulties in coming up with a valid metric have, to date, diminished the impact of productivity-based approaches.

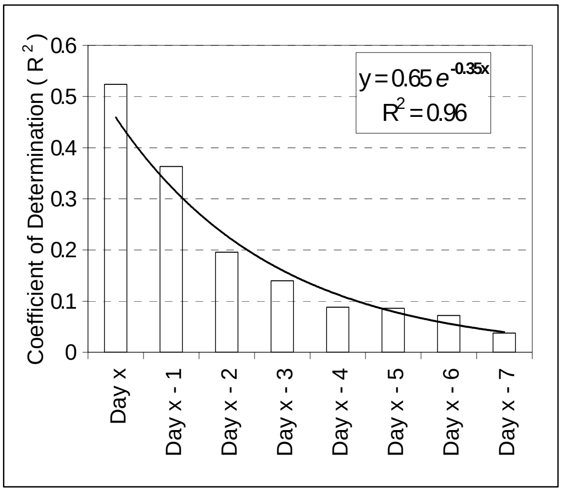

Fig. 1. The statistical relationship between clo levels worn by shopping mall patrons and the mean daily temperature, recorded outside at time-lags varying from same-day through to seven days prior [modified from 7].

A behavioral approach was adopted in a recent study in Sydney Australia [7] in which the customers using a suburban shopping mall were continuously monitored for a period of about six months (from mid-winter to mid-summer). Each day throughout the entire survey period a clothing garment checklist was unobtrusively applied to a random sample of about 45 subjects, and an ensemble clo value was estimated for each. The mean of each day's clo estimates was correlated with the outdoor temperature recorded at a nearby automatic weather station. Pearson correlation coefficients were computed between clo and outdoor temperature at various time lags, ranging from zero (i.e. same day clo and temperature records) through to seven days (i.e. clo recorded on day *x* and mean outdoor temperature recorded seven days earlier). The pattern of exponentially decaying coefficients of determination (R^2) can be seen in Fig.1. For example, the graph indicates that about 52% of the day-to-day variance in mean clothing insulation worn by the patrons of this Sydney shopping mall can be accounted for by the day-to-day variations in outdoor temperature. The explained variance drops down to 36% if mean daily outdoor temperature is lagged by one day (i.e. clothing today correlated with temperature yesterday). If the temperature is lagged by seven days the coefficient of determination (R^2) drops down to just 4% Fig.1 also includes an exponential regression equation fitted to the eight R^2 values and the statistically significant model ($p<0.01$) explains 96% of the variance in the eight coefficients of variation. The exponential function in Fig.1 indicates a half-life of between two and three days. Part of the explanation for such a good regression lies in the serial autocorrelation between successive days' weather (what meteorologists call *persistence*), but at least as important if not more so, is the tendency for people to wear clothes on any particular day that are broadly comparable, in clo terms at least, to what they wore the day before, which in turn approximated the thermal insulation of what they wore the day before, and so on.

This pattern of lagged clothing response represents a proxy for the temporal dimension of adaptive comfort mechanisms, namely *thermal expectation.* If one accepts this interpretation, then the exponential function depicted in Fig.1 can be used to develop a temporally more specific function for the running mean of outdoor temperature used in the adaptive thermal comfort model (i.e. ***m**ean **o**utdoor **t**emperature* T_{mot}).

The behavioral evidence in [7] suggests that the ideal outdoor temperature function for adaptive comfort is a weighted running mean spanning eight days, including the current day, but for some applications the current day cannot be used because it will not have occurred by the time it is actually needed for real-time calculation purposes. Removal of the "today" term leaves a seven-day integration period; short enough to incorporate recent weather dynamics, yet long enough to capture "weather memory and persistence" effects in human clothing behavior.

The weighting coefficients for the proposed running mean weekly outdoor temperature adaptive algorithm (T_{mot}) have been derived from the exponential function plotted in Fig. 1 but excluding the "today" data point. The resulting function can be written as:

$$\begin{aligned} T_{mot} = {} & 0.34T_{(day-1)} + 0.23T_{(day-2)} \\ & + 0.16T_{(day-3)} + 0.11T_{(day-4)} \\ & + 0.08T_{(day-5)} + 0.05T_{(day-6)} \\ & + 0.03T_{(day-7)} \qquad ({}^{O}C) \qquad eq.1 \end{aligned}$$

An example application of this running mean T_{mot} function in the Sydney context is seen in Fig.2. Outdoor air temperature was recorded at 15 minute intervals from mid-March through mid-April 2006, and mean daily temperatures calculated from these. Synoptic variability on a time-scale of a couple of days is evident in the plotted daily means, but the weighted, running mean weekly temperature in the T_{mot} is lagged and noticeably smoother.

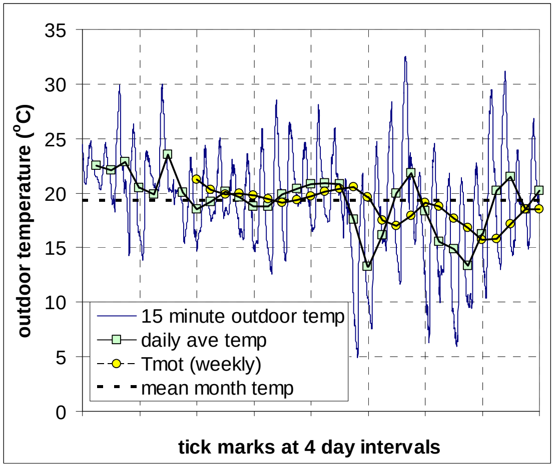

Fig. 2. One month (March/April 2006) of outdoor temperature records for Sydney and the corresponding T_{mot} weighted running weekly mean temperature based on *eq*.1.

3 Applications of the T_{mot} function in adaptive comfort problems

Having established an empirical basis for the outdoor temperature forcing function, the intention is for it to drive an adaptive comfort model such as that developed in the ASHRAE RP-884 research project in the 1990s [3,6]. In that paper the adaptive regression model for naturally ventilated buildings was fitted to either observed, or climatological **m**ean **m**onthly **o**utdoor **t**emperatures (in that order of preference), designated here as T_{mmot}, resulting in the following expression:

Comfort temperature = $0.31 * T_{mmot} + 17.8$ *eq*.2

I propose substituting the weighted, running mean weekly outdoor temperature in place of the mean monthly temperature, i.e. replace T_{mmot} with T_{mot} in *eq*.2. This invites technical criticism; namely the fitting of a regression model to an outdoor temperature recorded on a *monthly* timescale, and then applying that same regression model to outdoor temperatures integrated over a *weekly* timescale. This mixing of timescales may well offend the statistical purists, and the only defense is a pragmatic one. The adaptive comfort model represented in *eq.* 2 represents the line of best fit of observed comfort temperatures in a large number of naturally ventilated buildings from around the world, to an index representing their occupants' recent outdoor thermal history. Mean monthly temperature was used as a readily-available surrogate for thermal history, and I am now proposing to sharpen the temporal focus by adopting a running weekly mean (exponentially weighted) in situations where meteorological data are available at that finer resolution. It is simply impossible to statistically test the effect of this change in timescale on the original RP-884 database because the comfort temperatures (neutrality or preference) of each building represent results from varying timescales ranging from a few days up to a month. Nevertheless there is every reason to expect that the strength of the adaptive model's statistical significance would improve with this change, not decrease.

In the original adaptive model papers by de Dear and Brager [3,6], the 90% and 80% acceptable ranges around the comfort temperatures predicted by eq. 2 were derived from the RP-884 database by applying some practical logic;

1. A regression equation of group mean thermal sensation vote on mean indoor operative temperature at the time of votes was derived for each naturally ventilated building in the database.
2. The mean of the gradient terms in these regression models was calculated across all naturally ventilated buildings within the database.
3. The same assumptions about interindividual variability that link PPD to PMV [2] were then applied. A mean thermal sensation vote of ±0.5 was assumed to correspond to a 90% acceptable operative temperature, while a mean thermal sensation vote of ±0.85 was assumed to correspond to an 80% acceptable operative temperature.
4. These thresholds were then applied to the average regression gradient derived in step 2 above, symmetrically straddling the comfort optimum predicted by *eq*.2. The following acceptability criteria resulted;

$$\textit{Upper 80\% Acceptable Limit} = 0.31T_{mot} + 21.3 \quad \textit{eq}.3$$
$$\textit{Upper 90\% Acceptable Limit} = 0.31T_{mot} + 20.3 \quad \textit{eq}.4$$
$$\textit{Lower 80\% Acceptable Limit} = 0.31T_{mot} + 14.3 \quad \textit{eq}.5$$
$$\textit{Lower 90\% Acceptable Limit} = 0.31T_{mot} + 15.3 \quad \textit{eq}.6$$

Van der Linden *et al.* [9] required an extension of these acceptability functions to the 65%, so the same PPD/PMV logic was applied the mean of the regression gradients again (step 2 above), leading to the following;

$$\textit{Upper 65\% Acceptable Limit} = 0.31T_{mot} + 22.0 \quad \textit{eq}.7$$

Equations 2 through 7 represent a suite of adaptive comfort algorithms ready for real-world applications. Providing the usual caveats and assumptions detailed in ASHRAE's Standard 55 [1] are adhered to, these algorithms represent, for example, a rational basis for deciding when a mixed-mode or hybrid ventilation system switches from natural ventilation to air conditioning. What should happen to the comfort controls *after* the switch-over from natural to conditioned occurs is another matter that requires further research, but at least we have some simple logic based on extensive field observations that could readily be programmed into a hybrid-ventilation building's management system (BMS). Assuming such buildings have an automatic weather station or at least an external air temperature sensor wired into their BMS, it should be an easy task to derive the running weekly weighted outdoor temperature (*Tmot*) for input to these algorithms in real-time, and so we have a modern implementation of the "thermobile" originally proposed by Auliciems back in the mid-80s [11].

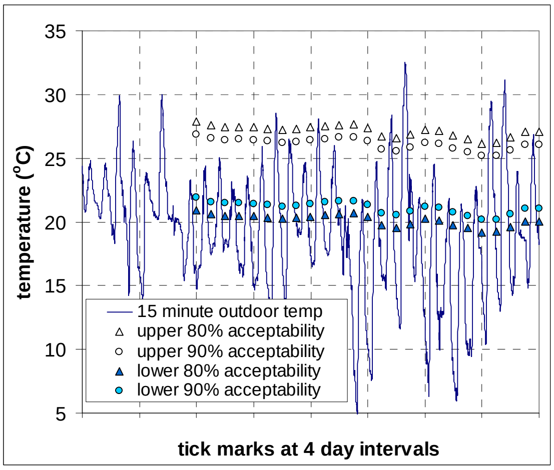

Fig. 3. One month (March/April 06) of outdoor temperature records for Sydney and the corresponding indoor 80% and 90% acceptability indoor temperature limits based on the adaptive *eqs*.3 through 6.

An example of what the adaptive acceptability criteria in such a BMS might actually look like in relation to a sample of outdoor temperatures in Sydney during March-April 2006 is depicted in Fig.3. The cold front before day 20 in Fig.3 did not register immediately in the adaptive indoor acceptability limit temperatures, but rather lagged a day or two behind. This lag is obviously accentuated by the omission of today's average outdoor temperature from the running weekly mean (*eq*.1). This might be a point for discussion because building occupants' usually have an expectation or forecast of today's weather at the time of their clothing decisions in the morning, but how can a building's BMS system anticipate today's mean outdoor temperature?

Another application of these adaptive comfort algorithms is the assessment of building performance, such as the methods adopted recently in The Netherlands and described by van der Linden *et al.* [9, 10]. As discussed earlier, the Netherlands Government Building Agency throughout the 1970s and 80s assessed thermal performance of buildings using the sum of "weighted excess hours." An acceptable range of PMV values was defined and each hour that had an internal temperature outside that range was weighted by the corresponding PPD for the same hour. For a variety of reasons detailed in [9, 10] the Dutch thermal performance techniques have evolved into new indoor thermal climate directives in which acceptable operative temperatures are defined on the basis of the adaptive model of thermal comfort [3,6] instead of PMV/PPD.

In the context of retrospective (post-occupancy) or even prospective (design stage) thermal performance assessment, it seems reasonable to include today's outdoor temperature in the calculation of the weekly running mean (T_{mot}) since the meteorological data used in these contexts are historical rather than real-time. This requires a re-calculation of the weights in the eq.2 running weekly mean function which closely resembles the version described in eq.1 except the weights have been shifted forward by one day;

$$\begin{aligned} T_{mot} = {} & 0.33T_{(today)} + 0.23T_{(day\ -\ 1)} \\ & + 0.16T_{(day\ -\ 2)} + 0.11T_{(day\ -\ 3)} \\ & + 0.08T_{(day\ -\ 4)} + 0.05T_{(day\ -\ 5)} \\ & + 0.04T_{(day\ -\ 6)} \qquad eq.8 \end{aligned}$$

Despite the inclusion of today's temperature in this version of the running mean, eq.8 produces adaptive comfort limit temperatures that still lag behind those based on the new Dutch indoor thermal climate directives [9] because the latter's weights are more biased towards present rather than past weather, as seen in eq.9:

$$\begin{aligned} T_{mot} = {} & 0.42T_{(today)} + 0.33T_{(day\ -\ 1)} \\ & + 0.17T_{(day\ -\ 2)} + 0.8T_{(day\ -\ 3)} \qquad eq.9 \end{aligned}$$

While the basis of that bias was not discussed in the van der Linden *et al.* paper [9], the effect is to confer an advantage in terms of thermal performance to light-weight structures that respond more readily to weather changes than thermally massive ones.

In another example application is the Australian National Greenhouse Office's current revisions to the energy star-rating protocol known as National Housing Energy Rating Scheme (NatHERS). It is proposed to replace static comfort temperature limits with adaptive comfort algorithms.

4 Conclusions

The application of adaptive thermal comfort principles in various contexts has been discussed in this paper, with particular attention being paid to the way in which the outdoor meteorological and climatic context of a building should be represented in the adaptive algorithms. The default representation is an actual or a climatological monthly mean air temperature. However, certain application problems have much richer meteorological data possibilities which invite an empirically-justified and more sharply focused outdoor meteorological parameter to represent recent thermal experiences of building occupants.

The paper examined the time-lagged correlations between clothing insulation and outdoor weather to and used these as the basis of defining exponentially decaying weights in a running weekly mean outdoor temperature. It was argued that clothing behavior represents a proxy for thermal comfort expectations, and as such, these weekly mean temperatures represent a more specific independent variable for input to adaptive thermal comfort models than the default monthly mean.

The paper illustrated the ways in which these adaptive concepts could be applied, including algorithms for the control of mixed-mode building management systems and building performance rating schemes such as those currently undergoing revision in Australia (National Housing Energy Rating Scheme - NatHERS) and The Netherlands (ATG).

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Indoor air quality and energy performance of buildings

C.-A. Roulet[1]

[1]Ecole Polytechnique Fédérale de Lausanne, LESO-PB, Station 18, CH 1015 Lausanne
email: claude.roulet@epfl.ch http://lesowww.epfl.ch

***Summary**:. Indoor air quality requires airing. Depending on the climate, energy is lost with exhausted or exfiltrated air and energy may be used to condition the new air and to move the air in a mechanical ventilation system. After the first oil cost crisis, energy saving measures were hastily taken without taking care of IAQ, thus decreasing it below acceptable levels and resulting in other damages such as mould growth. Therefore, it was believed that energy saving measures decrease IAQ. This is however not necessary. When properly designed and applied, combinations of energy saving measures indeed increase indoor air quality and even indoor environment quality, including comfort and well being. Inversely, appropriate measures to improve indoor air quality, comfort and well being at the same time improve the building energy performance. After a presentation of energy uses in buildings and in particular of energy needed for ventilation, this paper presents the relationships between IAQ and ventilation, ending by general guidelines on how to improve both IAQ, comfort, well being and energy performance of buildings.*

***Keywords**: energy, indoor air, buildings, indoor environment, comfort, health*

1 Introduction

Indoor air quality (IAQ) is obtained by reducing the emission of gaseous indoor pollutants and by airing. The new air should be passively or actively conditioned to have comfortable temperature and humidity levels, and this uses energy. In cold season, the building and its indoor air are heated, and the air is moistened by various water vapour indoor sources, such as occupants, cooking, laundry and humidifiers. In hot climates or during the hot season, some buildings are mechanically cooled, often through air conditioning.

In 2002, the household sector consumed 274 million tons oil equivalent, that is 25% of the final energy demand in the European community[1]. A significant part of this is used to condition the air by heating, cooling, dehumidifying or humidifying it. In central Europe, between 20% and 40% of the heating needs (depending on the type and quality of building) are for compensating ventilation heat losses in buildings. A part of the energy used in other sectors is also used for this purpose.

After the oil crises of the seventies, actions were taken in many buildings to reduce the energy use. One of these actions was reducing the airflow rate. At that time, windows opening combined with infiltration through unknown and uncontrolled leakage was a very common ventilation system, leading to drafts and energy waste. Caulking and weather-stripping was therefore used for reducing the envelope leakage, in too many cases without any care for IAQ. The result was insufficient airing, increased indoor pollution and humidity, mould growth, etc. Another unfortunate result was a growing opinion that energy saving measures are bad for IAQ, health and comfort.

Energy is used in buildings for improving indoor environment quality (heating, cooling, ventilation, and lighting) and for other services (hot water, transportation, cooking, leisure, production, etc.). Energy use related to IAQ is a fraction of the total energy use, which may be very small in naturally ventilated buildings in warm climates or rather important in fully air conditioned buildings.

When energy totally lacks, the comfort generally decreases. A question remains however: does it improves when more energy is used? Is IAQ better or worse in low energy buildings?

Several field studies have shown that appropriate building design and use allows obtaining better IAQ with a reduced energy use. The intention of this paper is to present facts that support this affirmation.

2 Energy use in buildings

2.1 Statistics

According to [2, 3] the energy performance index of a building is the total annual energy use of the building divided by the conditioned floor area. It is expressed in MJ/m² or kWh/m². According to the European directive on energy performance of buildings,[4] the energy use itself should be expressed in terms of primary energy or CO_2 production, but we found only energy performance indexes expressed in terms of energy delivered to the building (final energy).

As shown in figures 1 to 3, the distributions of the energy performance indexes are rather broad, spreading from half up to twice the most frequent value. This value depends on the type or use of the buildings and also on the fuel used for heating (*Figure 3*).

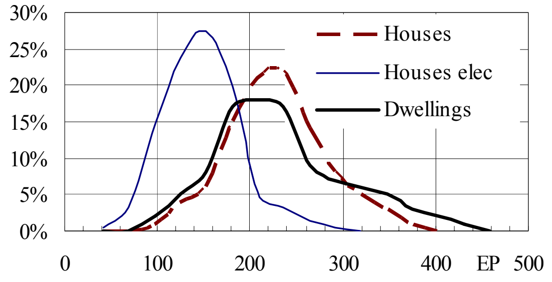

Figure 1: Frequency distribution of energy performance indexes [kWh/m²] of Swiss residential buildings.

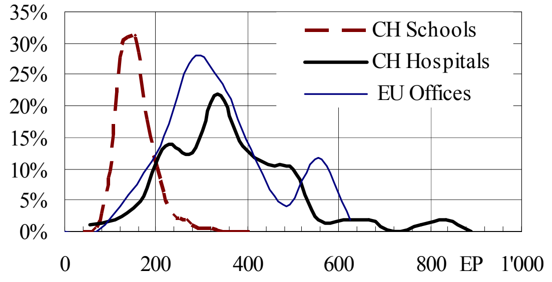

Figure 2: Frequency distribution of energy performance indexes [kWh/m²] of various non residential buildings.

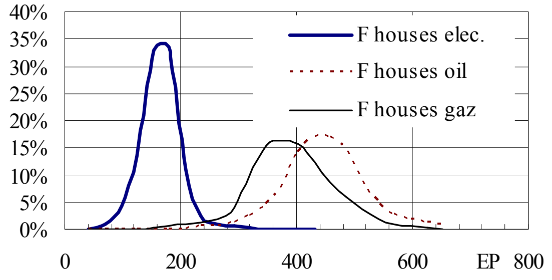

Figure 3: Frequency distribution of energy performance indexes [kWh/m²] of French houses heated with various energywares[1].

It is well known that such a large spread is the result of many causes: building design, climate, thermal insulation, performance of HVAC systems, occupant behaviour (including ventilation, artificial lighting, etc.). As it was already observed in the seventies, the energy performance of identical buildings also shows a large spread, which can mainly be attributed to occupant's behaviour[5].

The existence of buildings with low EP indexes or good energy efficiency proves that there is a large energy saving potential. Experiences in several countries have shown that good design and construction result in buildings using less than 25% of the building stock average energy use. Retrofit measures in existing building with large EP indices very often show a very good return on investment and may reduce the energy use by half.

2.2 EPBD

2.2.1 The directive

Tee directive 2002/91/EC[4] on the energy performance of buildings (the EPBD) requires several different measures to achieve prudent and rational use of energy resources and to reduce the environmental impact of the energy use in buildings.

This is to be accomplished by increased energy efficiency in both new and existing buildings. One tool for this will be the application by Member States of minimum requirements on the energy performance of new buildings and for large existing buildings that are subject to major renovation (EPBD Articles 4, 5 and 6). Other tools will be energy certification of buildings (Article 7) and inspection of boilers and air-conditioning systems (Articles 8 and 9).

This directive also requires that "*The measures further to improve the energy performance of buildings should take into account climatic and local conditions as well as indoor climate environment and cost-effectiveness. They should not contravene other essential requirements concerning buildings such as accessibility, prudence and the intended use of the building.*" Energy savings should not be achieved to the expense of poor indoor environment, since this is not only opposite to the purpose of buildings, but would also result in a bad perception and unexpected energy waste.

2.2.2 Related standards

A total of 30 European standards (EN) and 24 international (EN ISO) standards are being drafted or revised to help European countries implementing the EPBD. These standards and their interrelationship are presented in a so-called "Umbrella Document"[6]. The four main components set out in the Directive relate to:

- calculation methodology;
- minimum energy performance requirements;
- energy performance certificate;
- inspections of boilers, ventilation and air-conditioning systems.

The main goal of these standards is to facilitate Member States in the implementation of the Directive. In

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[1] Note that values in Figure 3 should not be compared to the other two, since the conditioned floor area was not calculated in the same way (internal dimensions in France and external dimensions for the other curves).

consequence they do not prescribe a single definition of energy rating or the expression of energy performance, but rather give a limited number of options. Similarly the items on inspections offer various levels of inspection.

The Technical Committees of CEN that are involved in the preparation of the standards comprise:

CEN/TC 89	Thermal performance of buildings and building components;
CEN/TC 156	Ventilation for buildings;
CEN/TC 169	Light and lighting;
CEN/TC 228	Heating systems in buildings;
CEN/TC 247	Building automation, controls and building management.

The process is being overseen by CEN/BT WG 173, Energy performance of buildings project group, to coordinate the work and to ensure that standards prepared in different committees interface with each other in a suitable way.

3 Ventilation and energy use

3.1 Mechanical and natural ventilation

Natural ventilation is the passive way to evacuate indoor contaminants. Wind and air density differences - resulting mainly from temperature differences - induce pressure differences that blow air through ventilation openings or natural ventilation ducts. Other openings such as doors and windows are also used for natural ventilation when large air flows are needed. The advantages or natural ventilation are the following:

- it is generally well accepted by the occupants, who understand and control it easily,
- its cost is very low,
- the energy for moving the air is small and free,
- it allows very large airflow rates (more than 10 volumes per hour), in particular for passive cooling,
- it does not break down.

It has however some drawbacks, which are:

- it cannot be used in noisy or polluted areas,
- it is efficient only in rooms with a depth-to-height ratio smaller than 3 or having openings on both sides,
- heat recovery is nearly impossible,
- the airflow rate varies with the meteorological conditions, and an adequate control is needed to ensure the ventilation requirements. An alternative solution is using self-regulated (pressure-controlled) ventilation grilles.

Mechanical ventilation is often used where natural ventilation cannot fulfil the requirements, either because of poor outdoor conditions (noise, pollution, climate) or in locations that cannot be naturally ventilated. It has the following advantages:

- it allows ventilating deep spaces with low ceilings and rooms that are not accessible to natural air flow,
- where well designed and built in an airtight building, it ensures a total and continuous control of air flows and also allows a better control of the indoor climate,
- it can protect from outdoor noise and pollution,
- heat recovery from exhaust air is relatively easy.

Its drawbacks are however:

- mechanical ventilation is often not well accepted by the occupants, who lack control on it.[7]
- the system, especially air ducts, uses a large part (up to 25%) of the building volume,
- the installation and exploitation costs are high,
- it uses energy not only to condition the air but also to move it,
- it can be noisy, especially at low frequencies,
- the quality of delivered air may be poor if special caution is not brought to it when building and maintaining the system[8],
- it may break down or function in an improper way.

Audits in European buildings[9, 10] have statistically shown that, on the average, the number of building related symptoms per person is larger in buildings with mechanical ventilation than in those with hybrid and natural ventilation, and in buildings with sealed windows than in buildings with operable windows. There were however no significant differences for the perceived air quality, perceived comfort, and energy use.

However, it should be emphasised that there are buildings equipped with mechanical ventilation or air conditioning that are healthy and comfortable. It is those in which design, installation and maintenance are appropriate.

3.2 Ventilation rates

Ventilation is mainly required to evacuate pollutants. Depending on its activity, a human being breathes between 0.4 and 3 m^3/h[11], but he pollutes 20 to hundred times this volume. An airflow rate between 14 and 36m^3/h is required to keep the concentration of odours or humidity generated by a quiet person below at an acceptable level[12].

Since the buildings should be designed and built for occupants, the occupants and their activities should be the only internal source of pollution. As it was shown in several studies[9, 13], this is by far not the case. The building itself and its installations are often the main source of pollution (*Figure 4*)

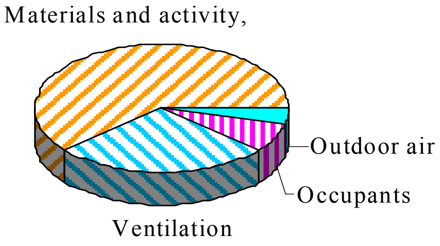

Figure 4: Average source strength for bad odours in buildings audited in 1993 during the European IAQ Audit. [9, 13]

Therefore, prEN 15251 proposes additional ventilation rates for the building emissions, which are listed in *Table 1*. Even with only 20 m^2 per person, we see that the ventilation rate required to evacuate pollutants may be much larger than that for persons only.

Table 1: Ventilation rates for persons and for building pollutants according to prEN 15251.

Airflow rate for	Category:	A	B	C
Occupants	$l/(s\cdot person)$	10	7	4
Low pollution bldgs	$l/(s\cdot m^2)$	1,0	0,7	0,4
Other buildings		2,0	1,4	0,8

3.3 Energy for conditioning the air

The air leaving the buildings has the characteristics (temperature, humidity, chemical composition) of the indoor air. It is replaced at the same mass airflow rate by outdoor air, which has its own characteristics. Therefore, the building gives or takes heat, water vapour and other chemical components to or from the air entering the building to reach the characteristics of the indoor air.

Energy is needed, on the one hand, to heat or cool the air and on the other hand to evaporate water in it or to condense water for drying it. Taking as a reference dry air at 0°C, the increase of specific enthalpy (in J/m^3) of the mixture air-water vapour at temperature θ and humidity ratio x is:

$$h = c_{da}\theta + \left(L + c_w\theta\right)x \qquad (1)$$

where

c_{da} is the s specific heat capacity of dry air (about 1'006 J/(kg·K)

c_w is the specific heat capacity of water vapour (about 1'805 J/(kg·K)

L is the latent heat of evaporation, i.e. the heat required for evaporating 1 kg water, about 2'501'000 J/kg.

x is the humidity ratio, i.e. the mass of water vapour per kg of dry air.

Figure 5 illustrates the paths of temperature and humidity ratio of air for two processes, both ending at 20°C and 50% relative humidity.

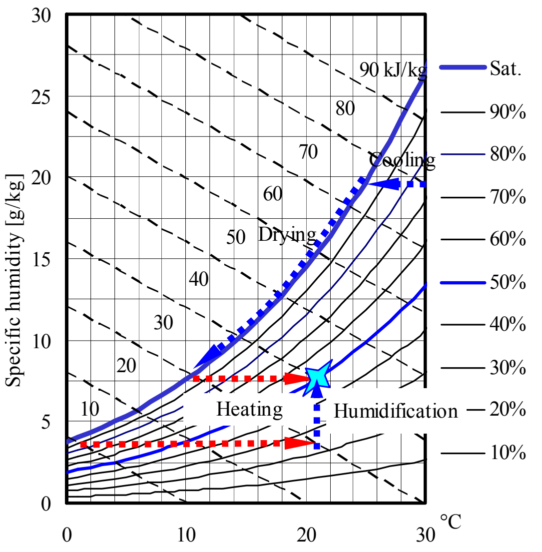

Figure 5: Psychrometric chart with constant relative humidity curves and constant enthalpy lines, in which paths for heating outdoor air at 0ºC and 80% RH or and cooling air at 30ºC and 75% RH to get indoor air at 20ºC and 50% RH are shown.

The heat required for heating and humidifying the air may be brought from free sources such as solar radiation or metabolic activity of occupants. Lighting and electrical appliances that are not part of the heating system may also give heat to the indoor air. Water vapour may be added to indoor air by plants and occupants and their activities such as cooking and drying laundry. However, this "free" energy may not suffice, and, in this case, the complement is provided by a heating system. In this case, about 0.34 Wh is needed to heat or cool 1 m^3 of air by 1 degree, as long as its specific humidity does not change or if the air is humidified by "free sources". This value is therefore used in models calculating the energy for heating buildings.

Hot and humid outdoor air cools down and eventually dries at the contact of cold surfaces, on which excess water vapour may condense. If these surfaces are not constantly cooled, such as the building fabric or furniture, their temperature will rise and cooling stops after a while. However, the air temperature rises more slowly if the air is in contact with massive structures that were cooled down before, for example by strong airing during the cool night.

Mechanical cooling is needed to keep the surfaces in contact with the air cold, and to get continuous air drying and cooling. Starting from warm, humid air, it is first cooled down when passing through a refrigerated heat exchanger (horizontal "cooling" line in *Figure 5*) until it reaches its dew point. Then it is dried by loosing the water that condenses on the heat exchanger ("drying" curve") until it reaches the required specific humidity, at a new, lower dew point. It should then be heated at the required temperature.

The largest change in enthalpy is when drying, since 2500 Joule should be withdrawn from the heat exchanger to condense each gram of water.

The energy required to reheat the dried, cold air can be provided by various means:

- The indoor environment, from heat loads and solar gains. This way is common in tropical climates. It saves the investment of the heating system, and heating energy is free. It has however the disadvantage to blow cold air in the occupied spaces, often leading to draughts. The temperature control is obtained by varying the supply airflow rate.
- Heat provided to a warm heat exchanger by a separate heating system. This is expensive both in investment and running cost and should no more be used.
- Heat provided to a warm heat exchanger by the chiller. The heat pump used to cool down the chilled water must also be cooled, and therefore provides cooling water at temperatures higher than indoor temperature. This water or a part of it can be circulated into the warm heat exchanger without any running cost. The investment is limited to pipes connecting the chiller condenser to the warm heat exchanger and to a control valve.

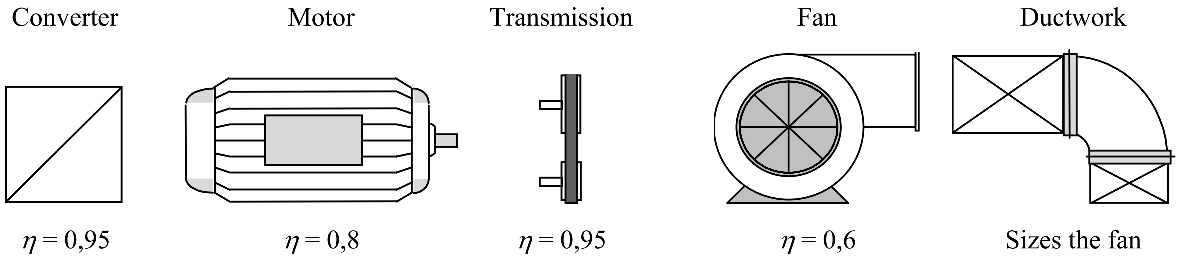

Figure 6: Approximate figures for the efficiencies of various elements needed to move the air in the ductwork.

3.4 Energy to transport the air

In natural ventilation, the energy moving the air through the building is provided by wind and stack effect. In mechanical ventilation systems, this energy is provided by the fan. The mechanical power delivered by a fan is the product of the volume airflow rate $\dot{V}$ delivered by the fan, by the pressure differential Δp, across the fan.

$$\Phi_m = \Delta p \dot{V} \qquad (2)$$

The mechanical power required to move the air through a ductwork is also the product of the volume airflow rate through the ductwork, by the pressure difference between the main supply and main exhaust ducts. Since the pressure difference is proportional to the square of the airflow rate, the mechanical power for ensuring a given airflow rate into a ductwork is proportional to the cube of the airflow rate! Increasing the airflow rate in a room by 10 % requires 33% more fan power and doubling the airflow rate requires a power 8 times larger if the ductwork is not changed.
The electrical power used by the fan motor is larger than Φ_m, because of the motor and fan losses. The energy losses of fans are shared between the elements of the chain linking the electrical network to the ductwork (*Figure 6*).

Typical values for the specific ventilation energy, i.e. the energy used to move one cubic meter of air in a ventilation network or the power required to ensure 1 m³/h airflow rate are given in *Table 2*. It should be noticed that there is a factor close to two between typical and energy efficient systems.

Table 2: Energy for moving one cubic meter of air in typical and energy efficient buildings (from [14])

Use of ventilated room	Typical [Wh/m³]	Energy-efficient [Wh/m³]
Dwelling	0,42	0,17
Office and meeting	0,56	0,35
Shop	0,35	0,22
Shopping centre	0,90	0,56
Classroom, auditorium	0,35	0,22
Hospital room	0,35	0,22
Hotel room	0,56	0,35
Restaurant	0,35	0,22
Professional kitchen	0,42	0,28
Workshop	0,35	0,22
Toilets	0,14	0,08
Couloirs, archives	0,28	0,17
Garage (private)	0,14	0,0 1)
Garage (public)	0,28	0,0 1)
Computer room (exhaust only)	0,14	0,08

1) Natural ventilation

3.5 Heat recovery

Mechanical ventilation systems with energy-efficient heat recovery are often proposed to reduce energy consumption. In such systems, heat exchangers of various types are used to transfer heat or enthalpy from the exhaust air to supply air. Some systems also transfer heat via a heat pump to the hot water heater.

However, air-handling units may have parasitic shortcuts and leakage[15-18], which can decrease dramatically the efficiency of ventilation and heat recovery. Moreover, leakage in a building's envelope allows warm air to escape outdoors without passing through the heat recovery system. In addition, these units use electrical energy for fans, which may, in some cases, overpass the saved heat.

The global heat recovery efficiency of the system, η_G, is the ratio of recovered enthalpy to the enthalpy of the air leaving the ventilated space. It can be calculated as a function of the fresh airflow, exfiltration, and recirculation rates, by taking account of mass conservation at the nodes of the system [18]. The full relation is rather complex but, when there is no external recirculation, the global efficiency can be expressed as a function of exfiltration ratio γ_{exf} and internal recirculation rates R_{xs} only:

$$\eta_G \cong \frac{(1-\gamma_{exf})(1-R_{xs})}{1-R_{xs}\,\gamma_{exf}}\varepsilon_{HR} \qquad (3)$$

where the internal recirculation rate is the ratio of the recirculated airflow rate to the extracted airflow rate:

$$R_{xs} = \frac{\dot{m}_r}{\dot{m}_x} \qquad (4)$$

and the exfiltration ratio is defined as the ratio of the exfiltration airflow rate to the total outdoor air entering the ventilated space, i.e. the outdoor airflow rate plus the infiltration airflow rate:

$$\gamma_{exf} = \frac{\dot{m}_{exf}}{\dot{m}_o + \dot{m}_{\text{inf}}} \qquad (5)$$

Any increase of the exfiltration ratio or the internal recirculation rate strongly decreases the heat recovery efficiency.

Measurements performed in several units and illustrated in *Figure 7* have shown that the actual heat recovery efficiency is always smaller then the nominal efficiency of the heat exchanger. In several cases, the recovered energy is not worth the cost of the system, and in worst cases, the system uses more energy that the recovered amount.

An efficient heat recovery system requires first that the building envelope be airtight, so that exhaust air passes through the system, and second that no parasitic recirculation occurs in the mechanical ventilation system.

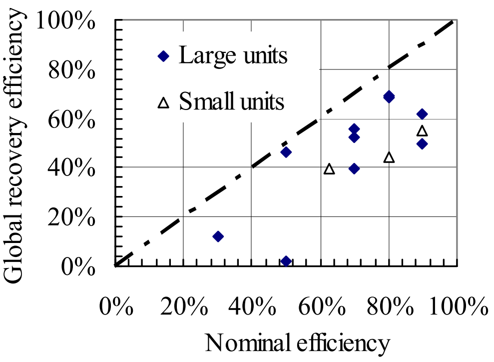

Figure 7: Global heat recovery efficiency versus nominal heat exchanger efficiency measured in several units [18].

When well designed and built, mechanical ventilation systems with heat recovery may improve IAQ, by ensuring a sufficient ventilation even during the coldest months, when occupants of naturally ventilated buildings tend to reduce airing.

A specific survey of allergens performed by the Vaud state hospital in Swiss buildings found significant difference for concentration of Der f1 allergens between flats in low energy buildings and a reference group of flats in "normal" buildings[19] . This difference may be explained by the difference in relative humidity (dryer in low energy buildings), itself explained by the mechanical ventilation systems with heat recovery found in low-energy buildings, ensuring a constant airing of the flats.

4 IAQ and ventilation

4.1 Ventilation rates and pollutant sources

The ventilation rate required to limit the concentration of pollutants emitted indoors at an acceptable level is, at steady state:

$$\dot{V} = \frac{S}{C_{\text{lim}} - C_o} \qquad (6)$$

where S is the pollutant source strength, C_{lim} is the accepted concentration and C_o the outdoor concentration of the pollutant. When there are several pollutants, the calculation is performed for each of them and the required airflow rate is the largest result.

It can be deduced from equation (6) that increasing the airflow rate will decrease the contaminant concentration. This is true for pollutants emitted in the ventilated space, but not for those emitted in the ventilation system.

In a study aiming to find and cure pollution sources in air handling units[8], it was found first that filters, humidifiers and ducts may be the most important pollution sources, and second that the intensity of these sources increases with the airflow rate. In this case, increasing the airflow rate does not improve, and may even reduce the air quality.

A better interpretation of equation (6) is that reducing the pollutant source strength will increase the indoor air quality (decrease the pollutant concentration) without increasing the airflow rate and the related energy use. This can be achieved by applying the following recommendations:

- Choose building materials that do not emit pollutants or that have low source strength. More and more providers and the SOPHIE database [20] give information on the emissions of their materials and products.
- Avoid polluting activities indoors, or ventilate strongly and locally the areas where these activities are performed.
- Use cleaning agents and maintenance material such as paints that do not contain toxic solvents or components
- Do not smoke in buildings (now prohibited in transportation systems, office and public buildings in most countries).
- Use only clean materials in mechanical ventilation systems and keep them clean.

4.2 Ventilation and well being

The sick building syndrome (SBS) was often attributed to poor air quality. Indeed, the presence of toxic gases in too large concentration is not healthy, but the sick building syndrome was also found in buildings where all requirements related to IAQ were met[21]. Also no correlation was found between airflow rates in buildings and SBS in a study involving 56 office buildings (*Figure 8*).

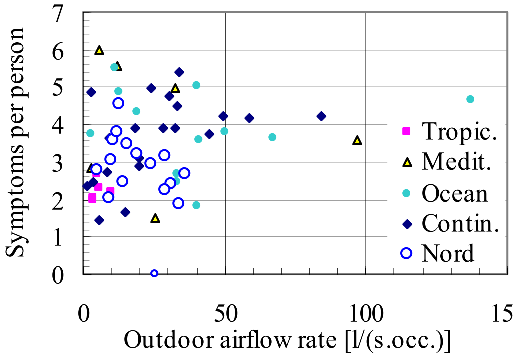

Figure 8: SBS and outdoor airflow rates in 56 office buildings located in various climates in Europe and Singapore.

Out of 64 office buildings recently audited throughout Europe[22], two groups of 21 buildings were selected, one group included the buildings where the SBS was least present, and the other those buildings where the SBS was more present[22] Note that none of these buildings was considered as sick. It was found that healthy building group is, on the average, more recent (completed in 1994 against 1981), have less stories, 50 cm higher ceilings and much more space per person (63 m² against 38 m²). Both groups have neighbouring noise sources, but the occupants of the less-healthy group are more disturbed by busy road and air traffic. There are more healthy buildings in mixed industrial/residential areas and in suburban areas, while there are more less-healthy buildings in city centres.

Especially in office buildings, the prevalence of SBS is strongly correlated with perceived thermal and acoustical comfort, as well as with lighting, and office environment[7]. The perception of having some control on the environment also correlates with well-being. Good perceived comfort and control corresponds to low prevalence of SBS.

All these differences have nothing to do with IAQ, but there are however some differences directly related to IAQ. All healthy buildings have operable windows, and 66% have natural or hybrid ventilation system, while more than one third of less healthy buildings have sealed windows, and two third have mechanical ventilation. On the average, ventilation systems in healthy buildings are better designed and maintained than in the other group. Perceived air quality is also better in healthy buildings than in the other ones.

It can be concluded that efficient airing is necessary, but not enough to ensure occupant's well being. Enough space per person, a good thermal comfort, efficient noise protection and lighting, a pleasant space layout, and the possibility of controlling the indoor environment seem as important as air quality.

5 Energy and IEQ

Therefore, we will not restrict this contribution to the relationship between energy and IAQ, but extend it to the relationship between energy and indoor environment quality (IEQ), which includes not only air quality, but also comfort and well being of occupants.

As mentioned in the introduction, directly following the oil cost crisis in the seventies, measures were hastily taken in many buildings to reduce their energy use. These measures were planned with only two objectives in mind: energy efficiency and return on investment. The effects of these measures on indoor environment, health or comfort were completely neglected. Therefore, in many cases, the results were dramatic. Not only comfort was decreased, but cases of mould growth, increased indoor pollution, and health hazards were observed. Since then, there seems to be a conflict with the aim of saving energy in buildings and the aim of creating a good indoor environment quality.
Of course, some energy conservation opportunities (ECO's) may degrade the indoor environment. Meas-

ures such as low internal temperature or too low ventilation rate should therefore either be avoided, or taken only in case of emergency and for a limited period of time.

Some other ECO's should be used only in conjunction with others. For example, retrofitting windows in poorly insulated dwellings lead to mould growth hazard, and improving the envelope air tightness without taking care of ensuring and controlling a minimum ventilation rate may decrease the indoor air quality.

Table 3: Functions of the building requiring energy, together with some ways to save energy and effects of these energy saving measures on comfort.

Energy required for	Ways to save energy	Impact on indoor environment
Compensation of transmission heat loss in winter	Better, thicker insulation, low emissivity-coated multiple glazing.	Improves thermal comfort by increasing internal surface temperatures. Prevent mould growth.
Compensation of ventilation heat loss in winter	Lower ventilation rate Limit the ventilation rate to the required level Use heat recovery on exhaust air.	May result in low IAQ not recommended. Less drafts, less noise, good IAQ Generally improves IAQ in winter.
Winter heating in general	Improve solar gains with larger, well located windows. Improve the use of gains by better insulation and good thermal inertia.	If windows are poor: cold surfaces. Overheating if poor solar protections. If well designed: good visual contact with outdoor environment, excellent summer and winter comfort.
Elimination of heat gains during warm season	Use passive cooling by night time natural ventilation Use efficient, well commissioned and maintained systems Higher internal temperature	Very comfortable in appropriate climates and buildings. Better IAQ and comfort Should be kept within comfort zone.
Internal temperature control	Comfortable set-point temperature, improved control	Avoids over- and under-heating
Humidification	Switch it off.	No effect in many cases.
Lighting	Use daylighting Use efficient artificial lighting.	Comfortable light, with limited heat gains when well controlled. Comfort depends on the quality of light. Limited heat gains.

In buildings, energy is required, among others, for purposes given in the first column of *Table 3*. This table also proposes known ways to save energy, and presents some effects of these energy saving measures on comfort or indoor environment quality. It can readily be seen that there are many cases where ECO's, when well designed and applied, not only save energy but also improve the indoor environment quality.

6 Conclusions: Have a cake and eat it

There are many ways for designing buildings that are at the same time healthy, comfortable and energy efficient. Several recommendations, resulting from experience and recent surveys performed within European projects [9, 23] are given below.

6.1 Design intentions

The building is designed and constructed to bring a good indoor environment to its occupants. There could be other objectives, such as:

- prestige, image;
- low cost;
- energy saving;
- real estate business, speculation;

However, the occupants should nevertheless be given the highest priority. The experts in the HOPE project[2] propose the following definition for a high quality (HQ) building [10]:

A healthy and energy-efficient building does not cause or aggravate illnesses in the building occupants, assures a high level of comfort to the building's occupants in the performance of the designated activities for which the building has been intended and designed, and minimises the use of non-renewable energy, taking into account available technology including life cycle energy costs.

Indeed, sustainable development requires that HQ buildings should be designed, built and maintained taking account of environmental, economical, and

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[2] Reports and publications from the HOPE project can be found on http://HOPE.EPFL.ch

social stakes. Healthy, comfortable and energy efficient buildings are the result of a conscious design keeping constantly these three objectives in mind. It is not by chance that most of the 16 apartment buildings and 7 office buildings fulfilling at best the HOPE criteria for these objectives were designed that way[24].

Essential recommendations that could be given to reach these objectives are:

- prefer passive methods to active ones wherever possible;
- think about the user comfort, needs and behavior;
- adapt the building to its environment and climate.

6.2 Passive and active ways to get HQ buildings

Passive ways are architectural and constructive measures that naturally provide a better indoor environment quality without or with much less energy use. Examples are:

- ensuring indoor air quality by using low-emitting materials and controlled natural ventilation;
- improving winter thermal comfort with thermal insulation, passive solar gains, thermal inertia, and controlled natural ventilation;[3]
- improving summer thermal comfort with thermal insulation, solar protections, thermal inertia, and appropriate natural ventilation;
- providing controlled daylighting;
- protecting from outdoor noise with acoustical insulation, adjusting the reverberation time for a comfortable indoor acoustics.

Passive means are often cheap, use very little or no energy, and are much less susceptible to break down than active means. However, they often depend on meteorological conditions and therefore cannot always fulfil the objectives. They should be adapted to the location and therefore need creativity and additional studies from the architect, and a design error may have dramatic consequences.

Active ways allow reaching the objectives by mechanical means, using energy for complementing the passive ways or even for compensating poor building performance. Examples are:

- heating boilers and radiators for winter comfort;
- artificial cooling by air conditioning or radiant panels for summer comfort;
- mechanical ventilation;
- artificial lighting;
- actively diffusing background music or noise to cover the ambient noise.

Active or technological ways, when appropriately designed, applied and maintained, are perfectly adapted to the needs. The architect does not have to take much care of them, since these are designed and applied by specialised engineers according to known technology. Flexible and relatively independent on meteorological conditions, they allow correcting architectural errors. However, the required technology is often expensive, requires a higher maintenance and uses much energy. It may break down, and when it does, the resulting situation may be dramatic. Furthermore, the fact that they allow correcting architectural 'errors' can also be considered as a disadvantage….

Passive ways are preferred, but cannot always fulfil the comfort objectives. Therefore, the appropriate strategy is to use them as much as reasonably possible and to compensate for their insufficiencies with active systems, which will then be smaller. This strategy often allows more freedom in choosing the type and location of active systems.

6.3 Taking account of the user

The occupant of a building expects that the building provides an acceptable indoor environment, according to his wishes. The occupant likes to have a control on this environment and even needs such a control to adapt his environment to his needs. The control an occupant has over his environment not only affects his perceived comfort, but is correlated with SBS prevalence [7].

Where the design does not allow the occupant to adapt his environment, he finds another way: bringing in heaters, opening the window in winter instead if he cannot put the thermostat down, using tape or paper to close draughty ventilation openings, etc.

6.4 Adaptation to the environment

The outdoor environmental characteristics (temperature, solar radiation, wind, dust, pollution, noise, etc.) change with the location of the building. Therefore, a design that is well adapted to a place may be completely unsuitable to another one: Bedouin tents, igloos, tropical huts, all well adapted to their environment, cannot be used elsewhere. This is also valid for contemporary building design: it is of course possible to compensate for environmental changes using active techniques, but this often decreases the indoor environment quality and increases the energy use.

A building that is well adapted to its climate protects its occupants against the extreme conditions observed outdoors without creating uncomfortable internal conditions. According to [25], the internal climate in a free-running building (that is, without any heating or cooling system running) should be at least as comfortable as the outdoor climate. This strategy is explained below and in *Figure 9*.

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[3] Natural ventilation can be controlled by installing (automatically or manually) adjustable vents in an airtight building envelope.

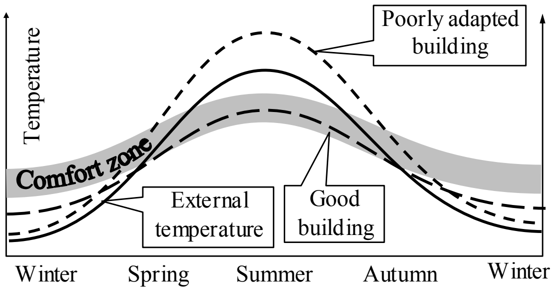

Figure 9: Evolution of temperatures in a free-running building and its environment throughout the year.

Because of changes in their clothing, the comfort 'zone' (the range of comfortable temperatures) is higher in summer than in winter. In naturally ventilated building, the comfort temperature is even closely correlated to outdoor temperature[26, 27]

A well-adapted building (curve A in *Figure 9*) has a good thermal insulation, appropriate passive solar gains (including moveable and efficient shading systems) and adaptive ventilation devices. In summer, it is protected against solar radiation and designed for passive cooling. In winter, it uses solar gain to increase the internal temperature. The result is a building that, in most temperate climates, provides comfort without energy sources other than the sun during most of the year. The energy use for heating is strongly reduced as a result of a shorter heating season. Cooling is not required in temperate climates as long as the internal heat load stays within reasonable limits and, in warmer climates, cooling energy is kept reasonable.

On the other hand, a poorly adapted building is not well insulated and protected against solar radiation. It is designed neither for an efficient use of solar energy, nor for passive cooling. Its free-floating internal temperature is then too low in winter and too high in summer. Expensive and energy-consuming systems have to be installed in order to compensate for this misfit between the building and its surrounding climate. Such buildings will require heating in winter and cooling in summer and are one of the cause of the belief that the use of large amounts of energy is necessary for comfort.

Adaptation of the building to the environment includes the following:

- Adaptation to climate: Appropriate thermal insulation, solar protections and ventilation openings.
- Adaptation to noise: Improve acoustical insulation in noisy areas, for example by using a double skin, and installing mechanical ventilation with sound barriers.
- Adaptation to pollution: Locate air intake as far as possible from pollution sources, install mechanical ventilation with appropriate filters and ensure appropriate maintenance.

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Indoor Temperature, Productivity and Fatigue in Office Tasks

S. Tanabe[1]

[1]Waseda University, Dept. of Architecture, 3-4-1 Okubo Shinjuku-ku, Tokyo 169-8555
e-mail: tanabe@waseda.jp http://www.tanabe.arch.waseda.ac.jp

Summary: *To promote the effort for energy conservation, it is also important to estimate the indoor environmental quality from the aspect of office worker's productivity. Several experiments in moderately high temperature environment were mentioned in this paper whose results showed that the effects of thermal environment on task performance were contradictory among the task types, while the subjects complained the feeling of mental fatigue more, and more cerebral blood flow were required to maintain same level of task performance at hot condition than that at thermally neutral condition. For evaluating task performance, cost of maintaining the performance, namely fatigue and mental effort, is important in evaluating and predicting productivity. In experiment with long period exposure, indoor air temperature has effects on workers' performance, and the relationship between performance and complaints of fatigue were shown. Also, two examples of field surveys on thermal environment were described. One survey showed the decline in performance in warmer environment, and other showed the decline in performance in cooler environment.*

Keywords: *Productivity, Temperature, Cerebral blood flow, Fatigue, Task performance, Energy conservation*

1 Introduction

Indoor environmental quality may affect physiological and psychological process, which may affect activities that may affect performance at tasks that may interact with other factors to affect overall productivity [1]. Seppänen and Fisk developed a conceptual economic model for owner-occupied buildings that shows the links between improvements in indoor environment quality and the financial gains [2]. It is very important to consider the effect of indoor environmental quality on office worker's health and productivity.

Earlier studies about the effect of thermal conditions on productivity were mainly by field study. They showed that accident rates were high or output rate decreased in hot environment [3], [4]. Some reviews and summarized model for the effects of the thermal environment on mental performance showed that mental performance decreases with heat [1], [5], [6]. On the other hand, it was also reported that performance of mental tasks has been generally unaffected by heat [7], [8]. Productivity research is somewhat confusing because the results are sometimes conflicting [9], [10]. The difference of task types or workers' psychological factors such as motivation and arousal levels may affect the results. In our study, we tried to evaluate the effect of thermal environment on productivity not only by task performances, but also physiological measurements, psychological measurements, and structural analysis of fatigue.

In this paper, the current status of Japanese office buildings are taken as an example and the balance of environmental concerns and office productivity are discussed by introducing our previous subjective experiments about the effect of moderately high temperature on office worker's productivity. The results of a further experiment on long period exposure in thermal environment were also discussed to show two important relationships: exposure time and performance; and level of fatigue and performance. Then two recent works on field survey were introduced to relate performance with room temperature.

2 Current Status of Japanese Office Buildings

As an effort for energy conservation, Japanese government recommends to keep an office temperature setting of 28°C in summer. If we keep an office temperature setting of 28°C, we may reduce 1~2% of expenditure of energy cost, which would be no more than 50[\$/m^2 year] and accounts for only 4% of real-estate rental service. As a result, reduction in the quality of office environment will occur. It will decrease the office worker's productivity and have much effect on income, which account for 68.9% of real-estate rental service. Since building owner's interest is to raise income or to reduce expenditure, nobody will take that risk.

How does reduction of energy use for controlling indoor environment affect productivity in office?

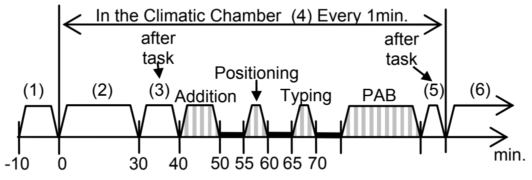
We must balance environmental concerns and office productivity.

3 Effect of High Temperature on Task Performance and Fatigue (Short Exposure)

3.1 Method

To study the effect of moderately high temperature on task performance and fatigue, a subjective experiment was conducted in a climate chamber. College-age subjects, 20 males and 20 females, participated in the experiment. The chamber was conditioned at operative temperatures of 25.5°C, 28.0°C, and 33.0°C with still air. Previous to these three conditions, a practice session at an operative temperature of 25.5°C was conducted. Relative humidity was controlled around 50%. Subjects wore a uniform with an insulation value of 0.76 clo. Task performance tests on computer were conducted for 1.5 hours.

The experimental procedure is shown in Figure 1. After entering the climate chamber, subjects waited in a sedentary position for 30 minutes, and then reported their first thermal sensation in the chamber and their feeling of fatigue. Four tests were carried out: the addition test for 10 minutes, the positioning test for 5 minutes, the text typing test for 5 minutes, and the Walter Reed Performance Assessment Battery test (PAB) [11] for about 15 minutes. After each test, an intermission of 5 minutes was taken and the subjects reported their thermal sensation, their feeling of fatigue, and their evaluation of the task load. Subjects filled in the sheets for evaluation of subjective symptoms of fatigue 30 minutes after entering the climate chamber as "before task" and after all computer tasks were finished, as "after task".



(1) Change Clothes, Weight
(2) Sedentary, Questionnaire, Oral Temperature
(3) Flicker Test, Evaluation of Subjective Symptom of Fatigue, Vote
(4) Physiological and Environmental Measurements
(5) Vote, Evaluation of Subjective Symptom of Fatigue, Flicker Test
(6) Change Clothes, Weight
▬ Vote, Intermission

Figure 1 Experimental Procedure

Subjective vote on thermal sensation using ASHRAE scales of male subjects were 0.1 ±0.83 for 25.5°C, 1.2 ±0.69 for 28.0°C and 2.5 ±0.49 for 33.0°C condition and those of female subjects were -0.6 ±1.03 for 25.5°C, 1.1 ±0.78 for 28.0°C and 2.5 ±0.63 for 33.0°C condition. At 25.5°C, the average values of the thermal sensation vote and the sweating sensation vote of female subjects were significantly lower than that of male subjects ($p<0.01$).

3.2 Task Performances

For female subjects, there was no significant difference in the performance of all computer tasks under the environmental conditions. For male subjects, there was no significant difference in the performance of the addition test and the positioning test under the environmental conditions. As regards the performance of PAB, there was no significant difference under all environmental conditions except for "four choice serial reaction time". The performance of this test at 33.0°C was significantly lower than at 28.0°C ($p<0.05$) for male subjects. The performance of the text typing test at 25.5°C was significantly lower than at 28.0°C and 33.0°C ($p<0.05$) for male subjects. The performance of addition task, text typing and "four choice serial reaction time" (PAB) are shown in Figures 2, 3 and 4. In this study, the effects of thermal environment on task performance were contradictory among the task types as in previous findings [9], [10]. It is difficult to evaluate the effect of thermal environment on productivity by measuring only task performance.

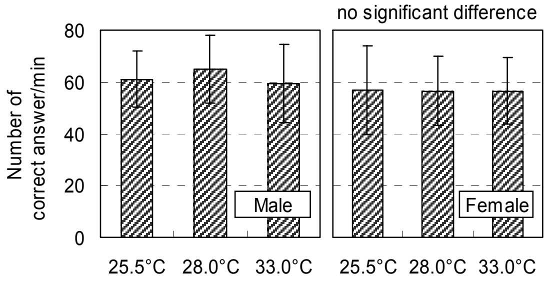


Figure 2 Performance of addition task

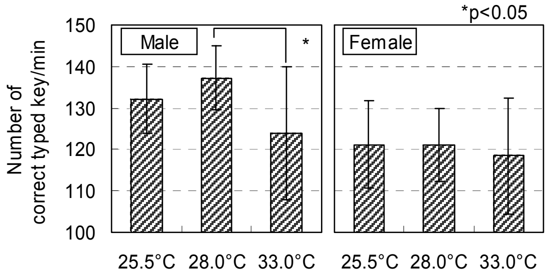


Figure 3 Performance of four choice (PAB)

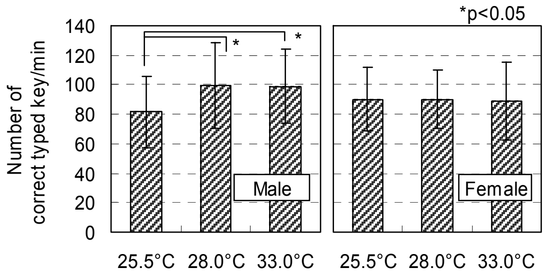


Figure 4 Performance of text typing

3.3 Evaluation of Subjective Symptoms of Fatigue

To evaluate the feeling of fatigue, subjects filled in the sheets of "Evaluation of Subjective Symptoms of Fatigue" [12]. It consists of three categories; I-group consists of 10 terms about "drowsiness and dullness", II-group consists of 10 terms about "difficulty in concentration", and III-group consists of 10 terms about "projection of physical disintegration". By the order of the rate of them, three types of fatigue feeling were estimated [12]: "I>III>II" for general pattern of fatigue, "I>II>III" for typical pattern of fatigue for mental work and overnight duty, and "III>I>II" for typical pattern of physical work.

The general rate of complaints before the task was the highest at 33.0°C, the next highest at 28.0°C, and the lowest at 25.5°C condition. The order among the categories of subjective symptoms of fatigue is shown in Table 1. Before the task, at 25.5°C and 28.0°C, I>III>II was observed in both female and male subjects. On the other hand, at 33.0°C, it was I>II>III in both female and male subjects. For male subjects after the task, the type of fatigue was I>II>III under all environmental conditions. For female subjects, it was I>III>II at 25.5°C and 28.0°C, and I>II>III at 33.0°C. The subjects complained of a feeling of mental fatigue and complained the most just being in the room with operative temperature of 33.0°C.

Table 1 The order among the three categories of subjective symptoms of fatigue

	Temp. °C	I %	II %	III %	order of categories
Before task (Male)	25.5	15.5	3.5	5.5	I>III>II
	28.0	23.0	5.0	7.0	I>III>II
	33.0	24.0	12.0	11.5	I>II>III
After task (Male)	25.5	21.5	14.0	13.5	I>II>III
	28.0	28.0	15.5	13.5	I>II>III
	33.0	24.5	21.5	14.5	I>II>III
Before task (Female)	25.5	16.5	1.5	5.5	I>III>II
	28.0	26.5	8.0	11.0	I>III>II
	33.0	32.0	14.0	12.0	I>II>III
After task (Female)	25.5	31.5	12.5	14.0	I>III>II
	28.0	31.5	15.0	18.5	I>III>II
	33.0	34.0	19.0	16.5	I>II>III

4 Effect of the Difficulty Level of Tsks and High Temperature on Cerebral Blood Flow

4.1 Near Infrared Spectrometer

The near infrared spectrometer (NIRS) is shown in Figure 5 [13]. Near infrared light was produced by laser diodes and carried to the tissue via optical fibres [14]. The light emerging from the tissue was returned to the instrument through another optical fibre by detector, and incident and integrated values of transmitted light intensities were recorded every second. The sampling rate was 2,000 times per second. Changes in the concentration of the chromophores oxygenated hemoglobin "ΔO_2Hb" and deoxyhemoglobin "ΔHHb" were calculated by Modified Beer-Lambert equation in $\mu M = 10^{-6}$ mol units [15]. The changes in concentration of total hemoglobin were calculated: Δtotal Hb $= \Delta O_2Hb + \Delta HHb$. The probes were placed on the subject's forehead.

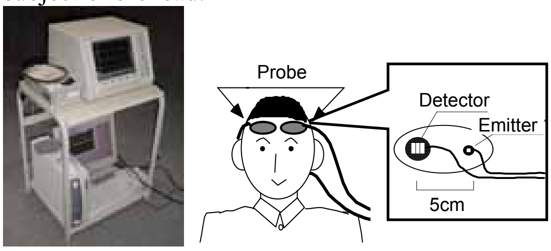


Figure 5 Near infrared spectrometer

Previous studies reported that increase of ΔO_2Hb and Δtotal Hb and decrease of ΔHHb were the typical findings by NIRS during the brain activation and mental work [16], [17]. The mechanism was explained as follows [18]: brain blood is necessary for active of brain but there are few stocks of glucose and O_2 in brain. So, it is necessary to supply them by blood flow. The ΔO_2Hb and Δtotal Hb becomes higher in brain activity. The consumption of O_2 in brain activity is much smaller than the increase rate of cerebral blood flow. So, ΔHHb becomes relatively lower in brain activity.

From the studies of split-brain, left brain is more dominant for linguistic abilities, calculations, math and logical abilities where right-brain is more dominant for spatial ability [19], and it was also reported that most right handed people's language center is on the left side of brain [20], [21].

4.2 Cerebral Blood Flow and the Difficulty Level of Tasks

Relationship between the changes in cerebral blood oxygenation and the difficulty level of a task was evaluated in a subjective experiment. Four tasks were given to the subjects: single-digit addition, double-digit multiplication, triple-digit addition, and triple-digit multiplication. It was evaluated that the more difficult the type of task, the more oxygenated hemoglobin and total hemoglobin concentration were required for their performance. There was a significant correlation between the subjective value of mental demand for tasks and the left side Δtotal Hb. The change rate of total hemoglobin during each task is shown in Figure 6. It was shown that tasks involving a higher mental demand required a higher cerebral blood flow. The correlation between the values of change rates of mental demand and left side Δtotal Hb, based on the single-digit addition task, are shown in Figure 7. Monitoring cerebral blood oxygenation changes could be applied to the evaluation of the input-side parameter of productivity to indicate the degree of mental effort required to perform the task.

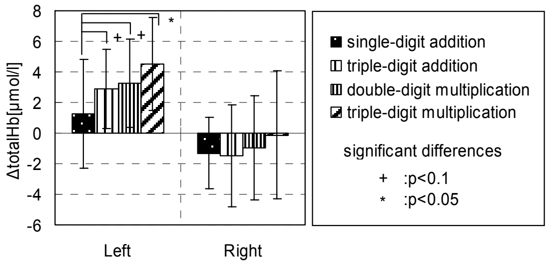


Figure 6 Δtotal Hb during each task

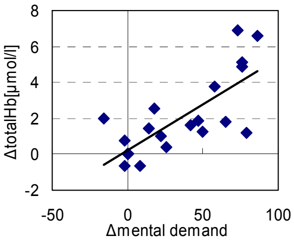


Figure 7 Correlation between values of change rates of mental demand and left side Δtotal Hb, based on the single-digit addition task

4.3 Effect of High Temperature on Cerebral Blood Flow

Another subjective experiment was conducted to study the effect of moderately hot environment on cerebral blood flow.

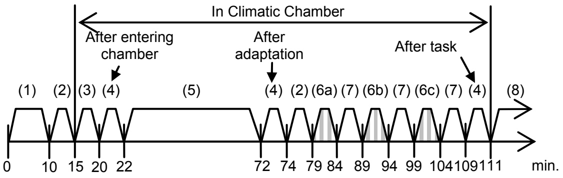
Twelve right-handed male subjects were exposed in a climatic chamber to two operative temperature levels of 26.0°C and 33.5°C. Subjects experienced these two conditions in balanced order. Before these two conditions, they participated in a practice session under operative temperature of 26.0°C at the first time. Experimental conditions are shown in Table 2. In this study, in order to increase their motivation to the same level, they were informed that the top 6 performers of the computer tasks could earn one hour's worth of bonus. Therefore, it could be assumed that subjects were highly motivated.

Table 2 Experimental conditions

	Temp °C	Radiant temp. °C	Operative temp. °C	Relative humidity %	CO_2 ppm
Practice	25.6	25.8	25.7	23 *	704
	(0.11)	(0.09)	(0.10)	(4.7)	(46)
26.0 °C	26.2	26.4	26.3	48	652
	(0.71)	(0.67)	(0.69)	(0.2)	(35)
33.5 °C	33.7	33.6	33.6	43	690
	(0.10)	(0.04)	(0.07)	(1.1)	(71)

(standard deviation)
Icl of the experimental clothes were 0.76 clo.
* Only in Practice, there was trouble with humidifier.

Experimental procedure is shown in Figure 8. After adaptation to the thermal environment for 50 minutes, three types of calculation task (single digit addition, triple digit addition and triple digit multiplication) were assigned to subjects.



(1) Change clothes, Weight, Questionnaire
(2) Fatigue Symptoms, Evaluation of Environment
(3) Setting sensors
(4) Relax with close eyes
(5) Adaptation
(6) Task (a: single digit addition; b: triple digit addition; c: triple digit multiplication)
(7) Fatigue Symptoms, Evaluation of Environment, NASA-TLX
(8) Change clothes, Weight

Figure 8 Experimental Procedure

Subjects evaluated the environment in 33.5°C as hotter and stuffier of air compared to that at 26.0°C. There were no significant differences in task performances between 26.0°C and 33.5°C conditions. According to the evaluation of subjective symptoms of fatigue, the subjects complained of the feeling of mental fatigue more at operative temperature of 33.5°C than 26.0°C.

The results of ΔtotalHb during triple-digit addition and triple-digit multiplication tasks were shown in Figure 9. The comparison between the difficulty levels of task revealed that Δtotal Hb was significantly higher for triple-digit multiplication in 26.0°C ($p<0.03$), which support the previously mentioned experiment. The increase of ΔtotalHb was significantly higher at 33.5°C than that at 26.0°C for both task types ($p<0.02$ for addition and $p<0.04$ for multiplication). Hot environments may require more cerebral blood flow to maintain same level of task performance.

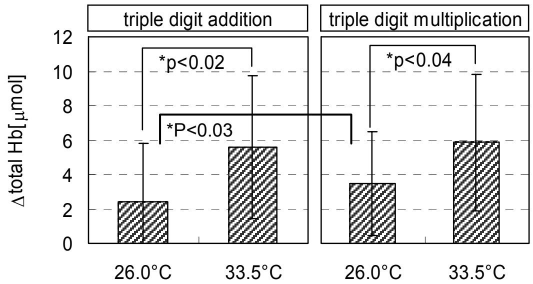


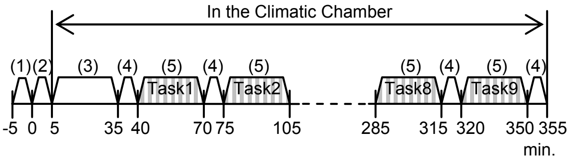
Figure 9 Δtotal Hb

5 Effect of High Temperature on Task Performance and Fatigue (Six Hours Exposure)

5.1 Method

To study the relationship between the task performance decrement and the work time, six hours of subjective experiment was conducted in a climatic chamber. Fifteen college-age male subjects participated in this experiment. The conditions were set by the combination of operative temperature in the chamber and the amount of clothing insulations as: 25.0°C with 1.0 clo; 28.0°C with 1.0 clo; 28.0°C with 0.7 clo. Previous to these experimental conditions, a practice at 25.0°C with 1.0 clo condition was conducted.

The experimental procedure is shown in Figure 10. After entering the chamber, the subjects waited for 30 minutes in sedentary position, and then reported their first thermal sensation in the chamber and their feeling of fatigue. Subjects were then assigned nine sessions of addition tasks. In each session, the subjects worked for 30 minutes on the task and they reported thermal sensation, their feeling of fatigue, their evaluation of the task load in 5 minutes.



(1) Change clothes
(2) Questionnaire, Flicker test
(3) Sedentary
(4) Vote, Evaluation of Subjective Symptom of Fatigue, Flicker test
(5) Addition task

Figure 10 Experimental procedure

5.2 Task performance

The task assigned in this experiment was one-digit addition, which was programmed in computers. The task performance for each subject was evaluated by his normalized performance to precisely reflect the performance change of each subject. The normalized performance was calculated from the equation (1).

Normalized performance $S_{A,i}$

$$= \frac{x_{A,i} - \overline{x}_A}{s_A} \times 10 + 50 \qquad \text{...(1)}$$

where,

$x_{A,i}$: number of correct answers during the session i for subject A [-]

$\overline{x}_A$: average number of correct answers of the subject A among all sessions [-]

s_A : standard deviation for the number of correct answers of the subject A among all sessions [-]

Figure 11 shows the result of normalized performance. The performance in the first session was compared with the sessions after that using one-way ANOVA and then Fisher's protected LSD when a statistically significant result was found. The level of significance was set at $p<0.05$. The normalized performance did not changed significantly at 25.0°C with 1.0 clo condition over the time. However, the performance was significantly lower after sixth session (each $p<0.05$) at 28.0°C with 1.0 clo condition. Also, the performance was significantly lower after the third session (each $p<0.05$) at 28.0°C with 0.7 clo.

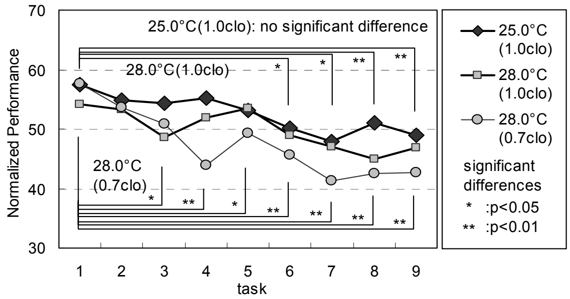


Figure 11 Result of normalized performance

5.3 Fatigue and Performance

To determine the relationship between the level of fatigue and performance, the results of "Evaluation of Subjective Symptoms of Fatigue" were analyzed. Personal rates of complaints of fatigue, which were the general rates of complaints of fatigue for each person in each environmental condition excluding the results of practice session, were calculated. Figure 12 shows the correlation of personal rate of complaints of fatigue and normalized performance. It showed strong relationship that performance decreased with the increase in the level of fatigue. The correlation coefficient was -0.87. From the regression equation obtained from the results, increase in 10% of fatigue corresponds to the decrement in performance by 2.4%. The result showed the link from the fatigue of the occupants to the performance of them. It implies that evaluating fatigue is useful for estimating the effect of indoor environment on performance in offices and in experiments.

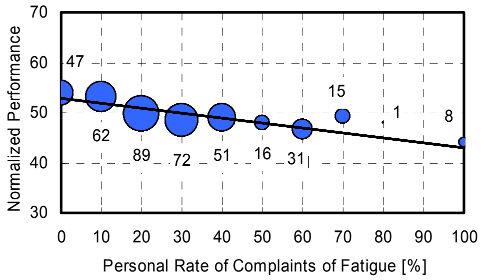


Figure 12 Correlation of the personal rate of complaints of fatigue and normalized performance

6 Field Survey in Call Center

6.1 Method

Data in a call center was collected for one year. Indoor air temperature, humidity, lighting, and CO_2 concentration were monitored. Measurement was conducted from February 18, 2004 to February 1, 2005. Figure 12 shows the interior of call center.

Call data of 13,169 were collected in total. This call center is performing guidance and consultation for customers, and technical support. Although the number of communicators changes with a day and time, total number of workers is about 70-120 persons/day in general. Business-hours of a call center are 8:45-19:00 from Monday to Saturday. Air-conditioning is operated from 8:00 to 20:00. Detailed research result is published by Kobayashi et al., see reference [22].

Figure 12 Interior view of a call center

6.2 Call response rate

The relationship between indoor air temperature and the average call-response rate is shown in Figure 13. Increasing of indoor air temperature of 1.0°C decreased 0.16 average call-response rate [calls/h]. When indoor air temperature of 25.0°C, the average response number of cases was 7.75 calls/h. When air temperature goes up at 26.0°C, it falls to 7.59 calls/h, and the decline in the workers performance was calculated as 2.1% per increase in 1°C of room temperature. Seppänen et al. reported that 1.0°C of room air temperature rise is equivalent to decline in 2% of working performance [15]. The result of this research agreed quite well with the model of Seppänen. The average arrival telephone calls time per response number of cases, average receivable time, and the average desk work time were performed stable for whole period. Call-response rate was adopted as an index to evaluate the worker performance. For long period field study indoor air temperature has effects on workers' productivity.

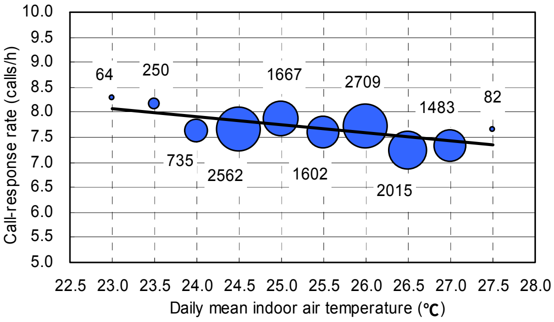


Figure 13 Relationship between indoor air temperature and the average response number of cases

7 Field Survey in an Office

7.1 Method

Field survey was conducted from July 4, 2005 to January 18, 2006 in the room for the System Engineering Section in an office building. Air temperature, humidity and CO_2 concentration were monitored. The interior view of the room is shown in Figure 14. Ten to twenty programmers were working in the room depending on the schedule of projects. In this survey, subjects were eight male programmers working in the room. They were asked to report on the indoor environment, feeling of fatigue, vigor, self-estimated performance by the reporting program installed in their PC before and after their working hours. A positioning test was also assigned by the reporting program to test and evaluate their performance.

Figure 14 Interior view of the room for the System Engineering Section

7.2 Air temperature and thermal sensation

Air temperature was measured nearby the subjects during the working hours, and the average was taken for each subject. Votes on thermal sensation collected after the work were related to the average air temperature as shown in Figure 15. The correlation coefficient for this relation was 0.75. Thermal neutrality from the results was assumed around 27.0°C. In this office, though the air temperature was rather high, most of the subjects felt neutral to cool. The results might be affected by the fact that their clothes were not regulated in the room during the work as shown in Figure 14, and air velocity was 0.2~0.4m/s during the measurements.

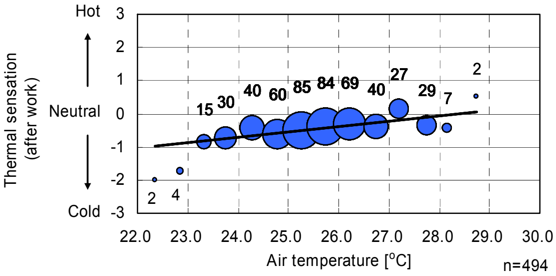


Figure 15 Air temperature and vote on thermal sensation after the work hours

7.3 Air Temperature and Performance

In the positioning test, subjects were asked to find a certain letter from the total of 25 randomly displayed letters in their own PC monitor. Each time they position the target letter, location of all letters was rearranged. In one trial of the task, the subjects were to position the letter for 70 times consecutively. The performance of this test after the work was evaluated by the number of positioned in a second.

Figure 16 shows the relationship between average air temperature of the day for a subject and performance in positioning test. The correlation coefficient was 0.87 for the linear regression on this result. It showed that the performance decreased by 2.9% below 27.0°C. In this survey, the performance decreased in cooler environment.

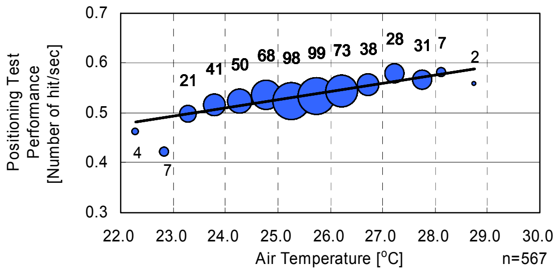


Figure 16 Air temperature and performance in positioning test

8 Discussion

In short period exposure experiment, it is difficult in acquiring data to show the significant differences in performance between environmental conditions. However, even in these experiments, the results on workers' complaints of fatigue and cerebral blood oxygenation changes show that the workers are tired in poor indoor environment. It was only an assumption when workers keep higher level of fatigue feeling for long period would result in decrement in performance eventually. The results from recent studies on long period exposure supported this assumption. The decline in performance with exposure time and with the increase in complaints of fatigue was shown. Also, in two field surveys showed the changes in performance by thermal condition.

It would be more preferable or easy to show the relation of physical environmental measurements and workers' performance to describe the concept of productivity. However, it is more practical to measure the rate of dissatisfied on the environment, Sick Building Syndrome symptoms and workers' fatigue to evaluate the effect of indoor environment on workers' performance. These measurements can also be used to evaluate the effect of indoor environmental factors regardless of its type of interest and even the effect of the combination of the factors.

It has been many researches on comfort and the percentage of dissatisfied in an office environment. Interest of future research in this field would be to relate these previous studies and performance, regarding arousal of the workers and their comfort.

9 Conclusions

1) In this study, the current status of Japanese office buildings are taken as an example and the balance of environmental concerns and office productivity are discussed. To promote the effort for energy conservation, it is important to estimate the indoor environmental quality from the aspect of office worker's productivity.
2) Subjective experiments were conducted to evaluate the effect of moderately hot environment on productivity. The effects of thermal environment on task performance for short time exposure were contradictory among task types as in the previous findings. It is difficult to evaluate the effect of thermal environment on productivity by measuring only task performance. According to the evaluation of subjective symptoms of fatigue, the subjects complained of the mental fatigue more at operative temperature of 33.0°C than 25.5°C and 28.0°C.
3) By monitoring cerebral blood oxygenation, an increment in oxygenated hemoglobin, an increment in total hemoglobin, and a decrement in deoxygenated hemoglobin were found at operative temperature of 33.5°C. In the previous study, it was reported that these findings were the typical ones during the brain activation.
4) Relationship between the changes in cerebral blood oxygenation and the difficulty level of a task was evaluated in subjective experiments. Monitoring cerebral blood oxygenation changes could be applied to the evaluation of the input-side parameter of productivity to indicate the degree of mental effort required to perform the task.
5) Subjective experiment was conducted to study the effect of moderately hot environment on cerebral blood flow. Twelve right-handed male subjects were exposed in a climatic chamber to two operative temperature levels of 26.0°C and 33.5°C. Hot environments may require more cerebral blood flow to maintain same level of task performance.
6) For long period exposure, indoor air temperature has effects on workers' performance.
7) The performance decreased with the increase in the complaints of fatigue of the subjects. It implied that the level of fatigue is useful index

for estimating the effect of indoor environment on performance in offices and experiments.

8) The results from the survey in call center showed lower performance in higher air temperature.
9) The results of field survey in office showed that the decline in performance when the indoor environment was cooler.

Acknowledgement

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Effect of Ventilation on Perceived Quality of Air Polluted by Building Materials–a Summary of Reported Data

H. N. Knudsen[1], P. Wargocki[2] and J. Vondruskova[2]

[1]Danish Building Research Institute, Dr. Neergaards Vej 15, DK-2970 Hoersholm, Denmark
email: hnk@sbi.dk http://www.sbi.dk
[2] International Centre for Indoor Environment and Energy, Department of Mechanical Engineering, Technical University of Denmark, Building 402, DK-2800 Lyngby, Denmark

Summary: *This paper summarizes existing data on how varying ventilation rates affect the perceived quality of air polluted by building materials. This is done by reviewing literature dealing with exposure-response relationships, i.e. the log-linear relationships between the concentration of pollutants (exposure) and the perceived air quality (response). The reviewed data originate from studies with single building materials performed in small-scale ventilated chambers and from studies carried out in a full-scale setting resembling normal offices. Perceived air quality expressed in terms of acceptability as assessed by untrained panels was included. The results show that the exposure-response relationships vary for different building materials as regards the impact of changing ventilation rate on perceived air quality and the level of perceived air quality at a constant ventilation rate. This applies both for the data collected in small-scale and in full-scale experiments. The differences may be caused by the experimental conditions, psychological factors, physiological factors, and chemical/physical factors. A well controlled study taking these factors into account with several different building materials, is thus recommended to further study whether the observed results have practical significance. These experiments should be carried out under realistic full-scale conditions.*

Keywords: *Building materials, emission, exposure-response relationship, perceived air quality, ventilation*
Category: *Human responses to IAQ*

1 Introduction

Good perceived indoor air quality can be obtained by a low pollution load on the air indoors and adequate ventilation. In practice it is fairly simple to reduce the pollution load by selecting low-polluting building materials, but still it is difficult to model how a varying ventilation rate in a room polluted by building materials affects the perceived air quality. A pragmatic model has been suggested in which the effect of ventilation on perceived quality of air polluted by sources different from human bioeffluents, e.g. building materials, is approximated by the relationship describing the effect of ventilation on perceived quality of air polluted by human bioeffluents [1].

Several studies have investigated the effects of ventilation on perceived quality of air polluted by building materials for single materials and the mixtures of building materials in small-scale and in full-scale settings.

The objective of this paper is to summarize the results of these studies and examine whether there are differences between the relationships between ventilation rate and perceived air quality, and to compare these relationships with the corresponding relationship for human bioeffluents.

2 Method

Peer-reviewed journals and proceedings of major conferences were searched for papers reporting the relationships between ventilation rate and perceived quality of air polluted by building materials. Studies reporting the measurements of perceived quality of air polluted by building materials in ventilated small-scale chambers and in full-scale climate chambers, test rooms or in actual buildings were included. Only papers that reported measurements of perceived air quality made by an untrained panel of subjects using the acceptability scale shown in Figure 1 were selected. The scientific literature reviewed included papers published since 1988.

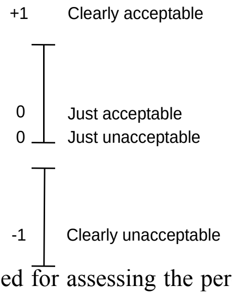

Fig. 1. Scale used for assessing the perceived air quality. The assessments are normally completed in the following context: "Imagine that during your work you would be exposed to this air". The scale was not numbered during the experiment, but the numbers were used for the data analysis.

Using original data reported in the selected papers, the exposure-response relationships between the acceptability of air quality and the dilution achieved by changing ventilation were created using log-linear regression [2-3]. They were created separately for studies carried out in small-scale and in full-scale, and separately for single materials or mixtures of building materials. To make a comparison possible between the different studies, ventilation rate was normalized by expressing it as an area specific ventilation rate for data obtained in small-scale experiments, and as an air change rate for data obtained in full-scale settings.

The slope of the regression line (±95% confidence interval (CI)), that expresses how a change of ventilation rate will affect the sensory response of acceptability, was compared for the different single building materials and for full-scale experiments. The same was done with the intercepts of regression lines (±95%CI), to study the difference in the acceptability of air polluted by different building materials at the same ventilation rate.

3 Results

Ten studies were included in the review, five of which were made in small-scale with only facial exposure [3-7] and five in full-scale with whole body exposure [6, 8-11].

3.1 Small-scale experiments

Figures 2 to 5 present the exposure-response relationships determined in small-scale experiments when the air was polluted by single materials. Figure legends, short description of materials, slopes ±95%CI and intercepts ±95%CI of regression lines are given in Tables 1 to 4. The figures and tables show that the slopes vary significantly and range from 0.13 to 0.86. This means that a 10-times increase in ventilation rate will improve the acceptability vote from 0.13 to 0.86 depending on the material. The intercepts vary up to about 1.0 on the acceptability scale (excluding sealants) which means that at the same ventilation rate different materials would cause considerable different levels of perceived air quality. The variation is probably caused by both differences in chemical composition and emission rates of odorous air pollutants from the different materials.

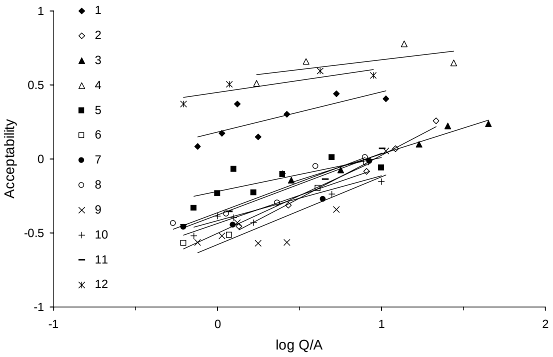

Fig. 2. Exposure-response relationships for different hard floor coverings. Legends are explained in Table 1.

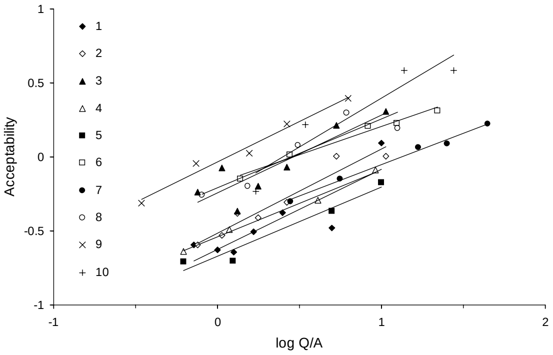

Fig. 3. Exposure-response relationships for different carpets. Legends are explained in Table 2.

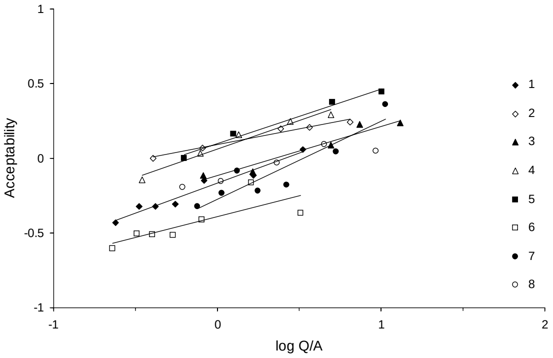

Fig. 4. Exposure-response relationships for different wall paints and other building materials. Legends are explained in Table 3.

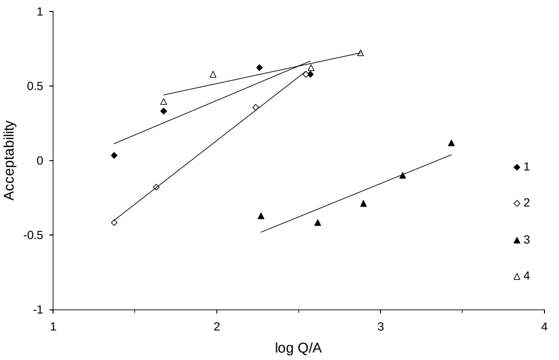

Fig. 5. Exposure-response relationships for different sealants. Legends are explained in Table 4.

3.2 Full-scale experiments

Figure 6 presents the exposure-response relationships determined in full-scale experiments when the air was polluted by single materials and mixtures of materials. Figure legends, short description of materials, slopes ±95%CI and intercepts ±95%CI of regression lines are given in Table 5. The figure and table show that the slopes vary significantly and range from 0.24 to 0.96. This means that a 10-times increase in ventilation rate will improve the acceptability vote from 0.24 to 0.96. The intercepts vary by about 1.0 on the acceptability scale (excluding legend 5) which means that different materials cause considerable different level of air quality at the same ventilation rate.

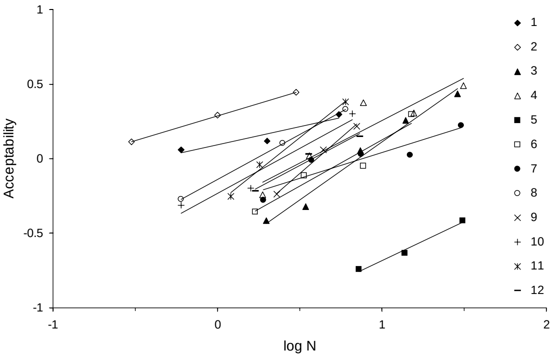

Fig. 6. Exposure-response relationships for different full-scale experiments. Legends are explained in Table 5.

4 Discussion

The present data for full-scale experiments show that the effect of changing the ventilation rate on the perceived quality of air polluted by different building materials can vary by up to a factor of about four. It thus seems that the suggested pragmatic approach [1] may often not be accurate. In this approach the perceived air quality is modelled using one exposure-response relationship between ventilation rate and the perceived quality of air polluted by human bioeffluents, independently of the type of pollution source. But as shown in Figure 7 the relationship between the ventilation rate and the perceived quality of air polluted by human bioeffluents is different from the corresponding relationships for building materials: the slope of 0.25±0.08 is lower than for the majority of the building materials. This implies that the effect on the perceived air quality of a change in ventilation rate will be underestimated when using the relationship for human bioeffluents rather than the actual relationship.

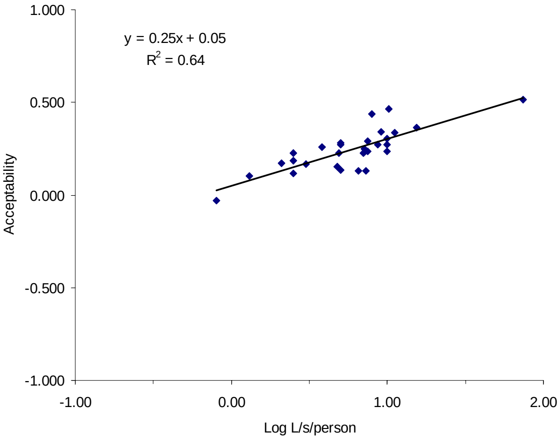

Fig. 7. Exposure-response relationship for human bioeffluents. The relationship was created using data from three studies [12-14]. In the original studies, the air quality was expressed by % dissatisfied with air quality. To obtain the corresponding acceptability vote the relationship between % dissatisfied and acceptability vote was used [15].

The present summary shows the relatively large differences in ventilation requirements to obtain a certain level of perceived air quality for emissions from different building products. There could be a number of factors causing the observed differences. They may for example include: the type of pollution source, psychological factors like the context in which assessments are made (in laboratory vs. in real buildings), expectations and previous experience with odours and what information is given about the pollution sources before assessments. Physiological factors like more or less adaptation to air pollution and perception of complex odour mixtures, like from combinations of building products. Chemical/physical factors like how products interact when air pollution are adsorbed and/or desorbed on material surfaces, and reactive chemistry like when odorous secondary emissions are formed in reactions with for example ozone. These factors should be taken into account in future experiments investigating the exposure-response relationships in real rooms.

A well controlled experiment is required in which the differences between exposure-response relationships are quantified in real rooms when the air is polluted by different realistic combinations of emissions from mixtures of building materials and humans.

Such exposure-response relationships can for example be used for estimating the energy saving potential of using low polluting building materials due to a reduced ventilation requirement. This may contribute to the compliance with the EU Directive 2002/91/EU on reduction of energy use without affecting indoor air quality negatively. The new relationships can also be used for determining requirements in labelling schemes for building material and in future ventilation standards.

5 Conclusions

Reported data on the relationships between ventilation rate and the perceived air quality were summarized.

The relationships between ventilation rate and the perceived air quality are different for different building materials, and different from the exposure-response relationship for human bioeffluents.

It is therefore recommended to verify the results summarized in the present paper in a well-controlled experiment as they may have large consequences for the determination of the required ventilation rate for different non-industrial environments.

Table 1. Legend, description, slope and intercept of trend line for small-scale experiments for hard floor coverings in Fig. 2.

Legend	Material description	Equation of trend line (a·x + b) Slope a [±95% CI]	Equation of trend line (a·x + b) Intercept b [±95% CI]	R^2	Ref.
1	Vinyl floor covering (low-emitting)	0.27 [0.02;0.52]	0.18 [0.05;0.31]	0.61	[4]
2	Soft PVC floor covering (Test 3)	0.58 [0.45;0.72]	-0.56 [-0.68;-0.44]	0.98	[5]
3	Soft PVC floor covering (Test 4)	0.35 [0.23;0.46]	-0.31 [-0.45;-0.17]	0.97	[5]
4	PVC floor covering	0.13 [-0.32;0.59]	0.54 [0. 10;0.98]	0.44	[7]
5	Linoleum	0.23 [0.01;0.45]	-0.22 [-0.33;-0.11]	0.59	[4]
6	Linoleum - Type 1	0.51 [0.29;0.73]	-0.50 [-0.63;-0.38]	0.98	[3]
7	Linoleum - Type 2	0.38 [-0.06;0.81]	-0.44 [-0.69;-0.19]	0.88	[3]
8	5 year old linoleum	0.41 [0.18;0.65]	-0.37 [-0.49;-0.24]	0.91	[6]
9	Varnish on oak floor	0.46 [0.11;0.81]	-0.58 [-0.76;-0.40]	0.70	[4]
10	Oil on oak floor	0.31 [0.04;0.57]	-0.42 [-0.55;-0.28]	0.63	[4]
11	Polyolefin - Type 1	0.42 [0.26;0.58]	-0.38 [-0.48;-0.28]	0.98	[3]
12	Polyolefin - Type 2	0.16 [-0.13;0.45]	0.45 [-0.13;0.45]	0.74	[3]

CI = confidence interval

Table 2. Legend, description, slope and intercept of trend line for small-scale experiments for carpets in Fig. 3.

Legend	Material description	Equation of trend line (a·x + b) Slope a [±95% CI]	Equation of trend line (a·x + b) Intercept b [±95% CI]	R^2	Ref.
1	Carpet with latex backing	0.54 [0.17;0.91]	-0.62 [-0.81;-0.44]	0.74	[4]
2	Carpet with textile backing	0.57 [0.39;0.74]	-0.52 [-0.61;0.43]	0.93	[4]
3	20-year-old used carpet	0.53 [0.20;0.85]	-0.25 [-0.41;-0.08]	0.78	[4]
4	Tufted nylon carpet, latex foam backing (1)	0.45 [0.33;0.58]	-0.54 [-0.62;-0.47]	0.99	[3]
5	Tufted nylon carpet, latex foam backing (2)	0.47 [0.14;0.79]	-0.67 [-0.87;-0.47]	0.95	[3]
6	Nylon carpet with rubber backing	0.38 [0.27;0.48]	-0.17 [-0.27;-0.08]	0.98	[5]
7	Nylon carpet without rubber backing	0.42 [0.35;0.50]	-0.48 [-0.56;-0.39]	0.99	[5]
8	20-year old felt carpet without backing	0.47 [0.08;0.85]	-0.21 [-0.46;0.05]	0.83	[6]
9	20-year old carpet with latex backing	0.55 [0.38;0.71]	-0.03 [-0.11;0.04]	0.97	[6]
10	Nylon carpet on latex backing	0.66 [-0.07;1.40]	-0.27 [-0.98;0.44]	0.88	[7]

Table 3. Legend, description, slope and intercept of trend line for small-scale experiments for wall paints and other building materials in Fig. 4.

Legend	Material description	Equation of trend line (a·x + b)		R^2	Ref.
		Slope a [±95% CI]]	Intercept b [±95% CI]		
1	Painted gypsum board	0.40 [0.30;0.50]	-0.17 [-0.21;-0.13]	0.96	[4]
2	Water-borne acrylic paint on gypsum board	0.21 [0.14;0.27]	0.09 [0.06;0.12]	0.97	[5]
3	Water-borne acrylic paint on gypsum board	0.33 [0.17;0.49]	-0.12 [-0.23;-0.00]	0.94	[5]
4	Water-based paint on gypsum board	0.38 [0.24;0.52]	0.06 [0.01;0.12]	0.96	[6]
5	Water-borne acrylic paint on gypsum board	0.37 [0.21;0.52]	0.10 [0.21;0.52]	0.98	[7]
6	Prefabricated gypsum wall	0.28 [0.03;0.53]	-0.39 [-0.49;-0.29]	0.63	[4]
7	Ceiling acoustic plate	0.52 [0.26;0.79]	-0.27 [-0.41;-0.14]	0.84	[4]
8	1 year old plain chipboard	0.24 [0.07;0.42]	-0.13 [-0.23;-0.04]	0.87	[6]

Table 4. Legend, description, slope and intercept of trend line for small-scale experiments for sealants in Fig. 5.

Legend	Material description	Equation of trend line (a·x + b)		R^2	Ref.
		Slope a [±95% CI]	Intercept b [±95% CI]		
1	Water-borne acrylic sealant - type 1	0.46 [-0.10;1.03]	-0.52 [-1.67;0.62]	0.86	[3]
2	Water-borne acrylic sealant - type 2	0.86 [0.76;0.95]	-1.58 [-1.77;-1.38]	0.99	[3]
3	Sealant	0.45 [0.07;0.82]	-1.49 [-2.58;-0.41]	0.83	[6]
4	Water-borne acrylic sealant	0.23 [-0.04;0.51]	0.05 [-0.59;0.69]	0.87	[7]

Table 5. Legend, description, slope and intercept of trend line for full-scale experiments in Fig. 6.

Legend	Floor area [m^2]	Short description of office (pollution source)	Equation of trend line (a·x + b)		R^2	Ref.
			Slope a [±95% CI]	Intercept b [±95% CI]		
1	108.0	Typical office equipment, 20 year-old carpet	0.24 [-0.86;1.35]	0.092 [-0.439;0.623]	0.89	[8]
2	34.2	2 year-old linoleum, water-based wall paint, 10 year-old furniture	0.33 [0.24;0.43]	0.288 [0.250;0.325]	1.00	[9]
3	40.0	20 year-old felt floor covering without backing	0.78 [0.58;0.98]	-0.67 [-0.86;-0.48]	0.98	[6]
4	40.0	20 year-old carpet with latex backing	0.57 [0.16;0.98]	-0.31 [-0.72;0.09]	0.87	[6]
5	40.0	1 month- old water-based wall paint on gypsum board	0.52[-0.30;1.35]	-1.21 [-2.19;-0.21]	0.96	[6]
6	40.0	5 year-old linoleum	0.62 [0.05;1.19]	-0.50 [-0.95;-0.05]	0.92	[6]
7	81.0	1 year-old plain chipboard	0.35 [0.06;0.63]	-0.31 [-0.58;-0.03]	0.84	[6]
8	108.0	20 year-old carpet, 7 year-old linoleum, 5 year-old chipboard	0.60 [0.58;0.63]	-0.14 [-0.15;-0.12]	1.00	[10]
9	40.0	Used filter (used for 1 year)	0.96 [-0.00;1.92]	-0.58 [-1.20;0.04]	0.99	[11]
10	108.0	20 year-old carpet, 6 year-old linoleum, 3 year-old chipboard	0.60 [-1.34;2.55]	-0.23 [-1.21;0.75]	0.94	[11]
11	108.0	Mixture of sources (materials from exp. 9, 10 and 12)	0.88 [-0.12;1.87]	-0.30 [-0.77;0.18]	0.99	[11]
12	40.0	3 new CRT monitors	0.59 [-0.79;1.97]	-0.34 [-1.17;0.50]	0.97	[11]

Acknowledgments

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The Preference for Local Air Movement in the Facial Region during Long-Term Exposure in the Tropics

N Gong [1,2], KW Tham[1], AK Melikov[2], DP Wyon[2], SC Sekhar[1] and DKW. Cheong[1]

[1]Department of Building, National University of Singapore, 4 Architecture Drive, Singapore, 117566,
[2]International Centre for Indoor Environment and Energy, Technical University of Denmark, 2800, Lyngby, Denmark

Summary: *Human perception of local air movement under steady state conditions in the Tropics has been relatively little reported. This study explores the thermal and air movement perception of a group of Tropically acclimatized subjects (24 people) after 90 minutes of facial exposure to local air movement. The subjects were exposed to several predefined local air movement and temperature conditions. A clear tendency for thermal sensation to become cooler during the 90 minutes of exposure was observed, and subjects had almost reached their steady state sensation after about an hour of adaptation. There was a tendency for subjects to prefer a thermal sensation between 'neutral' and 'slightly cool', and an air movement sensation that was between 'just right' and 'slightly breezy'.*

Keywords: *Human Perception, Long-term Exposure, Local Air Movement, Tropics*
Category: *Thermal comfort*

1 Introduction

The existing draft guideline (ISO7730, 1995) is based on laboratory studies (Fanger and Christensen, 1986; Fanger et al, 1988), in which participants were exposed to each condition for relatively short time periods (15 minutes), but not long-term exposure to air movement. It is reasonable to speculate that people feel cooler after long-term exposure to air movement, and are more sensitive to draft.

Transient changes have been observed in longer time period studies of human perception to air movement. In these studies, subjective exposure to air flow is usually about one hour or longer. A study conducted by Jones and Ogawa (1992) found that transient responses typically last 20 to 60 minutes after changes in the environment and activity. Griefahn et al. (2001) observed that air movement-induced annoyance increased within the first 10 minutes of exposure and annoyance votes did not increase further in the subsequent 50 minutes.

The previous short and long term studies were mostly conducted on subjects' whole-body exposure to air flow. Only limited studies on human response to local air movement exposure have been reported, although such situations are often encountered in practice, for example in personalized ventilation. Some limited studies of subjects' facial exposure to local air movement have been conducted, such as spot cooling used to relieve thermal stress, (e.g., Melikov et al, 1994a; 1994b) or personalized ventilation used to improve inhaled air quality (e.g., Melikov et al, 2002). Preference for air velocity has been observed in a personalized ventilation study (Kaczmarcyk, 2003), in which the preferred velocity could be from 0.39 to 0.74 m/s with room air from 23 to 26 ºC. In a recent tropical study (Gong et al., 2006) on human perception during 15 minutes' exposure to local air movement (personalized ventilation), it was found that the subjects preferred local air velocities ranging from 0.3 to 0.45 m/s at an ambient temperature of 23 °C, while they preferred local air velocities from 0.3 up to 0.9 m/s at an ambient temperature of 26 °C.

It is important to understand whether longer exposures would aggravate draft discomfort, or whether occupants would habituate to the draft conditions or prefer air movement to a certain extent. More detailed data on preference for air movement would facilitate the effective application of personalized ventilation. This study explores the thermal and air movement perception of tropically acclimatized subjects over a 90-minute facial exposure to local air movement with the aim of:

a. Identifying when human perception of thermal comfort reaches steady state by using whole-body thermal sensation as the reference;

b. Studying whether there is a preference for air movement after 90 minutes facial exposure to local air movement.

2 Method

The experiment was conducted in a controlled Indoor Air Quality (IAQ) chamber with dimensions of 6.64m(L) x 3.74m (W) x 2.6m(H) in Singapore. The chamber adjoins a reference room, which is controlled at the same temperature as the chamber and serves as a "conditioning" room for the subjects. (a detailed description of the experimental chamber and facilities can be found in Sekhar et al, 2005). Interior partitions divided the chamber into six workstations, each being equipped with a personalized air terminal device to supply conditioned outdoor air (Figure 1). It is shaped as a truncated cone with a circular inlet (ø 70mm) and a circular (ø 180mm) panel outlet on which a number of Ø5mm holes were uniformly drilled. A thin layer of gauze was mounted closely inside the perforated cover of the outlet in order to make the air distribution more uniform. The air terminal device was located symmetrically in front of each subject.

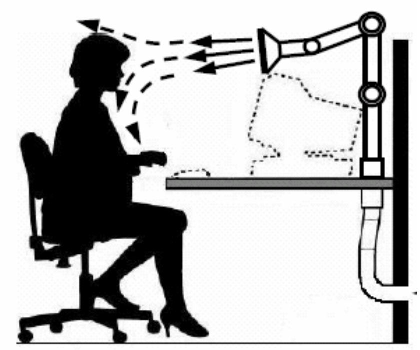

Fig. 1. Diagram of local air movement

Twenty-four tropically acclimatized subjects, 12 males and 12 females, participated in the experiments. The anthropometric data of the 24 subjects are shown in Table 1.

Table 1. Anthropometric data for the subjects

Sex	No	Age (years)	Height(m)	Weight (kg)	Skin area(m2)
Females	12	21.4±1.2	1.60±0.05	49.3±4.1	1.49±0.07
Males	12	22.2±0.9	1.73±0.07	63.8±5.1	1.76±0.10
Females & Males	24	21.8±1.1	1.67±0.09	56.5±8.7	1.62±0.16

The subjects were exposed to predefined local air movement with velocities ranging from 0.15 to 0.9 m/s, and localized (personalized ventilation) airflow temperatures of 21 and 23.5 °C at room temperatures of 23. 5 and 26 °C (refer to Table 2). Ambient-local temperature (Ta-Tf) is used to denote each condition.

Table 2. Experimental conditions

Room Temperature Ta (ºC)	26		23.5
Target Temperature Tf (ºC)	21	23.5	21
Target Velocity Vf (m/s)	0.15, 0.3, 0.45, 0.6, 0.75, 0.9		

The 24 subjects were randomly divided into four groups with 6 members corresponding to the 6 workstations in the experimental chamber. A total of 72 experiments (18 environmental conditions x 4 groups) were performed.

In the experiments, the subjects were first asked to stay in the control room for 30 minutes. During the stay, they could adjust their clothing so that they felt thermally neutral. The subjects would then proceed to the chamber room and were not allowed to adjust their clothing any more. The subjects then stayed in the chamber room for 90 minutes, and answered questionnaires regarding their perception of local air movement. The subjects were free to undertake light office-related tasks including reading and using the computer, but were tasked to respond to computer-administered questionnaires at the 5th, 10th, 15th, 30th, 45th, 60th, 75th and 90th minutes during the experiments.

To evaluate thermal sensation for various body segments and the whole-body, the ASHRAE 7-point scale (ASHRAE, 2004) was used in the questionnaires: +3 Hot; +2 Warm; +1 Slightly warm; 0 Neutral; -1 Slightly cool; -2 Cool; -3 Cold.

Subjects were also asked if they felt any air movement. If they felt air movement at any body segment, they were required to assess the air movement. To evaluate the perception of air movement at each body segment the following scale categories were adopted : +3 Much too breezy; +2 Too breezy; +1 Slightly breezy; 0 Just right; -1 Slightly still; -2 Too still; -3 Much too still. Linear visual analogue scales without intervals were used for the question about air movement preference. The end points were coded as -1 (less air movement) and +1 (more air movement) with 0 denoting "same air movement".

3 Results and Discussions

3.1 Thermal sensation

Thermal sensation was observed to become cooler with duration of exposure in each 90-minute exposure and to have reached steady-state after about one hour of exposure.

Figures 2 to 4 show the time course of whole-body thermal sensation under the three Ta-Tf experimental conditions. Logarithmic regression is applied between the thermal sensation and the time they were exposed to the localized air movement.

A decreasing trend was observed across the six air velocities (0.15, 0.30, 0.45, 0.60, 0.75 and 0.90m/s). Thermal sensation decreased at a relatively faster rate at the beginning of the exposure but slowed down after about one hour. This may suggest that the subjects were almost settled in their steady state after about an hour of adaptation, and it is consistent with the finding of Jones et al. (1992) that transient responses typically last 20 to 60 minutes after changes in the environment and activity.

Meanwhile, it may be seen that thermal sensation is usually lower (cooler) at higher local air velocity. This is expected as the heat loss, particularly from the facial region, is increased with the higher convectional heat loss (Sun, et.al., 2006a).

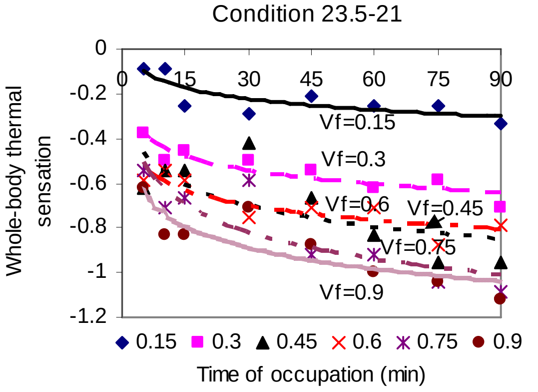

Fig. 2. Logarithmic regression of thermal sensation at condition 23.5-21 (Y-axis, -3=Cold; -2=Cool; -1=Slightly cool; 0=Neutral; 1=Slightly warm; 2=Warm; 3=Hot)

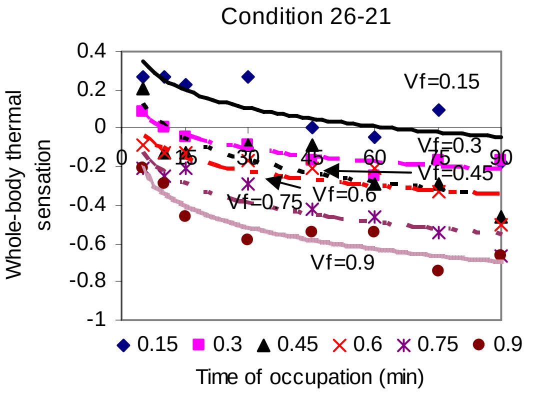

Fig. 3. Logarithmic regression of thermal sensation at condition 26-21 (Y-axis, -3=Cold; -2=Cool; -1=Slightly cool; 0=Neutral; 1=Slightly warm; 2=Warm; 3=Hot)

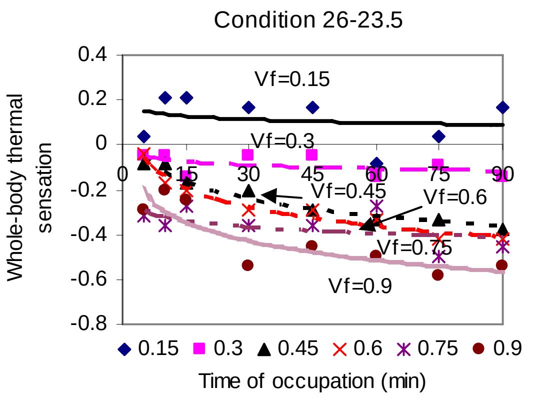

Fig. 4. Logarithmic regression of thermal sensation at condition 26-23.5 (Y-axis, -3=Cold; -2=Cool; -1=Slightly cool; 0=Neutral; 1=Slightly warm; 2=Warm; 3=Hot)

3.2 Preference of air movement at steady state

As thermal sensation had settled to steady state after one hour time of occupation, human perception at the 90th minute, i.e., at the end of the occupation, is used to investigate preference for air movement when thermal sensation has reached steady-state.

The relations between air movement perception/preference and local air velocity are respectively depicted in Figures 5 and 6.

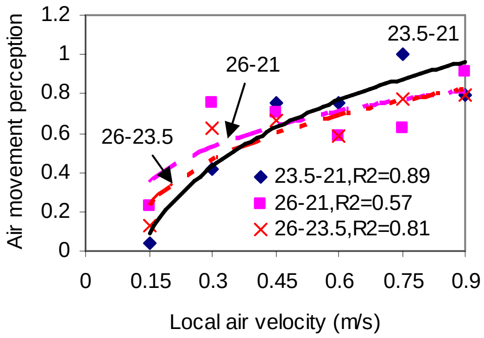

Fig.5. Logarithmic regression of air movement perception at the 90th minute (Y-axis -3=Much too still; -2=Too still; -1=Slightly still; 0=just right; 1=Slightly breezy; 2=Too breezy; 3=Much too breezy)

Air movement preference may be seen to decrease when local air velocity increases. Preferred air movement was around 0.45 m/s, 0.5 m/s, and 0.75 m/s for the 23.5-21, 26-21 and 26-23.5 conditions respectively.

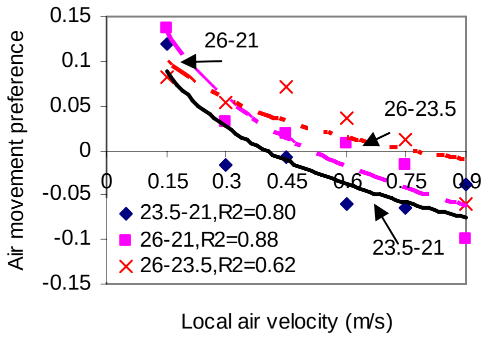

Fig.6. Logarithmic regression of air movement preference at the 90th minute (Y-axis -1=Less air movement; 0=Same air movement; 1=More air movement)

The regression between air movement perception and preference is shown in Figure 7. Tropically acclimatized people prefer more air movement even when they judge the air movement to be ‘just right’ (0 on the X-axis), and they would prefer the air movement not to be changed when they characterize the air movement as somewhere between ‘just right’ and ‘slightly breezy’ ("Slightly breezy" is coded as 1 on the X-axis).

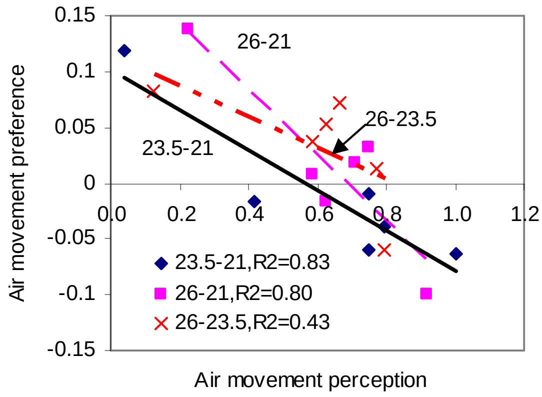

Fig. 7. Linear regression of air movement perception and preference at the 90th minute (X-axis: -3=Much too still; -2=Too still; -1=Slightly still; 0=just right; 1=Slightly breezy; 2=Too breezy; 3=Much too breezy; Y-axis: -1=Less air movement; 0=Same air movement; 1=More air movement)

Figure 8 shows the relation between facial thermal sensation and thermal comfort. It may be seen that tropically acclimatized subjects felt most comfortable when facial thermal sensation was between ‘neutral’ (coded as 0) and ‘slightly cool’ (coded as -1), and not when it was neutral.

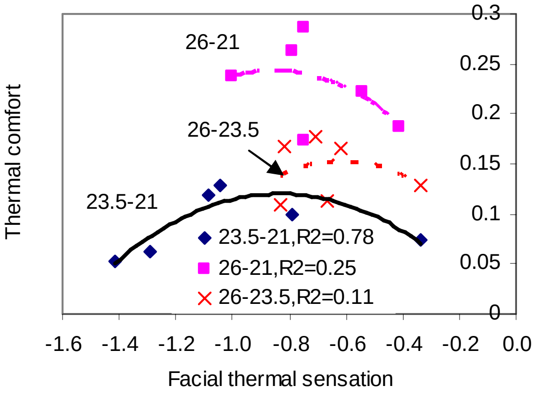

Fig.8. Quadratic correlation of facial thermal sensation and thermal comfort after 90 minutes. (X-axis: -3=Cold; -2=Cool; -1=Slightly cool; 0=Neutral; 1=Slightly warm; 2=Warm; 3=Hot; Y-axis: -1=very unacceptable, 0=just unacceptable/acceptable, +1=very acceptable)

A preference for a cooler than neutral thermal sensation was observed in other tropical studies. In a natural ventilation study (Feriadi and Wong, 2004), a strong preference (nearly 80% of those surveyed) was observed to have voted ‘just right/no change’ on the thermal preference scale (Mc Intyre scale, i.e., -1 for preference of warmer, 0 for no change, and +1 for preference of cooler), even though they had voted ‘cool’ on the ASHRAE 7-point scale (-2). In a series of call-centre studies performed in air-conditioned environments in Singapore, Tham and Willem (2005) alluded to the preference for slightly cool thermal sensation as “thermal relief” among call-centre operators when discussing the improvement in productivity that was caused by reducing room temperature from slightly warm to slightly cool.

Obviously, more local air movement causes more heat loss from the facial region, and the draft risks need to be ascertained. In short term exposures to localized air movement achieved through personalized ventilation, it had been demonstrated that tropically acclimatized subjects prefer facial air movement even when the draft risk is as high as 50% (Sun et. al., 2006b).

4 Conclusion

The key findings of this perception study of longer term exposure to local air movement of tropically acclimatized people are as follows:

a. Thermal sensation tends to decrease during the 90 minutes exposure, and the rate of decrease slows down after about one hour, suggesting that subjects reach their steady state of thermal sensation after about an hour of adaptation.

b. Tropically acclimatized subjects prefer some air movement; there was a tendency for subjects to prefer a thermal sensation between 'neutral' and 'slightly cool', and an air movement sensation between 'just right' and 'slightly breezy'.

5 Acknowledgement

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Effects of outdoor air supply rates on subjective factors in three call centers in the Tropics (a principal component analysis approach)

H.C. Willem[1], K.W. Tham[1], P. Wargocki[2], D.P. Wyon[2], P.O. Fanger[2]

[1]National University of Singapore, Dept. of Building, 4 Architecture Drive, Singapore 117566
Email: bdgtkw@nus.edu.sg http://www.nus.edu.sg
[2]Technical University of Denmark, Dept. of Mechanical Engineering, Nils Koppels Allé, 2800 Kgs. Lyngby

Summary: *Principal component analysis was carried out to reduce dimensionality of subjective responses from surveys conducted in three call centers, in which 300 call center operators participated. Results consistently revealed five clusters of variables (also termed as subjective factors): 1) intensity of neurobehavioral-related symptoms and self-assessed productivity, 2) perception of thermal environment, air quality, and intensity of cold hand and cold feet symptoms, 3) intensity of dryness and breathing system-related symptoms, 4) perceived odor and irritations, and 5) perceived thermal comfort and acceptability of air quality. Non-parametric analysis suggests that increased outdoor air supply rate would lead to significant improvements of several subjective factors.*

Keywords: *outdoor air supply rate, principal component analysis, subjective factor, call centers, tropics*
Category: *human responses to IAQ*

1. Introduction

A healthy and conducive working environment is arguably a worker's right [1] and this understanding extends beyond the industrial environment as the main job demographics has shifted from the industry and agriculture settings to the more sedentary office. Many studies have shown that the quality of the indoor environment to be a key determinant of well-being and productivity [2]. A call for better and even, excellent indoor environments has been articulated [3].

The Sick Building Syndrome (SBS) symptoms has been associated with a myraid of health-related complaints. This provide the evidence of the detrimental effects of poor indoor air quality, which could result in work distractions that culminate in absenteeism and productivity loss [4]. In a review based on 529 investigations conducted from 1971-1988 by the National Institute of Occupational Safety and Health (NIOSH), inadequacy of ventilation was considered a primary cause of building-related problems and the occurrence of SBS symptoms [5].

It has been postulated that the subjective responses may represent similar underlying mechanism and thus, could be clustered to reduce dimensionality of the subjective responses [6]. The data extraction method had been employed previously in study associating personal and workplace factors on health and comfort [7]. It was also used to classify buildings with low and high prevalances of SBS symptoms [8]. More recently, it has been used in linking the Dutch school environmental parameters and their pupils' health [9].

2. Objectives

This paper reports the results of the effects of outdoor air supply rate on office workers' subjective responses in the tropics. The study was conducted in three call centers in Singapore.

The main objectives of this paper are:

- to demonstrate the consistency in the perceptual constructs of the subjective responses of office workers
- to show the positive associations between outdoor air supply rate and the subjective factors derived from the principal component analysis

3. Method

Three call centers in the tropics, Singapore, provided their consent to participate in the survey. These offices are hereafter termed as Call center A, B and C. A questionnaire was distributed to the occupants to obtain their subjective responses on Thursdays over a nine-week (W1-W9) period. The experimental protocols are detailed in Tham [10]. Figure 1 depicts the weekly sequence of exposures for two air temperatures (T_1 and T_2) and two outdoor air supply rates (V_1 and V_2). The experimental design was balanced for testing the effects of either air temperature or outdoor air supply rate. Table 1 shows the parameters used in the blind intervention studies. Only the effects of outdoor air supply rate is reported in this paper.

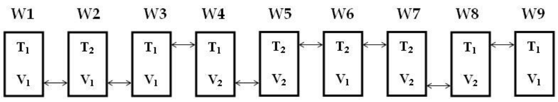


Fig. 1. Nine-weeks consecutive experimental design.

Table 1. Air temperature and outdoor air supply rate settings

Parameters	Call center A	Call center B	Call center C
T_1 (ºC)	22.5		
T_2 (ºC)	24.5		
V_1 (L/s/p)	9.0	6.0	3.0
V_2 (L/s/p)	18.0	12.0	6.0

The questionnaire comprised mostly of visual-analog scales (horizontal continuous scales) for the recording of occupants' perceptions towards various indoor environmental parameters and intensity of SBS symptoms. The questionnaire was modified from assessments for anxiety, alertness, mood, and quality of sleep, first introduced for subclinical symptoms by Wyon [11]. Several vertical continuous scales were including for assessing thermal comfort and acceptability of air quality. These scales were designed to circumvent some of the problems associated with verbal reports, and has proven to be a useful tool for the rating of subjective responses [11].

Principal component analysis was carried out to extract several factors from coherent subsets of data as described by Dunteman [12]. In order to allow for correlated subjective responses, the data was subjected to principal component analysis with oblique rotation. The two criteria for extracting the factors, hereafter termed as subjective factors (SF), were eigenvalues greater than one and the consistency of line gradients in the scree plot. Data variance explained by each SF was also reported. Each SF was derived from a cluster of subjective responses with varying weighting factors on the extracted SF. All factor loadings greater than 0.5 were presented in the observed pattern matrix (an output table showing clusters of subjective response under each SF: Tables 2-4). Subjective factor scores (SF scores) for each occupant was derived based on the factor loadings and the initial ratings given by the subjects. The non-parametric analysis for testing the main effects of outdoor air supply rate was subsequently carried out on the SF scores.

4. Results

A consistent and coherent structure of variable clusters was extracted through principal component analysis of the survey data from each call center. This comprises five subjective factors (SFs), namely:

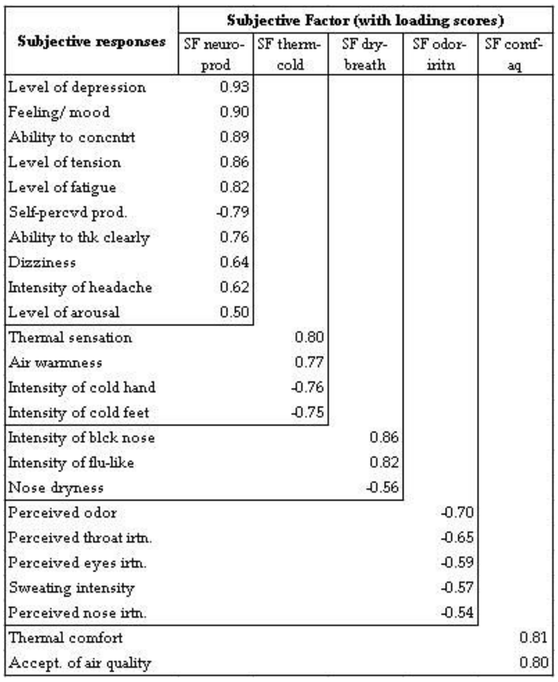
a) intensity of neurobehavioral-related symptoms and self-assessed productivity ($SF_{neuro\text{-}prod}$),
b) perception of thermal environment, air quality, and intensity of cold hand and cold feet symptoms ($SF_{therm\text{-}cold}$),
c) intensity of dryness and breathing-related symptoms ($SF_{dry\text{-}breath}$),
d) perceived odor and irritations ($SF_{odor\text{-}iritn}$),
e) perceived thermal comfort and acceptability of air quality ($SF_{comf\text{-}aq}$).

Tables 2-4 show these subjective factors and the subjective responses within each cluster extracted from the subjective data in each call center. $SF_{neuro\text{-}prod}$ accounted for the highest data variance in the three call centers (31-38%). Symptoms related to the central nervous system such as headache and dizziness, fatigue, abilities to think and concentrate, arousal and tension; and state of feeling/ mood. Self-perceived productivity was also consistently found in $SF_{neuro\text{-}prod}$ indicating that the intensity neurobehavioral-related symptoms were associated with subjects' perception about their ability to perform the work routines. Higher neurobehavioral-related symptoms were associated with lower self-perceived productivity.

Thermal-related responses formed the second subjective factor, $SF_{therm\text{-}cold}$, which accounted for 11-15% of data variance. Thermal sensation and air warmness were consistently present. The thermal responses also influenced other air quality perceptions such as air stuffiness, air humidity, and air stillness, particularly in Call center B. Warmer thermal sensation was related to perceived stuffy and humid air, while higher intensity of cold hand and cold feet symptoms, on the contrary, were associated with cooler thermal sensation.

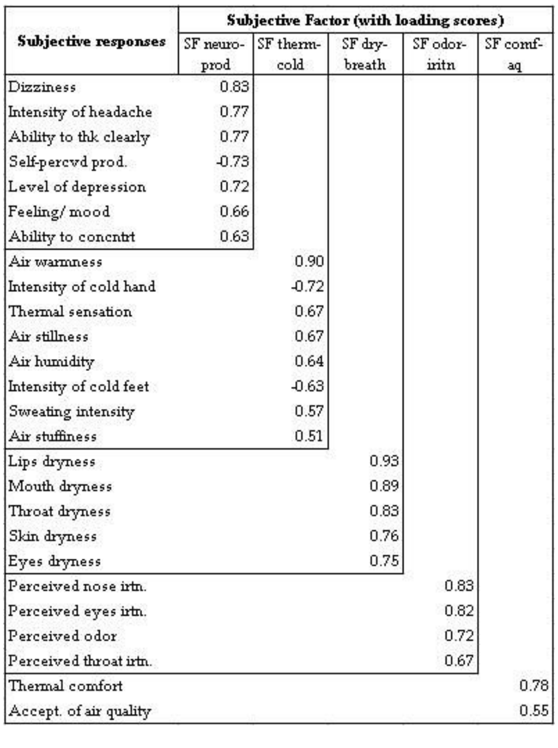
Each of the next three SFs explained less than 10% of the data variance. However, these SFs constituted distinct subjective variables which may explain various mechanisms in the interactions between occupants and the indoor environmental variables. There was a clear separation between irritations and dryness intensities as shown by $SF_{dry\text{-}breath}$ and $SF_{odor\text{-}iritn}$. Intensity of nose dryness and breathing-related symptoms such nose blocked and flu-like symptoms were more dominant (factor loadings > 0.5) in Call center A, whereas intensities of dryness dominated the $SF_{dry\text{-}breath}$ in the other call centers. Perceived odor and irritations to eyes, nose and throat formed a coherent $SF_{odor\text{-}iritn}$ latent variable. A change in odor perception was followed by irritations in the same direction of change. Finally, occupants also linked their thermal comfort with the acceptability of air quality. In other words, better thermal comfort would likely be associated with a more acceptable indoor air quality.

Table 2. Extracted subjective factors and the loading scores from Call center A.



Subjective responses	Subjective Factor (with loading scores)				
	SF neuro-prod	SF therm-cold	SF dry-breath	SF odor-iritn	SF comf-aq
Level of depression	0.93				
Feeling/ mood	0.90				
Ability to concntrt	0.89				
Level of tension	0.86				
Level of fatigue	0.82				
Self-percvd prod.	-0.79				
Ability to thk clearly	0.76				
Dizziness	0.64				
Intensity of headache	0.62				
Level of arousal	0.50				
Thermal sensation		0.80			
Air warmness		0.77			
Intensity of cold hand		-0.76			
Intensity of cold feet		-0.75			
Intensity of blck nose			0.86		
Intensity of flu-like			0.82		
Nose dryness			-0.56		
Perceived odor				-0.70	
Perceived throat irtn.				-0.65	
Perceived eyes irtn.				-0.59	
Sweating intensity				-0.57	
Perceived nose irtn.				-0.54	
Thermal comfort					0.81
Accept. of air quality					0.80

Table 3. Extracted subjective factors and the loading scores from Call center B.

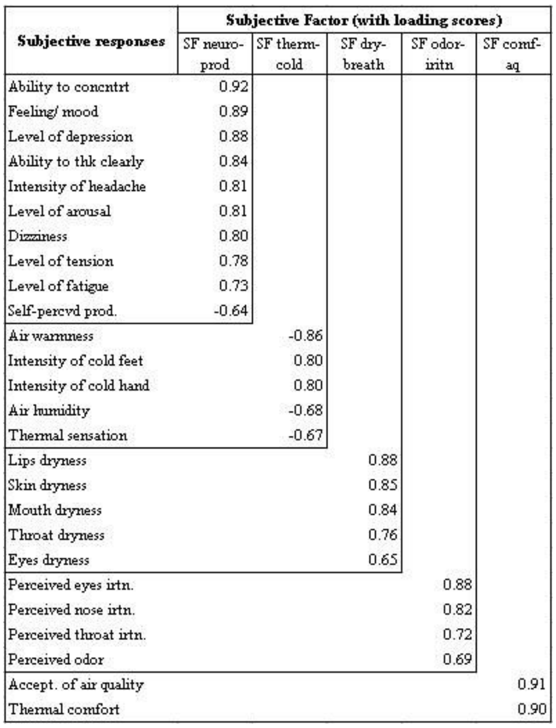


Subjective responses	Subjective Factor (with loading scores)				
	SF neuro-prod	SF therm-cold	SF dry-breath	SF odor-iritn	SF comf-aq
Dizziness	0.83				
Intensity of headache	0.77				
Ability to thk clearly	0.77				
Self-percvd prod.	-0.73				
Level of depression	0.72				
Feeling/ mood	0.66				
Ability to concntrt	0.63				
Air warmness		0.90			
Intensity of cold hand		-0.72			
Thermal sensation		0.67			
Air stillness		0.67			
Air humidity		0.64			
Intensity of cold feet		-0.63			
Sweating intensity		0.57			
Air stuffiness		0.51			
Lips dryness			0.93		
Mouth dryness			0.89		
Throat dryness			0.83		
Skin dryness			0.76		
Eyes dryness			0.75		
Perceived nose irtn.				0.83	
Perceived eyes irtn.				0.82	
Perceived odor				0.72	
Perceived throat irtn.				0.67	
Thermal comfort					0.78
Accept. of air quality					0.55

Table 5 shows the main effects of outdoor air supply rate on the extracted SFs across the call center groups. In Call center A, $SF_{neuro\text{-}prod}$ was significantly reduced at higher outdoor air supply rate ($P<0.007$). This result suggests that increased ventilation could reduce the intensity of neurobehavioral-related symptoms such as depression, fatigue, dizziness, negative feeling/mood and sleepiness. Concurrently, the ability to concentrate and think as well as the self-perceived productivity improved with higher outdoor air supply rate.

The significant effects of outdoor air supply rate on the SFs in Call center B were observed for $SF_{therm\text{-}cold}$ ($P<0.02$) and $SF_{odor\text{-}iritn}$ ($P<0.002$), while in Call center C, outdoor air supply rate affected $SF_{therm\text{-}cold}$ ($P<0.008$). These results highlighted the positive impacts of higher outdoor air supply rate on thermal-related perceptions, suggesting possible interaction effects between thermal environment and the indoor air quality parameters. Furthermore, higher outdoor air supply rate could reduce indoor air contaminants and thus, lower the perceived odor level and irritations.

Table 4. Extracted subjective factors and the loading scores from Call center C.



Subjective responses	Subjective Factor (with loading scores)				
	SF neuro-prod	SF therm-cold	SF dry-breath	SF odor-iritn	SF comf-aq
Ability to concntrt	0.92				
Feeling/ mood	0.89				
Level of depression	0.88				
Ability to thk clearly	0.84				
Intensity of headache	0.81				
Level of arousal	0.81				
Dizziness	0.80				
Level of tension	0.78				
Level of fatigue	0.73				
Self-percvd prod.	-0.64				
Air warmness		-0.86			
Intensity of cold feet		0.80			
Intensity of cold hand		0.80			
Air humidity		-0.68			
Thermal sensation		-0.67			
Lips dryness			0.88		
Skin dryness			0.85		
Mouth dryness			0.84		
Throat dryness			0.76		
Eyes dryness			0.65		
Perceived eyes irtn.				0.88	
Perceived nose irtn.				0.82	
Perceived throat irtn.				0.72	
Perceived odor				0.69	
Accept. of air quality					0.91
Thermal comfort					0.90

5. Discussions

The present study shows the potential application of the principal component analysis in analyzing the complex subjective responses. The extracted components or subjective factors offer insights to the latent perceptual constructs, which may explain various related mechanisms of occupants' perceptions. The present approach enables not only the detailed evaluation of effects of outdoor air supply rate on each subjective variables acting singly, but also the impact on various perceptual mechanisms involving strong and consistent clusters of air quality and thermal perceptions as well as the intensity of SBS symptoms.

Table 5. Effects of outdoor air supply rate (V) on subjective factors in three call centers

Subjective Factors	Factor score[#]									Score description
	Call center A			Call center B			Call center C			
	V_1^	V_2^	P	V_1	V_2	P	V_1	V_2	P	
INTENSITY OF NEUROBEHAVIORAL-RELATED SYMPTOMS & SELF-ASSESSED PRODUCTIVITY	0.10	-0.12	***	-0.06	0.04		0.14	0.20		Higher score indicates higher symptoms intensity but lower self-perceived productivity.
PERCEPTION OF THERMAL ENVIRONMENT, AIR QUALITY & INTENSITY OF COLD HAND AND COLD FEET SYMPTOMS	0.05	-0.07		0.10	0.01	**	-0.22	0.04	***	Higher score indicates perceived warmer, more humid and stuffier environment but lower cold hand and cold feet intensities, except for Call center C where higher score means perceived cooler environment with higher cold hand and cold feet intensities.
INTENSITY OF DRYNESS & BREATHING-RELATED SYMPTOMS	0.03	0.06		0.00	0.03		-0.07	-0.07		Higher score suggests higher dryness and breathing-related symptoms intensity.
PERCEIVED ODOR & IRRITATIONS	0.07	0.05		0.13	-0.19	***	-0.22	-0.01		Higher score suggests lower perceived odor and irritations, except for Call center C where higher score indicates higher perceived odor and irritations.
PERCEIVED THERMAL COMFORT & ACCEPTABILITY OF AIR QUALITY	0.06	-0.03		-0.02	0.05		-0.17	-0.15		Higher score suggests better thermal comfort and acceptability to air quality.

Note: *** denotes $0<P\leq0.01$; ** denotes $0.01<P\leq0.05$; * denotes $0.05<P\leq0.10$

^ : V_1 indicates lower outdoor air supply rates and V_2 indicates higher outdoor air supply rates

[#] : Andersen-Rubin factor scores

The subjective factors revealed a set of consistent perceptual constructs across the three call centers. The neurobehavioral-related symptoms were consistently more dominant than other subjective responses and were associated with the self-rated productivity, indicating the importance of mental performance to the office workers. Hovanitz et al [13] reported similar associations arising from the onset of headache. They demonstrated that both objective measure and subjective rating of accuracy were significantly lower in subjects reporting headache than those headache-free. The occurrence of headache symptom could cause lost workdays and reduced work effectiveness [14]. The inclusion of headache intensity in the cluster of neurobehavioral-related symptoms, $SF_{neuro-prod}$, suggests that the mental state affecting work performance may not depend only on a single symptom and that there could be cumulative effects of various related symptoms.

Outdoor air supply rate affected the intensity of $SF_{neuro-prod}$ in Call center A. This result is consistent with the analysis of the individual subjective responses reported in Tham et al [15]. It was shown that occupants reported a marked 19.5% reduction of headache intensity and 13.2% reduction of difficulty to think clearly, when outdoor air supply rate was increased from nominal 9.0 to 18.0 L/s/p. In another study conducted in the laboratory setting, Wargocki et al [16] reported that difficulty to think clearly, feeling of wellbeing/ mood, fatigue, and depression were also monotonically influenced by changing ventilation rate between 3, 10 and 30 L/s/p. In the present study, the positive effects on $SF_{neuro-prod}$ show that other neurobehavioral-related symptoms were similarly affected when outdoor air supply rate was altered.

The effect of outdoor air supply rate on $SF_{neuro-prod}$ in Call center A was not observed in the other call centers. At this point, it is worth noting that due to lower clothing insulation value, occupants in Call centers B and C experienced lower thermal sensation (~ -0.5 to -1.2 on the ASHRAE thermal sensation scale) than those working in Call center A (~ 0.2 to -0.3 on the same scale). Subjects in Call centers B and C were in a state of slightly cool thermal sensation, which may overcome other effects including the neurobehavioral-related symptoms. This is evident from the positive effects on $SF_{therm-cold}$ when outdoor air supply rate was increased in both Call centers B and C, which was likely related to the better perceptions of thermal environment and the indoor air quality.

Fang et al [17] demonstrated that reducing air temperature and humidity (enthalpy) led to better perception of indoor air quality, caused by the cooling effect in the respiratory tract. On the other hand, the present result of $SF_{therm-cold}$ shows that elevating ventilation level could improve subjects' thermal perceptions as the indoor air was considered fresher, less humid, and cooler. It is also pertinent to note that during interventions of outdoor air supply rate, the room thermal parameters were kept constant and therefore, the unconventional effect of altering ventilation rate on thermal perceptions was not influenced by thermal conditions.

Although the intensity of odor and irritations to the eyes, nose and throat were generally low, increasing outdoor air supply rate has improved the $SF_{odor-iritn}$ as perceived by the occupants in Call center B. Wolkoff et al [18] suggested that sensory irritation may be the result of odor annoyance and that various indoor air contaminants such VOCs and gas-phased oxidation products could influence the intensity of odor and irritations. In the call center, higher amount of outdoor air supply rate seemingly increased the dilution factor of the air contaminants, which subsequently reduced odor-irritations intensity. In a study of 44 office premises, Zweers et al [19] also arrived at a similar conclusion. It was shown that premises with higher air exchange rates were associated with better acceptability of odor.

6. Conclusions

- A consistent set of five subjective factors were extracted from subjective responses using principal component analysis from each of the three call centers, implying similar perceptual constructs of the tropically acclimatized office workers.
- $SF_{neuro-prod}$ explained most of the data variance and demonstrated the associations among the neurobehavioral-related symptoms and their influence on self-perceived productivity.
- Increasing outdoor air supply rate reduced $SF_{neuro-prod}$, improved $SF_{therm-cold}$, and lowered $SF_{odor-iritn}$, suggesting the potential benefits to the health and well-being of office workers.

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Effect of Local Cooling on Human Responses I – Effect of Local Thermal Sensation on Overall Thermal Sensation

Zhang Yufeng and Zhao Rongyi

Tsinghua University, Department of Building Science, 100084 Beijing, China
email: zhangyufeng96@tsinghua.org.cn

Summary: *The effect of local thermal sensation on overall thermal sensation was studied when single body part was cooled. It was found that local cooling affected local thermal sensations of the uncooled body parts significantly and a new influencing factor method was proposed based on this finding. Influencing factor and influencing weight was unaffected by room and local cooling air temperatures for each body part. Based on influencing factor and influencing weight, predictive models of overall thermal sensation were derived. Thermoregulatory reaction was the possible physiological mechanism of subjective response to local cooling.*

Keywords: *local cooling, influencing weight, influencing factor*
Category: *Global thermal comfort, Standards and analytical methodology*

1 Introduction

Local cooling is increasingly in focus, not only as an alternative to the conventional air conditioning when it is not feasible to control the environment in the entire space, but also as an advanced technology to provide an acceptable environment while using less energy. The effect of local thermal sensation on overall thermal sensation and the assessment of non-uniform environment are the key problems in the studies of human responses to local cooling. This paper presents the study on the effect of local thermal sensation on overall thermal sensation, and the study on the assessment of non-uniform environment is presented in another paper.

Weighting factoring is commonly used in the studies of the effect of local thermal sensation on overall thermal sensation, which is defined as the change of overall thermal sensation when local thermal sensation of a body part changes one unit on thermal sensation voting scale while others' remain constant. Ingersoll [1] proposed to use the respective surface area of each body part as its weighting factor to derive average PMV for whole body thermal sensation. Hagino [2] suggested that the whole body thermal sensation was governed by local thermal sensation of certain small areas of the body that were exposed to direct airflow or solar radiation in the passenger compartment in automobile. Zhang [3] found that as local sensation diverged from that of the rest of the body, weighting factor became larger, and certain body segments, such as chest, back and pelvis had larger weighting factors and dominated the influence on overall sensation, while hand and foot had small weighting factors. Li [4] reported that weighting factor changed with the intensity of local stimulus, and the weighting factor of head was biggest.

Weighting factor as a key index evaluating the effect of local thermal sensation on overall thermal sensation has been widely accepted. However, which body part has large weighting factor and what variables affect weighting factor remain inconsistent.

The purpose of the present study is to investigate the effect of local thermal sensation on overall thermal sensation systemically while local cooling is applied.

2 Experimental methods

The experiment was carried out in the Department of Building Science at Tsinghua University during the period March 2005 to June 2005.

2.1 Experimental design

A personalized ventilation system was used to supply the local cooling airflow and a set of special clothes was used to fix the cooling body surface area (see Figure 1). Three sensitive body parts: face, chest and back were selected to be cooled locally in the present study. A climate chamber was used to control the ambient room temperature for local cooling. Temperature in the chamber and temperature at the outlet of local airflow could be maintained with a precision of ±0.2°C.

1 2 3

1 Chest cooling 2 Face cooling 3 Back cooling

Figure 1. Devices for local cooling

Three levels of room temperatures, ranging from neutral to warm, and three levels of local cooling target temperatures (target temperature means the air temperature at the center of cooling body part surface), ranging from neutral to slightly cool, were chosen to be studied (see Table 1).

Table 1. Experimental conditions.

Factors	Levels
Room temperature (°C)	28 32 35
Target temperature (°C)	22 25 28

The relative humidity was kept constant at 40% and the air speed was less than 0.1m/s in the chamber. The air speed at the outlet of the local cooling airflow was maintained at 1m/s.

2.2 Measurements

Subjects reported their responses twice before local cooling and 16 times while local cooling, at one-minute intervals for six minutes and then at two-minute intervals for fourteen minutes and then at five-minute intervals during exposure. Overall thermal sensation and local thermal sensation for each of the body parts were reported on the 7-point ASHRAE scale at each voting time (Figure 2). Temperature in the room and temperature at the outlet of local airflow were measured and recorded every two seconds during each exposure.

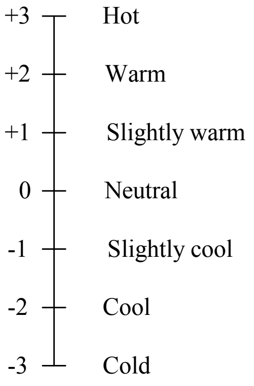

Figure 2. Voting scales

2.3 Experimental procedure

Thirty randomly selected chinese male students, dressed in short, with a normal range of age, height and weight participated in the experiment. Each test consisted of half-an-hour pre-conditioning and half-an-hour exposure. The room temperature was maintained constant for each test and no local airflow existed during pre-conditioning. The total duration of each subject's participation was 27 hours. The sequence of presentation was balanced for each subject using Latin squares. Subjects remained sedentary throughout each exposure. Subjects responding 'clearly unacceptable' at any point in time were allowed to terminate the exposure and leave immediately.

3 Results and Discussion

Shapiro-Wilk's W test was applied and the results show that human responses obtained in all conditions were normally distributed. They were therefore analysed using repeated measure ANOVA and paired-sample t-tests. It was found that human responses reached steady state within 25 minutes during pre-conditioning ($p>0.05$) and within 20 minutes during exposure ($p>0.05$) in all conditions. If not mentioned specifically, all responses reported below are steady state responses.

3.1 Change of local thermal sensations of the unexposed body parts

Figure 3 shows the change of mean thermal sensation vote with time in a face cooling condition. When face cooling was supplied (7th minute in Figure 3), not only face thermal sensation and overall thermal sensation decreased rapidly, but also local thermal sensations of the uncooled body parts, including chest, back and lower body part, changed obviously. Thermal sensation votes were analysed for significance using paired-sample t-tests and the results show that local thermal sensations of the uncooled body parts changed significantly ($p<0.01$).

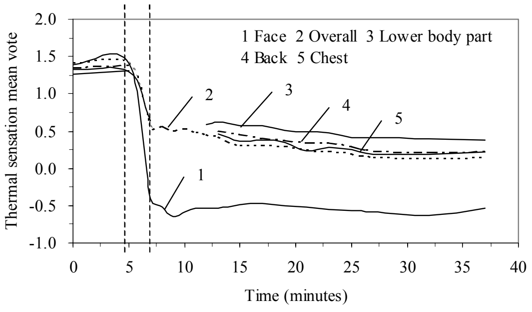

Figure 3. Change of mean thermal sensation votes with time (room temperature 35°C, target temperature 22°C, no votes between the dashed lines)

Responses in other conditions were analyzed and it was found that in most cases local cooling significantly ($p<0.05$) changed local thermal sensations of the uncooled body parts. This indicates that local thermal sensations of all body parts are not independent, but correlated with each other.

3.2 Influencing factor method

Weighting factor was adopted to evaluate the effect of local thermal sensation of a body part on overall thermal sensation in the present study. Multiple linear regression is widely used to obtain weighting factor for each body part:

$$S_O = \sum_{i=1}^{n} w_i S_i \qquad (1)$$

where S_O is overall thermal sensation, $i = 1,2\cdots n$ is the number for body parts, S_i is local thermal sensation of the body part i, w_i is the weighting factor of the body part i.

As local thermal sensations of all body parts are correlated with each other, correlation between the independent variables in equation (1) was analyzed for each condition using collinearity diagnostics and the results show that high collinearity exists in most cases (tolerance<0.1). As repeated-measures experimental design was adopted in the present study, sphericity assumption was applied to test whether the responses of one subject in different conditions correlated with each other and the results show that the autocorrelation in the responses is significant ($p<0.05$).

Collinearity and autocorrelation violate the independency of the data and may result in unreasonable results using multiple linear regression. To solve the problem, a new method was proposed, which can be expressed as:

$$\Delta S_O = f_{EO} \Delta S_E \qquad (2)$$

where ΔS_O is the change of overall thermal sensation, ΔS_E is the change of local thermal sensation of the cooling body part, and f_{EO} is the regression coefficient.

The new method is different from multiple linear regression in two aspects:

1. Taking local thermal sensation of the cooling body part as the only independent variable for regression.

2. Calculating the change of thermal sensation vote first and then making regression.

The effect of collinearity and autocorrelation can be removed using the new method. However, as local thermal sensations of the cooling body parts changed with local cooling, f_{EO} was not the weighting factor of the cooling body part, but the integrated result of the weighting factors of all body parts. Here a new term 'influencing factor' is proposed, defined as the change of overall thermal sensation when local thermal sensation of the cooling body part changes one unit on the 7-point ASHRAE scale under the condition of single body part cooling. Influencing factor represents the general effect of local cooling on overall thermal sensation, while weighting factor represents the importance of local thermal sensation of a single body part in the process of integration of overall thermal sensation.

Similarly influencing factor can be used to describe the effect of local cooling on local thermal sensations of the uncooled body parts and the relationship between influencing factor and weighting factor was obtained according to their definitions:

$$f_{EO} = \sum_{i=1}^{n} w_i f_{Ei} \qquad (3)$$

where f_{Ei} is the influencing factor of the cooling body part on local thermal sensation of the body part i.

Based on the discussion above, an influencing factor method was proposed: to obtain influencing factor by equation (2) and then to calculate weighting factor by equation (3).

3.3 Influencing factor and weighting factor

Influencing factor for face cooling at room temperature 28°C was analyzed and the result is shown in Figure 4. The change of thermal sensation in the figure means the mean thermal sensation vote during local cooling minus the one during pre-conditioning. A straight line passing origin fits the data well (R^2=0.9). The slope of the line is 0.6, which means that overall thermal sensation changes 0.6 units when face thermal sensation changes one unit, that is to say, the influencing factor of face on overall thermal sensation is 0.6. Figure 4 also shows the results in three levels of target temperatures and it can be seen that the influencing factor was unaffected by cooling air temperature.

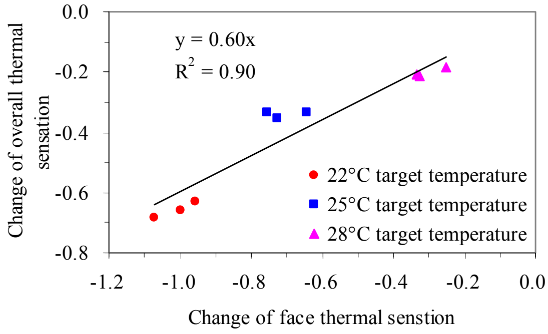

Figure 4. The influencing factor of face (room temperature 28°C)

Figure 5 shows the influencing factor for face cooling in all conditions. A line fits the data well (R^2=0.92) and the influencing factor of face is unaffected by room temperature.

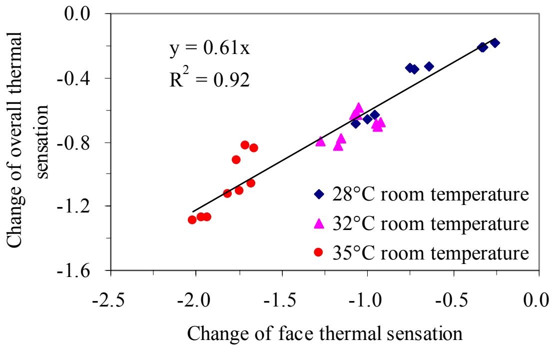

Figure 5. The influencing factor of face

The influencing factors of chest and back on overall thermal sensation and the influencing factors of the cooling body parts on local thermal sensations of the uncooled body parts were analyzed in the same way and the results show that all influencing factors do not change with room or cooling air temperatures significantly. Table 2 shows the results of all influencing factors.

Table 2. Influencing factors (to be continued).

Cooling body part	Face thermal sensation	Chest thermal sensation	Back thermal sensation
Face	1	0.54	0.57
Chest	0.16	1	0.4
Back	0.18	0.3	1

Table 2. Influencing factors (continued).

Cooled body part	Lower body part thermal sensation	Overall thermal sensation
Face	0.43	0.61
Chest	0.31	0.47
Back	0.3	0.45

It can be seen from Table 2 that face cooling affects overall thermal sensation and local thermal sensations of the uncooled body parts more than chest or back cooling. The impact of chest cooling on back thermal sensation is close to the impact of back cooling on chest thermal sensation. However, the impact of chest or back cooling on face thermal sensation is much less than the impact of face cooling on chest or back thermal sensation.

Based on the results of influencing factors and equation (3), plus the condition that the sum of the weighting factors of all body parts equals to one, the weighting factors of all body parts were calculated and the results show that all weighting factors are unaffected by room or local air temperature and the weighting factor of face, chest, back and lower body part is 0.21, 0.24, 0.25 and 0.30 respectively. This indicates that the role of local thermal sensation of face, chest and back are almost the same in the integration of overall thermal sensation.

Though the weighting factor of face is the same with the one of chest or back, face cooling affects local thermal sensations of the uncooled body parts more and results in a higher influencing factor on overall thermal sensation than chest or back cooling. Influencing factor represents the general effect of local cooling on overall thermal sensation and weighting factor is the internal reason for the effect, and they are correlated by the organic relationship between local thermal sensations of all body parts.

Dynamic human responses were analyzed and the result indicates that influencing factor changed significantly with exposure time (Figure 6). Initially influencing factor is small, and then increases gradually, and reaches steady state within 20 minutes.

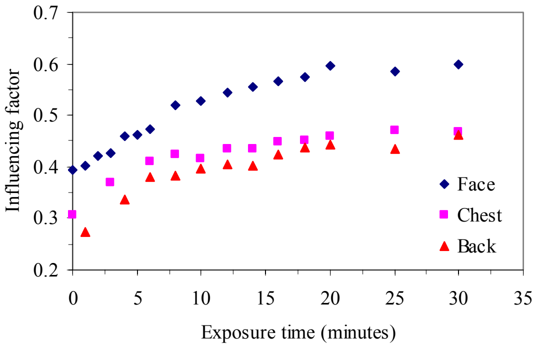

Figure 6. Effect of exposure time on influencing factors

3.4 Predictive models of overall thermal sensation

Based on influencing factor and weighting factor, predictive models of overall thermal sensation were obtained:

$$S_O = \sum_{i=1}^{n} w_i S_i \qquad (4)$$

$$S_O = f_{EO}(S_E - S_{E0}) + S_{O0} \qquad (5)$$

where S_{O0} and S_{E0} are overall thermal sensation and local thermal sensation of the cooling body part before exposure, S_E is local thermal sensation of the cooling body part while local cooling.

To predict overall thermal sensation, local thermal sensations of all body parts need to be known when using equation (4), while the initial whole body thermal state and local thermal sensation of the cooling body part need to be known when using equation (5). It is more convenient to predict overall thermal sensation using the model based on influencing factor for practical application.

4 Discussion

4.1 Comparison with other studies

The present study shows that weighting factor is unaffected by room or cooling air temperatures, and the weighting factors of face, chest and back are almost the same, which is different from the results reported by Li [4] or Zhang [3]. The discrepancies may be due to the differences below.

First one is the analyzing method. Li applied multiple linear regression to derive weighting factor, which could result in unreasonable results for the problem of collinearity and autocorrelation. Second one is the features of local cooling. The chest cooling area included both chest and abdomen in Zhang's study, while chest only in the present study. Weighting factor was studied under single body part cooling in the present study, while under multiple body parts cooling in Li's study. The intensity of the local stimulus was moderate in the present study while extreme in Zhang's study. Third one is the state analyzed. Zhang collected the data under steady and dynamic state together to analyze and the present study shows that the weighting factor under steady state is different from the one under dynamic state.

4.2 Physiological mechanism of the response to local exposure

The relationship between thermal sensation and the load on effector mechanisms has been established successfully in the studies by Fanger [5]. Thermoregulatory reactions to local stimulus are therefore investigated in literatures and compared with the subjective responses obtained in the present study.

Local stimulus has significant effect on whole body thermoregulatory reactions. If only part of the body is stimulated, the same general effects are observed on the whole body reaction as if the stimulus was averaged over the whole body surface [6]. Many studies [7][8][9][10] reported that local cooling could reduce overall physiological strain greatly. Thermoregulation of all body parts are correlated with each other. A person in a warm environment shows little vasoconstriction when putting a hand in cold water; conversely a cold person putting his hands in warm water does not show an increase in hand blood flow [11][12][13].

It can be seen that thermoregulatory reactions to local stimulus are similar to the thermal sensation responses to local cooling obtained in the present study. Thermoregulatory reactions are the possible physiological mechanism of thermal sensation. In addition, some studies [7][9] show that the body's circulatory system can transfer heat from other parts of the body to the zones of local cooling, and this could explain the correlations of thermoregulation reactions and thermal sensations between body parts.

Physiological advantages of face cooling could explain the big influencing factor for face cooling. Not only skin temperature, but also core temperature change with face cooling for the process of breathing. The normal skin temperature of the head is the highest of any body region [14]. The apparent lack of vasoconstrictive innervation in the scalp of the head results in the blood vessels being continuously dilated, even under extreme environmental conditions [15]. The head-neck area is perfused by a rich superficial vascular supply. The physiological advantages cause the head a good radiator [16] and a high influencing factor for face cooling.

5 Conclusions

The effect of local thermal sensation on overall thermal sensation was studied in the present experiment and the following conclusions can be drawn:

1. A new influencing factor method was proposed based on the fact that local thermal sensations of the uncooled body parts changed with local cooling. The influencing factor and weighting factor of each body part are unaffected by room or cooling air temperatures.

2. The difference on analyzing method, local cooling feature and the state analyzed could result in the difference on weighting factors. Thermoregulatory reactions are the possible physiological mechanism of subjective response to local cooling.

Acknowledgements

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OCA – A New Approach for Evaluating the Environment of Buildings

D. von Kempski

DVK air vitalizing system, Bäckergasse 2, 40213 Düsseldorf, Germany, email: info@dvk.net

Summary: *It is well known that indoor air quality has a great impact on health and behaviour and therefore becomes an economic issue regarding especially health costs and productivity. The existing evaluations of indoor air quality are not sufficiently related to psychological and physiological effects. In order to evaluate the well-being of occupants it is as well important to look at the structure of positive impacts within the air. Therefore a new approach for evaluation is required. The new OCA scale (olfactory comfort awareness) is determining the perception of the hedonic value of the indoor air taking into account the state of mood of the occupant.*

Keywords: *Olfaction, Awareness, Hedonic, Perception, Mood, Well-Being, PANAS*
Category: Human responses to IAQ

1 Introduction

The subjective well-being of room occupants is difficult to address comprehensively by measurements and standards. The traditional approach to creating good indoor air quality involves removing pollution loads and addressing thermal comfort by means of standards. This approach is now viewed as incomplete. The dissatisfaction rate resulting from the subjective perception of indoor air is a key reason for absenteeism and loss of productivity. The indoor air is perceived as positive or negative depending on whether the room occupants feel that the air is artificial or whether they accept the air as 'natural'. Most by a perception of artificial indoor air. These complaints mostly stem from the inadequate harmonization of olfactory and thermal comfort. The elimination of negative substances in the air typically also results in the elimination of any positive substances. Air that is perceived to be natural and fresh is perceived in this manner because of the presence of positive olfactory substances, which can be found in natural environments, these facts are determining the hedonic value [1].

2 Olfactory Comfort Awareness Scale

The question raised is: When do people really feel extremely well? When is the indoor air perceived as extremely pleasant? These are rated as +10 (extremely pleasant) on the OCA scale (Table 1). The OCA Scale will determine the positive and the negative hedonic value of the indoor air based on the perception of the indoor air either by the untrained room occupants (naïve participants) or evaluated by a sniff team (trained panel). The OCA hedonic scale will be extended in comparison to the VDI 3282 Part 2 pleasantness scale, which is based on a scale of +4 to –4, and the Meilgaard [2] Intensity Scale, which is based on 1-7. The OCA reaches from +10 "extremely pleasant" through 0 "neutral" to –10 "extremely unpleasant". +1 to +4 indicate only an unidentified perception. At +5/+6 the pleasantness will be of a cognitive nature and enhances the well-being. Any value above +6 will lead to a complete awareness of an additional increase in perceived pleasantness reaching extreme pleasantness at +10. 0 to –10 OCA should ideally correlate with Fangers 0 to 10 Decipol. 0 Decipol should be regarded as the neutral air with no positive or negative olfactory impact, suggesting that all malodors /negative olfactory substances have been eliminated and should be rated as neither pleasant nor unpleasant. At the neutral point people are ambiguous towards the indoor air.

Table 1. OCA Scale

10	Extremely pleasant
9	Good
8	Positive
7	Pleasant
6	Noticeably pleasant
5	Moderately pleasant
4	Slightly pleasant
3	Moderately detectable
2	Slightly detectable
1	Barely detectable
0	Neutral
-1	Barely detectable
-2	Slightly detectable
-3	Moderately detectable
-4	Slightly unpleasant
-5	Moderately unpleasant
-6	Noticeably unpleasant
-7	Unpleasant
-8	Negative
-9	Bad
-10	Extremely unpleasant

3 Hedonic Psychology and PANAS

Hedonic Psychology plays a more and more important role with respect to the well-being. Depending on the perception of the hedonic value of the environment the well-being of occupants will be either enhanced or diminished, which is an important factor for their productivity and health. Well-being defines hedonic psychology as the study of what makes experiences and life pleasant or unpleasant. Hedonic psychology therefore covers pleasure and pain, interest and boredom, joy and sorrow, satisfaction and dissatisfaction [3]. This reflects in the PANAScale. The PANAScale is designed to measure Positive and Negative Affect. These can be defined as follows: Positive Affect (PA) reflects the extent to which a person feels enthusiastic, active, and alert. HIGH PA is a state of high energy, full concentration, and pleasurable engagement LOW PA is characterized by sadness and lethargy. Negative Affect (NA) is a general dimension of subjective distress and unpleasurable engagement that subsumes a wide variety of aversive mood states. HIGH NA is associated with anger, contempt, disgust, guilt, fear, and nervousness. LOW NA is characterized as by a state of calmness and serenity[4]. Affective or pleasurable appreciation is not new to us since affective components have an influence on our daily life's decisions and action. PANAS focuses on mood valence and therefore a useful tool for evaluating indoor air quality as the PANAScale is used as well as a tool in the motivation psychology. [5]. In consideration to the fact that air quality has a great impact on well-being, the mood valence is an indicator for the quality of air and shows the importance for adjusting the environmental measurements of indoor air to the prevalent psychological concept of affect. The evaluation of well-being incorporates the mood valence as it is specified in PANAS and which is expressed in the OCA Scale is a necessary new approach for determining the environment in a building.

4 Interaction

The perception of olfactory stimuli is dominated by a hedonic dimension (pleasantness-unpleasantness) which is responsible for our mood or change in mood. Our limbic system, which is responsible for our emotions, is always operating if we want it or not. We use the hedonic characteristics of olfactory perception to learn more about the neural correlates of emotional processing in humans. The interaction between odor, temperature and humidity is frequently being neglected in the planning of buildings. Nimmermark [6] confirms in his doctoral thesis that odor with the variables temperature, humidity and dust can change significantly as a change of temperature and humidity leads to a change in emissions. This shows quite clearly that thermal and olfactory comfort must be evaluated on equal terms. Hyttinen [7] found temporary emission peaks when the moisture rapidly increased, in relation to dust from air filters.

5 Sensitivity and adaptation

The sensory quality of the indoor environment is determined significantly by the presence of the olfactory substances which are in the ambient air. Anderson [8] found significant correlations between subjective reports of the pleasantness and unpleasantness of odors and the strength of activation in areas of the orbitofrontal cortex, suggest that odor plays a major role in the perception of ambient air. Dalton [9] looked into the sensitivity to odors and found that long-term or repeated exposure to an odorant typically leads to a decrease of sensitivity to that odorant. Studies suggest that our brain and our nervous system may react to odorants in such low concentrations that one is not conscious of it [10]. This might partially explain why odor has been neglected within the indoor environment.

6 Threshold

Van Harreveld [11] pointed out that a remarkable volume of published data from the last century exists on odor-detection thresholds for compounds but that unfortunately the difference in the results are very considerable. Van Gemert [12] and Devos [13] published compilations of odor thresholds which show ranges of several orders of magnitude.

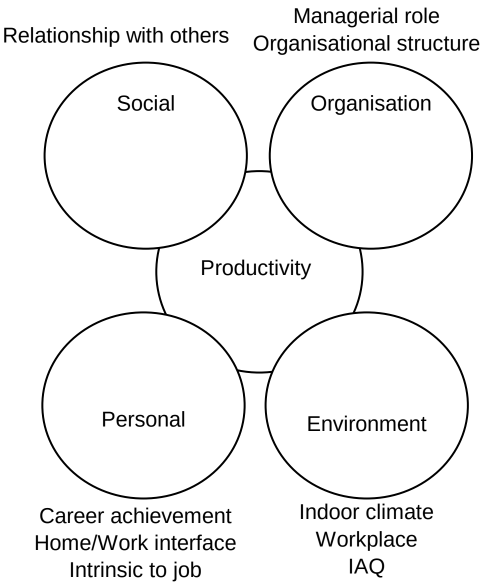
7 Measurements – Olfactometry

Olfactometry was taken out of academic research and was drawn into the arena of environmental management of odors. Standardisation was a logical next step. A number of standards were the consequence such as the German VDI 3881. Unfortunately this standard failed to address the “significant operational variables that had been accurately identified by Dravnieks”[14]. It is preferable to rely on quantitative measurements of odor based on measurement of emissions, dispersion modelling to define exposure and criteria derived from dose effect studies to define a level where no reasonable cause for annoyance exists. But this does not take into account the goal of fostering well-being. New units have been created such as the EROM (European Reference Odor Mass) defined as being just detectable when evaporated into 1 m^3 of neutral gas, as equivalent to 123 μn-butanol which is equivalent to 1 ou_E/m^3 = 40ppm/v. This method for outside odor concentration measurement is now available in the European Standard EN 13725[15]. Olfactometry with an olfactometer certainly has its place in some applications but for the definition of human perception of the hedonic odor tone within the indoor air olfactometry is not sufficient to account for the sensitivity of the human nose.

8 Productivity

There are a lot of definitions of productivity but the simplest is: productivity = the ratio of output to input. [16]. The economics of mood does not purport to replace the performance of a building and energy consumption but instead to complement it with broader measures of well-being of the occupants. The economics of mood assesses welfare by combining economists and psychologists' technique, and relies on more expansive notions of utility then does conventional economics. Therefore it is necessary to address the well-being of occupants in order to secure a high productivity. The key approach towards productivity is to invest in employees in order to enhance their performance and increase their productivity and reduce the absenteeism. The creation of a productive environment demands a healthy building which is expressed in a pollution free air, a thermal comfort according to the activity and the clothing and an olfactory comfort resulting in the perception of "natural" and fresh air. Furthermore a holistic approach towards a multisensory environment should be adopted in order to secure a complete hedonic perceived environment. In addition to the environmental factors, factors like social, personal and organisational play as well a major role. Therefore the interaction of the hedonic value and the psychological factors are indispensable. (Fig. 1) [17]

FIG. 1 Factors which affect productivity



Improving the indoor environment will provide a high return of investment through productivity gains, and health savings. The benefit of improved indoor environment are improved productivity, increased profits, greater employee-customer-visitor health and satisfaction, and reduced health costs. The potential productivity benefits of improved indoor environment are so large that the opportunity cannot be ignored. There are indirect, long term, and social benefits [18].

9 Silent Crisis

With the globalisation and the changing of handling Real Estate other demands have to be met in order to create an added value for buildings. Vacancies dominate the market and only a competitive advantage brings the necessary return of investment. Buildings with a low standard are not very likely to find tenants or if they have tenants the economic efficiency is audited since there is a presumption of loss of productivity and absenteeism. All this might lead to economic losses or even insolvency. Employees are the biggest expense factor in a company and therefore these human resource aspects are very important for the solvency of a company. Banks are going nowadays as far as to look into these aspects in order to reveal the so called "hidden costs", which have a significant impact in terms of solvency and high interest rates. Therefore an evaluation of buildings including the perception of indoor air and the environment of the occupants is necessary. The comparison of investment, sustainability and human resource costs will affect the market in future. Chen [19] found out that there is a strong awareness and growing concern over the "silent crises" of IAQ, and its potential to cause large industry losses. The source of these losses include both direct costs to insurers from paying health insurance and professional liability claims, as well as the cost of litigation.

10 Discussion

In order to fine tune the measurement of the indoor air quality, it is necessary to take into account the influence of the hedonic value on room occupants. Essentially, this hedonic value affects the well-being of the room occupants.

In order to understand olfactory comfort, we have to look into different psychological, neurological, physiological and aromachological aspects. Our sense of smell lets us explore our chemical environment. Therefore the perception of an odor will determine our reaction - approach or avoidance, positive or negative - depending on the type and concentration of the odor. Only a small amount of what we perceive passes through our consciousness and sense of smell - a factor of 10^{-5} [20]. The structure of mood can be represented by two orthogonal factors, which are called Positive Affect (PA) and Negative Affect (NA) and was developed into the PANAS (Positive and Negative Affect Schedule)[21]. Furthermore the hedonic perception is not only encompassing the sense of olfaction but as well all the other senses.

For the estimation of the hedonic perception it is necessary to implement a new scale, the olfactory comfort awareness scale OCA. In comparison to the Decipol-scale, this scale takes into account the perception of pleasantness of the room occupants in relation to the indoor air. 0 to –10 OCA should ideally correlate with Fangers 0 to 10 Decipol.

11 Results

The OCA scale allows specifying the increase in well-being and provides a standard for the perception of indoor air quality. It also intends to increase the awareness of important issues such as the positive hedonic values and their scope for improvement. The relationship between the Fanger Decipol-scale and the OCA-scale needs further research for validation. Theoretically, the OCA scale is consistent with Fanger's established Decipol scales in terms of negative impact. However, limitations to the OCA scale - similar to those of Fanger's Decipol scale - are that it is difficult for untrained room occupants to evaluate their perception of comfort and relate it to a numerical measurement. Further research, however, must include which effect variables such as humidity, air change and temperature have on the perception of the hedonic tone.

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Influence of Carbon-dioxide Pollutant on Human Well-being and Work Intensity

L. Kajtár[1], L. Herczeg[1], E. Láng[1], T. Hrustinszky[1] and L. Bánhidi[1]

Budapest University of Technology and Economics, Dept. of Building Service Engineering,
3. Mügyetem rkp., 1111 Budapest, Hungary email: kajtar@epgep.bme.hu http://host.epgep.bme.hu

Summary: *The goal of the present study was to examine the influence of CO_2 concentration in the air of indoor spaces on human well-being and intensity of mental work In the present paper two series of experiments are presented. In the laboratory measurements we set the following CO_2 concentrations: 600, 1500, 2500, 3000, 4000 and 5000 ppm. Microclimatic parameters (CO_2 concentration, temperature and relative humidity of the air, surface temperature of walls) were measured. Well-being of subjects has been evaluated with the aid of subjective scales, physiological variables were recorded and mental performance of subjects was measured by a standard test. Thus, the obtained results are related to the effects of CO_2. Results revealed that human well-being as well as capacity to concentrate attention are declining when CO_2 concentration in the air is increasing up to 3000 ppm.*

Keywords: *Air quality; Carbon dioxide; IAQ assessment; Measurement technique; Mental work*
Category: *Human responses to IAQ*

1 Introduction

The comfort in closed spaces is usually understood as thermal, air quality, acoustical and illumination engineering comfort. In the air-conditioning of comfort spaces the primary task is to provide a pleasant indoor microclimate for the people staying in the room. In addition to thermal comfort, air quality is also regulated by international requirements and standards. In the occupied zone a sufficient amount of fresh air of appropriate quality must be provided for the people staying in the room. Hungarian technical regulations do not fully cover these aspects yet—hence the complaints frequently heard from employees working in air-conditioned spaces: the air has an unpleasant 'smell', they experience 'lack of air' or perhaps have headaches. Among pollutants carbon dioxide, a by-product of the human metabolism, is regarded as one of the key factors. The carbon dioxide content of exhaled air is higher than that of the outdoor air, leading to an increase in the carbon dioxide concentration in the closed space. CO_2 concentration influences human well-being. In closed spaces the allowed CO_2 concentration may be ensured by supplying the adequate amount of fresh air. The exact volume of fresh air varies in Hungarian and international literature, ranging from 20 to 120 m^3/person. This is also a matter of economic efficiency as the volume flow of fresh air has an impact on the energy use of the air conditioning system [1], [5], [6].

2 Methods

In the framework of our research we investigated the impact of carbon dioxide concentration on well-being and performance in the office. In the laboratory measurements we set the following CO_2 concentrations: 600, 1500, 2500, 3000, 4000 and 5000 ppm. The laboratory measuring room contained two carbon dioxide sources: two main measuring subjects and carbon-dioxide, suitable for inhaling, fed from a bottle [3]. The circuit diagram for the laboratory measurements is shown in Figure 1.

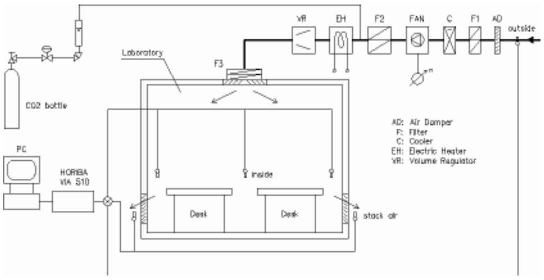

Fig. 1. Circuit diagram of the laboratory measurements

The carbon dioxide was fed into the measuring room mixed with 120 m^3/h fresh air (60 m^3/h, person). In the measurements the carbon dioxide concentration had to be kept at a constant level therefore the feeding valve had to be set accordingly. The share of carbon dioxide sources is contained in Table 1. The carbon dioxide concentration of outdoor air was 360 ppm.

Table 1. Carbon dioxide sources in the measuring room

Measuring room CO_2 ppm	Source of carbon dioxide		Share human/total; %
	Total D k, ppm	Human D k, ppm	
600	240	240	100
1500	1140	240	21,0
2500	2140	240	11,2
3000	2640	240	9,1
4000	3640	240	6,6
5000	4640	240	5,2

Carbon dioxide fed from the bottle was a gas of 99,995 V% cleanness, suitable for inhaling. Owing to their slight share other pollutants in the carbon dioxide gas ($O_2 \leq 25$ vpm, $N_2 \leq 25$ vpm, HC ≤ 1 vpm, $CO_2 \leq 1$ vpm, $H_2O < 5$ vpm) did not influence the results of the measurements. The pressure reducer and other armatures did not pollute the carbon dioxide gas as their use is permitted in case of a gas of greater cleanness (99,998 V%).

In the present paper two series of experiments are presented:

1. series of experiments carried out in 2001,
2. series of experiments carried out in 2002.

Both series of experiments were conducted in a laboratory constructed for the above purposes in the Building Service Department of the Budapest University of Technology and Economics. Inodorous air of appropriate cleanliness, thermal comfort, as well as appropriate acoustic conditions have to be ensured in the laboratory.

3 Subjects and procedures

In the laboratory measurements a pleasant thermal, acoustic and illumination technology comfort was provided to ensure that human well-being is only impacted by air quality (carbon dioxide gas).

A pleasant thermal comfort was ensured for all live subjects by regulating the air temperature and individually selecting the clothing. The sound level in the measuring room was 36,6-37,0 dB(A).

The set carbon dioxide concentrations were unknown to the subjects.

The number of subjects was defined through an empirical way. The 10 subjects were enough because significant differences could be found among the results.

1st series of experiments:

Ten subjects participated in the study (5 males and 5 females, mean age=22.5 years). Each subject participated in four experimental sessions with different pre-set CO_2 concentrations (600, 1500, 2500 and 5000 ppm). Sessions succeeded each other in the following manner: session N°l (1500 ppm CO_2), N°2 (2500 ppm), N°3 (600 ppm), N°4 (5000 ppm). Each session lasted for four hours and consisted of 2x70-minute mental work periods. The mental work involved the reading of a text manipulated for this purpose and the search for typographic errors. Performance of subjects was characterised by the number of rows read by the subjects (quantity aspect), and the percentage of misspelled words found by them (quality aspect). Prior to and following work periods questionnaires were to be filled in for evaluating subjective comfort and well-being, as well as physiological tests were carried out and measurements of skin temperature were taken.

2nd series of experiments

The same measuring stand was used as in the 1st set of experiments. Ten subjects participated in the study (4 males and 6 females, mean age=21.3 ± 1.5 years). Each subject participated in 4 experimental sessions with different pre-set CO_2 concentrations (600, 1500, 3000 and 4000 ppm). Sessions succeeded each other in the following manner: session N°l (1500ppm CO_2), N°2 (3000ppm), N°3 (600 ppm), N°4 (4000 ppm). Two sessions (with 1500 and with 4000 ppm CO_2 concentration) consisted of 2x70minute mental work periods. Two sessions (with 3000 and with 600 ppm CO_2 concentration) consisted of 3x70minute mental work periods. Subjects had to perform a mental work slightly different from the mental work performed in the 1st series of experiments. Prior to and following work periods questionnaires were to be filled in for evaluating subjective comfort and well-being, as well as physiological tests were carried out and measures of skin temperature were taken.

The exposure time was longer only for two levels of CO_2 (600 and 3000 ppm). Periods with corresponding exposure time were compared. The measuring stand was the same as in the first session (Figure 1).

4. Measurement of objective microclimatic characteristics

The following objective microclimatic parameters were examined:

- Measurements of CO_2 concentration
- PMV (Predicted Mean Vote), PPD (Predicted Percentage of Dissatisfied) values.
- Temperature of the supply air.
- The surface temperature of the four side walls of the floor and the ceiling.

5 Evaluation of subjective comfort

The following parameters were examined in the evaluation of subjective comfort:

- Fanger scale: subjects had to report whether they find air quality acceptable or unacceptable by marking +1 (clearly acceptable) and -1 (clearly unacceptable) on a scale.
- Hedonic scale: subjects' comfort was measured in the range of pleasant *(5)* and unbearable (1).
- Air Quality scale: analogue scale for evaluation of freshness of the air. The endpoints of the scale were fresh and very unpleasant sensation.
- In the examination of human well-being changes in subjects' freshness, tiredness and concentration were surveyed with upgraded scales.

The above measurements were carried out in each session at the beginning, at the end, and in the breaks between the 70 minutes working periods. These way questionnaires were filled in three times during sessions in the first series of experiments. In the second series of experiments questionnaires were filled in three times during session N°l (1500 ppm CO_2), and session N°4 (4000 ppm CO_2) consisting of two working periods, while during sessions consisting of three working periods (session N°2 with 3000 ppm CO_2, and session N°3 with 600 ppm CO_2) measurements were carried out four times.

The following measurements were carried out at the beginning and at the end of each session:

- Subjective evaluation of surface temperature of human skin: subjective thermal comfort was recorded with the help of a 7-grade scale (very hot: -3; pleasant: 0; very cold: -3) at 5 different points: forehead, nose, chest, right hand and left hand.

Subjective evaluation of general thermal comfort: subjects' thermal comfort was examined using an analogue scale.

6 Study of objective physiological parameters for humans.

The following physiological and psycho-physiological parameters were measured and computed: systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse rate, heart period (HP) beat by beat, spectral components of the power spectra of heart period variance (HPV), skin temperature. During each session SBP, DBP, pulse rate has been taken at the beginning and at the end of the session, as well as in the pause between two working periods by the aid of a wrist digital sphygmomanometer. The surface temperature of the human skin was measured with a surface thermometer at the beginning and at the end of the session (measured points: forehead, nose, chest and both hands).

Spectral analysis of heart period variance (HPV) is extensively used as a mental effort monitor in the field of ergonomics and psychophysiology [4].

It was hypothesized that in unfavourable environmental conditions such as higher concentration of CO_2 in the air mental task might request more mental effort.

To assess the actual balance of the autonomic nervous system on the basis of spectral analysis of heart period variance (HPV) an integrated system (ISAX) has been developed and validated.

In the second series of experiment ISAX system has been applied to 5 subjects.

7 Statistical analysis

Statistical analysis on the above variables was performed using SPSS 10.00 for Windows program package. Differences between sessions, as well as changes appearing during the same session (differences between measurements of the same session) were revealed using analysis of variance with repeated measurements and appropriate contrasts. Differences were considered significant when $p<0.05$ [2].

8 Results of the first series of experiments

8.1 Results concerning evaluation of subjective comfort

Differences between sessions: *Fanger scale:*

When comparing corresponding measurements of different sessions the analysis of variance revealed significant differences between sessions with 600 ppm CO_2 and 5000 ppm CO_2 already at the beginning of the sessions: subjects evaluated air quality less acceptable during session with 5000 ppm CO_2 than with 600 ppm CO_2. Between session with 5000 ppm CO_2 and session with 1500 ppm CO_2 a significant difference appeared only at the end of sessions, that is after 140 minutes: subjects evaluated air quality less acceptable during session with 5000 ppm CO_2 than with 1500 ppm CO_2.

Similar results were found with the *Air Quality scale.*

In the case of *Hedonic* scale subjects evaluated air with 600 and 1500 ppm CO_2 significantly less unpleasant than air with 5000 ppm CO_2.

Concerning *freshness, tiredness* scales difference between the first and the last measurements of the same session was the greatest in the case of session with 5000 ppm CO_2,showing that subjects became the most exhausted in this session. In this respect the difference between session with 5000 ppm CO_2 concentration and session with 600 ppm CO_2 concentration reached the level of significance.

8.2 Results concerning mental workload

Subjects' performance characterized by the number of rows read during the session (quantity aspect), as well as the percentage of mistakes found by the subjects (quality aspect of performance) was not significantly impacted by the degree of CO2 concentration.

8.3 Summary of results obtained in the 1st series ofexperiments

Significant differences were obtained concerning subjective evaluation of air quality and human well-being between work periods with 600 ppm and with 5000 ppm CO_2 concentration showing a decline of well-being when CO_2 concentration in the air reaches 5000 ppm. At the same time no significant differences were found concerning mental performance between work periods at different CO_2 concentrations. HPV analysis (MF component) revealed, however, that a mental task required more mental effort under 5000ppm CO_2 as compared to 600 ppm.

Moreover, the respiratory component of HPV reflected an increase in respiratory volume and respiratory frequency at 5000 ppm CO_2 concentration.

9 Results of the second series of experiments

9.1 Results concerning evaluation of subjective comfort

Changes appearing during the same session: *Fanger scale:*

The analysis of variance with repeated measurements revealed significant differences between measurements of the same session. Subjects evaluated air quality less acceptable at the end of the session than at the beginning of the same session. In the case of session with 600 ppm CO_2 subjects evaluated air quality less acceptable only after the second working period while subjects' well-being already declined following the first 70-minute working period during other sessions.

Air Quality scale: Similar results were found as in the case of Fanger scale.

Differences between sessions: *Fanger scale:*

When comparing corresponding measurements of different sessions the analysis of variance showed that significant differences appeared between sessions only following the second working period, that is after 140 minutes. Subjects evaluated air with 3000 and 4000 ppm CO_2 significantly less acceptable than air with 600 ppm CO_2. Air with 1500 ppm CO_2 concentration was judged as significantly more acceptable than air with 4000 ppm CO_2.In the case of sessions with 600 and 3000 ppm CO_2 three 70-minute working periods were used. After the third working period ,that is, after 210 minutes air was denoted significantly less acceptable during session with 3000 ppm CO_2 as compared to session with 600 ppm CO_2 (as it was the case already after 140 minutes).

Figure 2. shows the results of measurements with the Fanger scale.

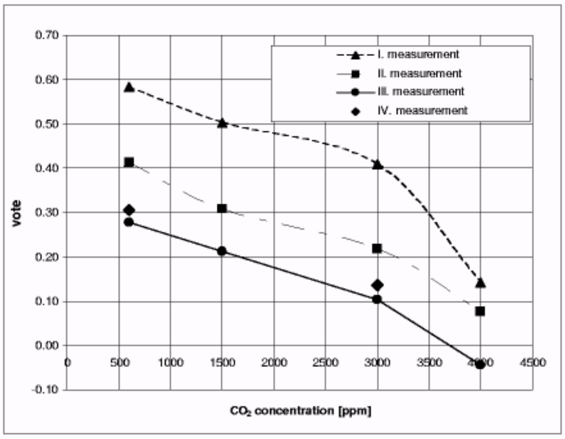

Fig. 2. Results of measurements with the Fanger scale

Air Quality scale:

Similar results were found as in the case of the Fanger scale, with the only advantage, that after 140 minutes air with 1500 ppm CO_2 concentration was judged as significantly fresher than air with 3000 ppm CO_2 concentration. Figure 3. shows the results of measurements with the Air Quality scale.

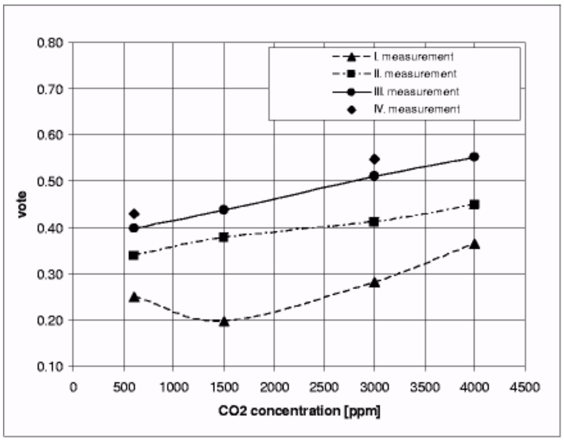

Fig 3. Results of measurement with the Air Quality scale

The analyses of variance performed on scores on *freshness, tiredness* and *concentration* scales revealed significant differences between measurements of the same session in the case of sessions with higher CO_2 concentration than 600 ppm showing that subjects get more tired, became less fresh, and their capability to focus their attention was declining in the course of the session. Concerning scores on *freshness* and *tiredness* scales when comparing corresponding measurements of different sessions the analysis of variance showed that significant differences appeared between sessions with 600 and 3000 ppm CO_2 concentration only following the third working period, that is after 210 minutes. Subjects became more exhausted at the end of session with 3000 ppm CO_2 concentration than at the end of session with 600 ppm CO_2 concentration.

9.2 Results concerning mental workload

As it was mentioned in the paragraph on Methods in the 2nd series of experiments a different text was used. In the 1st series neither the number of rows read by the subjects, nor the percentage of mistakes found by the subjects were influenced by the degree of CO_2 concentration. Therefore we decided to use a more difficult text in the 2nd series of experiments.

Subjects' performance characterised by the number of rows read during the session (quantity aspect) was not significantly impacted by the degree of CO_2 concentration. Concerning this variable 'time effect' (learning) was found: subjects' performance related to the quantity of read rows increased from the first to the last session. The quality aspect of performance (percentage of mistakes found by the subjects), however, proved to be more sensitive to the concentration of CO_2. The analysis of variance revealed that during the second 70-min working period the percentage of mistakes found by the subjects was significantly higher in session with 600 ppm CO_2 than in the corresponding working period of session with 4000 ppm CO_2 concentration. Moreover, during the third 70-min working period of session with 600 ppm CO_2 the percentage of mistakes found by the subjects was almost significantly higher than in the corresponding period of session with 3000 ppm CO_2 concentration. In this case the number of rows read by the subjects in the session with 600 ppm CO_2 also exceeded the number of rows read in the corresponding period of session with 3000 CO_2 concentration. That means that the third working period with 600 ppm CO_2 proved to be more advantageous for both aspects of mental performance than 3000 ppm CO_2 concentration (

The quality aspect of mental work expresses the ability to concentrate attention. It seems that human well-being as well as the capacity to concentrate attention decline when CO_2 concentration increases up to 3000 ppm.

9.3 Results concerning physiological parameters

The analysis of variance did not reveal any significant effect of CO_2 concentration in air (in the range of 600 to 4000 ppm) on the systolic blood pressure (SBP), and diastolic blood pressure (DBP). In these experiments these parameters were not sensitive enough to show the impact of CO_2 concentration in air under 4000 ppm.

Data obtained and processed by the ISAX system

The analysis of variance revealed that heart periods (HP) (time elapsed between two heart beats) increased during each session from the beginning to the end. This means that the pulse rate decreased from the beginning to the end of each session. This is a typical phenomenon when subjects are sitting quietly for hours. Concentration of CO_2 had no impact on HP-s. Absolute and relative values of MF (mid-frequency component) of heart period variability (HPV) are used to measure mental effort requested by the task. The less the value of the MF component the more pronounced the effort invested by the subjects along the mental tasks. As it was mentioned in the paragraph on Methods MF component of HPV was proposed to be used as an objective psycho-physiological measure of actual mental effort invested by the subjects. As a tendency the lowest values of the MF component could be seen during the session with 4000 ppm CO_2 while the highest values of MF component were obtained in session with 600 ppm CO_2. Concerning HF component just the contrary was the case. HF component reflects the frequency of respiration and might reflect the volume of respiration. A significant difference was revealed between session with 600 and session with 4000 ppm CO_2 by the analysis of variance performed on MF/HF ratio as well as on relative values of MF and HF components. Increase of HF component indicates increased volume of respiration in session with 4000 ppm CO_2 concentration. Decrease of MF component and MF/HF ratio indicates more effort invested by the subject in session with 4000 ppm CO_2 concentration. This is in accordance with the declining ability to concentrate attention in session with 4000 ppm CO_2 as shown by the scores on freshness and tiredness scales as well as by the decrease of mental performance.

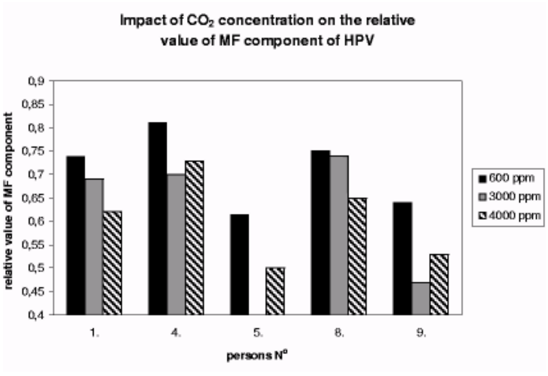

Fig. 4. Impact of CO_2 concentration on the $MF_{relative}$ of HPV in 5 subjects.

Figure 4. shows that $MF_{relative}$ of each subject reaches a higher value in session with 600 ppm CO_2 concentration than in session with 4000 ppm CO_2.

9.4 Summary of results obtained in the 2nd series of experiments

Significant differences were obtained concerning subjective evaluation of air quality and human well-being between work periods with 600 ppm and with 4000 ppm CO_2 concentration after 140 minutes. After 210 minutes significant differences appeared between work periods with 600 and 3000 ppm CO_2 concentration showing a decline in human well-being in closed spaces with 3000 ppm CO_2 concentration in the air. The same was true for results concerning mental workload: during the second 70-min working period the percentage of mistakes found by the subjects was significantly higher in session with 600 ppm CO_2 than in the corresponding working period of session with 4000 ppm CO_2 concentration. Concerning the third 70-min working period, session with 600 ppm CO_2 proved to be more advantageous for both aspects (quantity and quality aspects) of mental performance than 3000 ppm CO_2 concentration. These results are in accordance with the objective psycho-physiological measurements of actual mental effort derived from HPV spectra.

10 Summary and conclusions

A specific laboratory and measuring stand was constructed to investigate the impact of CO_2 concentration in the air on human well-being and office work intensity, and to determine the necessary fresh air demand.

It was shown that subjects evaluated air quality less acceptable, more unpleasant and became more exhausted when CO_2 concentration increased up to 3000 ppm. 3000 ppm CO_2 concentration in the air proved to be less advantageous for mental performance than 600 ppm. Several physiological measures (spectral components of HPV) show that the mental task required more effort from the subjects when CO_2 concentration in the air reached 3000 ppm.

It was shown that human well-being as well as the capacity to concentrate attention decline when subjects spend 2 to 3 hours in a closed space with 3000 ppm or higher CO_2 concentration in the air.

In the literature we can find requirements about good IAQ and human well-being (Pettenkofer number: 1000 ppm CO_2 concentration). We evaluated when can find a decline in the human well-being with CO_2 pollutant.

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Mitigation of Strong Individual Complaints Related to the Indoor Environment

J.L. Leyten [1] and L.P. Hulsman[1]

[1]BBA Boerstra Environmental Consultancy, P.O. Box 774, 3000 AT Rotterdam, The Netherlands
email: joeleijten@planet.nl http://www.binnenmilieu.nl

Summary: *Occasionally an individual employee has much more physical symptoms he/she attributes to the building they work in than colleagues. At the same time working conditions comply with accepted guidelines. This often ends in a stalemate between the employer who is convinced that the building is alright and that the employee is exaggerating, even malingering, and the employee who feels unrecognised. Such a situation may end in discharge or even disability. This paper proposes a pragmatic procedure to avoid this stalemate which comes down to finding a solution without focussing primarily on who is right or wrong. A case is presented.*

Keywords: *individual complaints, multiple chemical sensitivity, mitigation, psychological factors*
Category*: Sick Building Syndrome (SBS)*

1 Introduction

When in an office building there are complaints about the indoor environment there is usually a larger group of employees who report complaints. Usually these complaints are not so strong that they are very detrimental to health or the productivity of these employees. Apart from that it happens that individual employees report very strong health complaints that they themselves attribute to their stay in the building. Often these employees have a hard time to get recognition and proper mitigation for their complaints. Both the employer and IEQ experts tend not to take these employees seriously. In many cases such a situation ends in a stalemate between the employer who is convinced that the building is alright and that the employee is exaggerating or even malingering, and the employee who feels unrecognised by the employer and the expert(s). Often such a situation ends in discharge or even disability, if the social security system provides for that option. This paper proposes a procedure to avoid this stalemate.

The strong building related complaints that some individuals report vary from heavy headaches to respiratory problems and allergic complaints. These complaints start after entering the building and often diminish or disappear after working hours and especially in the weekend and on holidays. In some cases the individual reports that these complaints did not occur in a previous building or in the same building before a refurbishment. Medical examination often shows no clear diagnosis. Sometimes the diagnosis of multiple chemical sensitivity (MCS) is suggested, predominantly in the USA, but its scientific validity is doubtful [1], [2]. Furthermore a technical investigation of the building or the workplace shows nothing extraordinary in most of the cases. The indoor environment complies with accepted standards and guidelines. In this situation it is understandable that the employer concludes that the complaints are of psychological origin. Experts also tend to draw such a conclusion. A search for publications giving suggestions for dealing with strong individual complaints gave only one serious result: [1]. This publication suggests that when medical tests and indoor measurements show no causes of strong individual complaints, the conclusion to psychological causes may be drawn. But these conclusions to psychological causes are unfounded for the following reasons.

First of all [3], a literature review, concludes that the thesis that IEQ complaints in office buildings may be totally or predominantly caused by psychological factors has to be rejected. Specifically it turns out that individual differences in sensitivity to the indoor environment are of medical rather than of psychological nature. In [4] subjects performed office work for four hours in a normal well ventilated work space. During some sessions pollution from used carpet was added to the supply air. The pollution was non-odorous and the office room was never changed, so the subjects did not know in which condition they were. Before the experiment the subjects were interviewed about their previous experience in office buildings. On basis of this they were classified into two groups: those who so far had experienced little or no complaints working in office buildings (the non-sensitive) and those who had experienced complaints doing so (the over-sensitive). Among the dependent variables were physical complaints. In the condition without the artificial pollution both groups had little complaints. In the condition with the artificial pollution the non-sensitive still had little complaints, but the over-sensitive did have statistically significant more complaints. Exactly the same results were reported for a replication of this part of the study with other pollution sources, among them new CRT monitors [5]. Because in both studies the subjects did not know in which condition they were, the effect on the over-sensitive must have been caused by the artificially added pollution. This indicates that the over-sensitive have some physical over-sensitivity rather than a tendency to suggest complaints to themselves in certain environments. [6] investigated an office building with marked indoor air complaints. The occupants were classified as non-sensitive or over-sensitive. Both groups were asked to keep a diary of indoor air complaints 5 times a day during one week. The results show that the non-sensitive had far less complaints than the over-sensitive, but that the fluctuations of the complaints over time show a similar pattern. This also indicates that the complaints of the over-sensitive are caused by the environment rather then by self-suggestion.

Secondly the impact of the indoor environment on health is much more complicated than accepted standards and guidelines suggest. Therefore compliance with standards and guidelines cannot guarantee that there will be no complaints [2], [7]. Furthermore conventional methods to investigate the indoor environment tend to miss significant problems in the indoor environment because they focus on establishing whether the environment complies with standards and guidelines instead of forming and testing diagnoses [8]. Recent developments in IEQ science have shown that traditionally used measurements like VOC, TVOC, particulate matter and microbially produced matter [9], and in many cases also measurements of thermal comfort, ventilation and CO_2 are not associated with health effects. This need not be a surprise at all. Some field studies show that higher TVOC concentrations are associated with lower level of health effects, e.g. [10]. Recent insight in indoor air chemistry [11], [5] make this fully understandable: VOC´s themselves are relatively harmless but they react with ozone to form more irritating products, that are not measured by traditional methods. Other field studies show that higher CO_2 levels are associated with lower levels of health effects, e.g. [12], [13]. This is explained by the fact that generally naturally ventilated buildings show higher CO_2 levels but at the same time less health symptoms. This also shows that CO_2 levels as such are no indicators of indoor air quality and that low CO_2 levels may coexist with high levels of health effects. Although generally higher ventilation is associated with lower health effects, this need not be so in individual buildings. [14] shows that in the case of polluted air intake filters increased ventilation causes lower indoor air quality and [5] shows that in the case of indoor pollution sources susceptible to oxidation processes, increased ventilation does not improve indoor air quality as much as theoretically expected because these sources increase emissions with higher ventilation because of higher ozone supply. So ventilation rates that comply with standards may coexist with higher levels of health effects. All these examples show that it is perfectly possible that the indoor environment is flawed and causes health effects and at the same time measurements comply with standards. Concluding to psychological causes because measurements comply with standards is therefore not valid.

While indoor environmental measurements show little association with occupant complaints in field studies, risk factors do. [15] and [16] therefore propose to base diagnoses of occupant complaints on risk factors present in the building and the workspace rather than on measurements. A building or workstation characteristic is considered a risk factor if it simultaneously complies with all of the following criteria:

- Field studies show a more or less consistent relation between the presence of the risk factor and higher occupant complaint rates.
- Although the causal mechanism need not be known in detail, there should in principle be a plausible causal explanation, based on established existing knowledge, for the relation between the presence of the risk factor and occupant complaints.
- Removal of the risk factor should not by itself lead to higher risks or other complaints.

Important risk factors are:

- sealed windows
- lack of occupant temperature control
- all air heating with no radiant heating
- mechanical cooling of supply air
- humidification of supply air
- recirculation of exhaust air into the supply air
- rotary heat exchangers
- printers or copiers in the workspace
- textile floor covering or other dust reservoirs in the workspace
- larger numbers of occupants per workspace.

This paper proposes that a risk factor approach is also the best approach to deal with strong individual complaints.

Furthermore it is important to realise that the employer and the employee see things from different perspectives. The employer sees a large group of employees in the same building of whom most do not have strong complaints and only one or few who do have strong complaints. It is understandable that the employer tends to see the individual employee and not the working environment as the cause of the complaints. The employee perceives that he or she has more complaints inside the building and less complaints outside. So it is understandable that the employee sees the working environment as the cause of his or her complaints. If both parties hold on to their positions, chances are high that the matter will escalate into a controversy, that the employer will see the employee as a malingerer and that the employee will feel unrecognised by the employer. To get out of this stalemate it is crucial that both parties learn to admit that they are both partly right and partly wrong. The common sense allows attributing phenomena to a single cause, but science tells that reality is often more complicated. In a case like this complaints are caused by the interaction of oversensitivity of the employee and the fact the in the building there are more exposures (of whatever kind) than in other buildings. On the one hand this means that the employee may be so sensitive that, given the characteristics of the building in question, it is not possible to limit exposures enough to take away all complaints. On the other hand the employer should realise that exposures within the building may very well contribute to the employee´s complaints and that measures concerning the building or the workspace which limit exposures may decrease the employee´s complaints. The IEQ expert should explain this to the employer and the employee and commit both parties to this position. If such a commitment is reached, a solution is possible.

2 Proposed procedure

What is needed to reduce strong individual complaints is a procedure that complies with the following conditions:

- It is not assumed that complaints are of psychological origin when measurements of the indoor environment comply with standards and guidelines and no specific medical cause can be found.
- Causes of complaints are sought in risk factors rather than in results of measurements.
- The procedure is directed to finding a pragmatic solution instead of establishing who is right and who is wrong.

Therefore the following procedure is proposed:
Step 1: Take a thorough history of previous workspaces where the employee has worked and of the complaints he or she has had there. Which buildings did it concern, how long did the employee work there, which complaints did he or she have there, why did he or she leave there.
Step 2: Where possible conduct a survey of these previous workspaces to ascertain risk factors. In contrast to measurements these risk factors do give an indication of the exposures that may cause complaints [15], [16]. If accurate data concerning previous buildings are not accessible, than make more coarse categorisations like operable windows vs. sealed windows or natural ventilation vs. air conditioning.
Step 3: Establish if there exists a *prima facie* relation between complaints reported by the employee and the existence of risk factors in the different buildings.
Step 4: Reduce risk factors in the present workspace, especially those which appear to be associated with complaints in the present and previous buildings. Options are:

- Measures focused on the workspace itself, e.g. providing for a single occupant room, providing for occupant temperature control, removing dust reservoirs, removing printers and copiers.
- Measures concerning the HVAC of that particular workspace. With some employees their sensitivity to exposures caused by the HVAC system is so high that they have more disadvantages than benefits from the HVAC system. In that case it can be beneficial to provide for a workspace that is more or less detached from the HVAC system. This may imply shutting of the supply air, the exhaust may be maintained, and providing for an operable window. If the building has mechanical cooling of the supply air, this will not apply anymore to the adjusted room. This need not be a problem. To begin with the internal heat load can be reduced by assigning a room originally meant for two or more occupants to solely the employee in question and to minimise office equipment. The employee can be imformed that prudent use of artificial lighting may help to control temperature. Furthermore it is known that in workspaces with operable windows and no cooling occupants accept higher temperatures than the PMV model predicts [17].
- Measures concerning the HVAC system of the whole building, e.g. stopping or minimising recirculation, stopping or minimising humidification of supply air. The last option may be considered if other employees report similar complaints, albeit on a lower level.

Step 5: If step 4 is not feasible, consider moving the employee to another (part of the) building used by the same employer where there are less risk factors, e.g. a building with natural ventilation or simple mechanical ventilation.

By following a procedure that not aims at establishing who is right or wrong but at arriving at a pragmatic solution both the employer and the employee feel their experience and point of view are recognised and controversy is avoided. To the extent that the employee does not get precisely the situation he or she wants or needs and complaints are not fully taken away, this is expected to be accepted by the employee because it is compensated for by the fact that the employer has given recognition to the employee by refraining from investigations aimed at establishing whether the employee is right or wrong and by consenting in a pragmatic procedure and the measures that follow from that procedure.

3 A case

A female employee has been working for some years in a naturally ventilated Dutch office building heated with radiating panels. There she experiences few complaints. Then she is transferred within the same organisation to a newly built office building with sealed windows, no occupant temperature control, an all air HVAC system and cooling of the supply air. There are SBS symptoms and thermal and indoor air complaints among the occupants of the new building. In this building the specific employee has strong respiratory and eye complaints, comparable to SBS symptoms, but more acute. Medical tests do not give a clear cause. Nor do measurements in the building, they comply with accepted standards. When a history is taken concerning previous buildings it turns out that the employee worked for a previous employer in an air conditioned building with a sealed facade and that she had strong complaints there too. Cooling and lack of occupant control seem to be the main risk factors in this case, but these cannot be taken away within the new building. The present employer also uses a naturally ventilated building in the same city and the employee could perform her task there if she would be transferred. Therefore the IEQ consultant advises the employer to transfer the employee to the naturally ventilated building. The employer follows this advise and since the transferral the employee´s complaints have decreased and she can perform her task well.

4 Conclusion

Strong individual complaints about the indoor environment are generally not of psychological origin or caused by malingering. Furthermore it is entirely possible that the indoor environment complies with accepted standards and is at the same time flawed and causes occupant complaints. Therefore in the case of strong individual complaints measurements of the indoor environment should not be the main approach to the problem and especially they should not be used to determine whether the complaints are justified or not. Such an approach will lead to a stalemate between the employer who feels the complaints to be unjustified and the employee who feels unrecognised. Instead consultants should look for risk factors in the indoor environment of the employee with strong individual complaints. Risk factors that are detected should be taken away or mitigated as much as possible, especially if the individual´s history of complaints in previous buildings points at the same risk factors. By following this approach a stalemate between the employee and the employer is avoided and a solution that satisfies all parties is within reach.

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Sick Building Syndrome (SBS): Prevalence of Symptoms Among Workers of a Sealed Office Building Before and After Changes in Air Conditioning System

Rios JL [1], Boechat JL [1], Freitas T [2], Lapa e Silva JR [1], Aquino Neto FR [2]

[1] Institute of Thoracic Diseases, Clementino Fraga Filho University Hospital,
Federal University of Rio de Janeiro, Brazil
e-mail: jboechat@nitnet.com.br
[2] LAGOA – LADETEC, Organic Chemistry Department, Chemistry Institute,
Federal University of Rio de Janeiro, Brazil

Summary: *To compare the prevalence of symptoms of Sick Building Syndrome (SBS) among office workers, a cross-sectional study was performed, involving workers of a 42-storey sealed office building in Rio de Janeiro, before and after exchange in the heating, ventilation, and air conditioning (HVAC) system. In the first time 967 employees was accessed by a standardized questionnaire and, two years later 742. Some symptoms, like dry throat, lethargy and chest tightness have improved. Changes in air conditioning system, improving the control of indoor pollution, may modify the quality of life of the office workers.*

Keywords: *Sick Building Syndrome, air quality, indoor pollutants, office work*
Category: *Cross-sectional Studies*

1 Introduction

Since the beginning of the Industrial Revolution, the increases in time spent indoors has made the indoor environment more significant for health considerations than the outdoor environment. An increasing number of complains and health effects related to time spent in artificially ventilated buildings, above all in the workplace, have been progressively reported.

The indoor environment affects the occupants, mainly by means of the air. Contaminants agents, whether volatile or in suspension, enter into direct contact with the occupants through the skin and the eyes, nose and lungs mucosae [1].

Sealed buildings with heating, ventilation, and air conditioning (HVAC) systems usually present high pollutant levels due to the low internal /external air exchange rate. Advances in construction technology have led to a greater dependence on synthetic chemical materials. Pollutants emitted to the indoor air have much less opportunity to become diluted than those emitted outdoors. As a result, individuals encounter a broad range of pollutants as they travel through a succession of microenvironments in the course of their daily activities [2]. The symptoms are generally not related to a specific substance but are usually attributable to exposures to a combination of substances or to an individual's increased susceptibility to lower concentrations of contaminants [3].

The set of health problems related to the internal environment of non-industrial, non-residential buildings, the majority of which are office blocks, are denominated building related illnesses (BRI) [4]. The BRI are considered specific when characterized by objective abnormalities under clinical and laboratorial evaluation, with a well-defined causal agent. They are non- specific when they refer to a heterogeneous group of symptoms: respiratory, cutaneous, ocular or even ill defined, such as headache, fatigue and difficulty of concentration, related to the work environment [4][5][6][7]. These non-specific building-related complaints are called Sick Building Syndrome.

In Brazil, as in other tropical countries, there is growing concern with regard to the increasing utilization of HVAC systems in sealed buildings, drawing the attention of researchers from several areas and of the Ministry of Health [5][8][9].

Problems associated with the indoor environment are the most common environmental health issues faced by clinicians, but the factors associated with the perceived indoor air quality (IAQ) are not fully understood. Factors contributing to perceived IAQ include temperature, humidity, odors, air movement and ventilation, and bioaerosol and volatile organic compounds (VOC) contamination [10].

Pollution is known to be one of the main reasons for occupant complaints. The sources of indoor air pollution differ considerably. An exposure may be classified by the way it is generated, by the type of pollutant group present (VOC, fibers), or by location, rate, and pattern of emissions [3].

Concentrations of single pollutants, however, have not been shown to consistently associate with symptoms in observational studies. Researches that attempt to associate occupant symptoms and total VOC (TVOC) levels report inconsistent findings, just like the studies concerning workers symptoms and total suspended particles (TSP) [11].

Various international studies have sought to evaluate the prevalence of BRI symptoms. With the aim of standardising the diagnosis and enabling comparison between different studies, the Royal Society of Health Advisory Group on Sick Building Syndrome (SBS) has developed a standard questionnaire [12].

The aim of this study was to evaluate the association of work-related symptoms, accessed by a standardized questionnaire, of full-time workers from a sealed building before and after changes in the HVAC system, in Rio de Janeiro, a metropolis with hot and humid climate.

2 Methods

Cross-sectional study involving full-time office workers of a sealed 42-storey office building, situated in the downtown area of Rio de Janeiro. The edifice was totally sealed, with HVAC systems without opening windows. All offices were fully carpeted and equipped with fax machines, laser printers, and video terminal displays.

After the authorization of the managers and workers, and the approval of the Ethics Committee of the Federal University of Rio de Janeiro (UFRJ), a self-administered questionnaire, was applied to the workers. The questionnaire was elaborated by The Royal Society of Health Advisory Group on Sick Building Syndrome and addressed questions about environmental comfort, personal well-being, and background information about the sample. The questions about symptoms asked if they had been present in the last 12 months, improvement out of the workplace, and their frequency.

The first evaluation occurred in 2003 and the second in 2005, both performed at the same season of the year. In this meantime the HVAC system, dated from 1980, was changed, by a retrofit technique, into an up-to-date, more efficient and economic one. The conditioners filters were updated to the G3 class, witch improves the indoor air quality.

EPI-INFO 6 software was used to perform the statistical analysis of the data. The prevalence of symptoms was analyzed using chi-square tests.

3 Results

The questionnaire was answered by 967 of 1736 (55,7 %) workers in 2003 and by 742 of 1420 (53%) employees in 2005. The mean age was around 40 years old, the proportion of males and type of job was quite similar in both investigations. But the mean number of hours per week in the workplace has improved. The characteristics of the population studied are presented in table 1.

Symptoms of the upper airways and ophthalmic were highly prevalent in both evaluations, around 40%, in contrast to the lower airways symptoms, lower than 20%. Unspecific symptoms, like tiredness and headache were the most prevalent. All symptoms showed a high proportion of improvement away from the office. Headache and wheezing presented the lowest ratio of improvement.

Table 1: Population Characteristics

	2003		2005	
Response rate	967	55.7 %	742	52.3 %
Gender (male)	575	59.5 %	412	55.6 %
Mean Age (years)	39.9 yr	0.27 *	39.2	0.34*
Hours of work (p/week)	37.4 hr	0.42 *	41.0	0.26*
Type of job				
Managerial	200	20.7 %	125	16.8 %
Professional	43	4.5 %	32	4.3 %
Clerical /secretarial	405	41.8 %	312	42.0 %
Other	228	23.5 %	129	17.4 %
No answer	91	9.4 %	144	19.4 %
Smoking (active)	46	4.7 %	19	2.6 %

* standard error of mean

The prevalence of dry throat, lethargy/tiredness and chest tightness has increased between 2003 and 2005. Table 2 shows the prevalence of symptoms in both investigations and the ratio of improvement away from the workplace.

Table 2: Symptoms Prevalence Among the 2 Years

Symptoms	**2003** *N* **= 967**				**2005** *N* **= 742**			
	Prevalence		%Improve out of office		**Prevalence**		%Improve out of office	
	N	**%**	***N***	**%**	***N***	**%**	***N***	**%**
Dry eyes	322	33	282	88	236	32	210	89
Ocular itching	395	41	288	73	303	41	235	77
Stuffy nose	501	52	345	69	385	52	262	68
Runny nose	361	37	239	66	278	38	184	66
Dry throat	406	42	308	76	260	**35***	206	79
Lethargy/ Tiredness	566	58	350	62	377	**51***	242	64
Headache	537	55	270	50	399	54	210	53
Itching, dry skin	250	26	131	52	166	22	91	55
Breathless	193	20	120	62	140	19	100	71
Chest tightness	200	21	123	61	125	**17***	74	59
Wheezing	80	8	30	37	52	7	23	44

***** ***p*** **< 0,05** Chi-square comparing the differences in prevalence among the years

4 Discussion

In this study we observed a high prevalence of ophthalmic and upper respiratory symptoms, likewise tiredness and headache in both evaluations of the sealed building workers. The nasopharyngeal and ocular manifestations seem to be those that suffer a greater influence from the internal environment, for they also presented the highest indices of improvement when the worker was out of the workplace. It is important to highlight that the allergic rhinoconjuntivitis symptoms prevalence (ocular itchiness, runny nose and stuffy nose), is twice as high in the population studied as that observed in the general population, indicating probable environment's influence on these symptoms [13][14][15].

The lower airways manifestations are among the least prevalent in both evaluations. The anatomical characteristics of the airways could explain this discrepancy between the nasal and bronchial symptoms. The nose mucosae, as the entrance to the respiratory system, is more exposed to volatile substances and inhalable particles, and the nose's configuration hinders progress of these substances toward the lower airways [16].

Robertson et al. [17], in a similar design study, suggest that in absence of conditions such as hypersensivity pneumonitis, or humidifier fever, upper airways could be more sensitive to air-conditioning-related conditions than lower airways. Although occupational asthma is a classic condition described in the literature, there are no up-to-date references associating this ailment with the type of environment studied in this research [18].

Graundenz et al [9], using a methodology similar to ours, to evaluate 2500 office workers in São Paulo, Brazil, also observed a greater prevalence of naso-ocular symptoms, in employees of sealed buildings in comparison with workers of natural ventilated buildings. But, in their study, persistent cough and sinusitis was highly prevalent too.

Dry throat, lethargy/tiredness and chest tightness was significantly less prevalent in 2005 than in 2003. The improvement of these symptoms may be related to the changes in the HVAC system, as they are non-specific manifestations, usually associated with SBS symptoms. Dry throat, is a complaint not included in the more expressive questionnaires about allergic rhinitis [19]. In the same way, chest tightness is considered an accessory query, used to increase the sensibility of the more specific lower airways questions, like breathless and wheezing. Lethargy or tiredness actually belongs to the core questions about SBS symptoms [12]. The greater prevalence of tiredness in the first inquiry may reflect a low air exchange rate with the outdoor environment, leading to CO_2 and VOC accumulation [20].

On the other hand, in spite of the decrease in 2005, lethargy/tiredness prevalence, as like as headache, was very high in the two evaluations. These symptoms could be associated not only with indoor air quality, but also to stress arising from the workloads or other emotional concerns. When general, skin or mucosal symptoms are experienced in a building, one should have in mind that these symptoms have multiple causes. It is important to control for the individual variables when evaluating the impact of physical and chemical exposures [11].

In this study, all symptoms showed a high proportion of improvement out of the workplace. It may denote a possible effect of the indoor conditions on their prevalence and that, despite of the changes performed in the HVAC system, the indoor environment of this sealed building is not enough healthy.

The response rate, obtained in our study, was somewhat lower than desired in both investigations (little above 50%), perhaps because of the size of the questionnaire, witch demanded more time to be completed. One might expect that persons experiencing symptoms or having an individual disposition would be more likely to respond, and it could lead to bias. A low response rate may result in relatively high prevalence of symptoms [21]. Nevertheless, the response rate quite similar in the two inquiries can somehow neutralize this selection bias. It must be considered, however, that there are some potential information biases such as job satisfaction, quantity of work and job-related stress and other unknown job-related factors that could influence the outcomes [22].

This research found a reduction in the prevalence in three of seven high prevalent SBS symptoms, after a renovation in the HVAC system. Changes in air conditioning system, improving the control of indoor pollution, may modify the quality of life of the office workers. More researches, with different methodologies, are necessary to access a causal relationship between indoor air quality and the workers health.

5 Conclusion and Implications

Our study suggests that indoor pollution of sealed buildings may be implicated with general, ocular and respiratory symptoms in office workers. This is an ongoing study that will now evaluate the indoor environment by chemical and microbiologic analyses. The employees will be followed up by medical and laboratorial investigations, during 18 months. The purpose of this prospective study is to check if there is a causal relation between indoor environmental and the workers health.

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A Remote Expert System for Building Diagnosis

Z. Chen[1], D.J. Clements-Croome[1], H.H.C. Bakker[2], K. Liu[3]

[1] School of Construction Management & Engineering, University of Reading, Reading, RD6 6AW, UK
E-mail: z.chen@reading.ac.uk http://www.reading.ac.uk
[2]Institute of Technology and Engineering, Massey University, NZ
[3]School of System Engineering, University of Reading, UK

Summary: *This paper presents a conceptual model of remote expert system for building diagnosis. The model is set up based on an integrative application of expert system technology and remote monitoring technology. The overall objective of this integration is to modernize the traditional-used expert systems for diagnosis by using a web-based telepresence system. The research methodology adopted includes literature review, product modelling, and experimental case study. The result from this research is the product model of a remote expert system, which can be used to diagnose the defects of buildings with technical supports from real-time remote consultancies. The authors hope that the remote expert system can effectively and efficiently facilitate building diagnosis. Moreover, potential applications of the model are also discussed to improve efficiencies in the design and the operation of healthy buildings.*

Keywords: *building diagnosis, expert system, telepresence, decision support system*
Category: *Modelling*

1 Introduction

Buildings, as one inportant part of infrastructures, are vital to any nation as they provide essential support to most economic activities. However, buildings are simultaneously ageing. Therefore, the emphasis has shifted towards how to efficiently preserve existing buildings through effective and economical repair, rehabilitation and replacement activities. In this regard, it requires a rapid collection and processing of a large amount of data related to existing buildings to select and prioritize the preservation strategies and actions. On the other hand, a huge amount of investment is flowing into new buildings every year; and this also requires a rapid prototyping approach to select the most appropriate solution. Therefore, nondestructive inspection methods for existing buildings and knowledge-based evaluation methods for both existing buildings and new buildings are all necessary for the information collection and the performance assessment of buildings. The assessed condition of either existing buildings or new buildings, including components and systems, can actually provide basic information from which environmental, social and economic issues can be dealt with and enable sustainable facilities management practice to take place.

In order to facilitate the decision-making process in building diagnoses, this paper presents the model of a novel decision support system, called a remote expert system (ES), which can be generically used to diagnose various defects of both existing and new buildings. The effectiveness of the proposed remote ES for building diagnoses should depend on expertise from the front line and the background, as well as the contents of a central knowledge base to support the system (refer to Figure 1). Key issues about the remote ES are briefly discussed, including on-site data collection and basic decision support, and remote data analysis and superior decision support. As a part of current research, it is expected that the utilization of remote ES can make it much easy and more reliable for building professionals to effectively, efficiently and economically reuse accumulated knowledge and expertise in building diagnoses.

2 Building inspection and diagnosis

The building inspection and diagnosis should cover a group of their performance issues. The goal of general building inspection and diagnosis is to identify and solve problems such as temperature condition, energy flows, system reliability problem and indoor air quality complaints in a way that can identify exact faults and provide remedial measures against them; and can prevent them from recurring and can therefore avoid the creation of other related problems during buildings services life [1]. There are many items that need to be addressed in building inspection and diagnosis. For example, according to the *ASHI Standards of Practice* [2], buildings inspectors need to go through the following ten groups of items:

- Structural system such as foundation, floor structure, wall structure, ceiling structure, and roof structure, etc.;
- Exterior such as exterior wall, exterior doors, eaves, vegetation, surface drainage, retaining wall, walkways, patios, and driveways, etc.;
- Roof system such as roof covering, roof drainage system, flashings, skylights, chimneys, and roof penetrations, etc.;

- Interior such as walls, ceilings, floors, steps, stairways and railings, countertop, installed cabinets, doors, windows, and garage doors and operators, etc.;
- Pipeline system such as interior water supply and distribution system, drainage system, waste system, vent system, water heating equipment, vent systems, fuel storage and fuel distribution system, and drainage sump system;
- Electrical system such as service drop, service entrance conductors, cables and raceways, service equipments and main disconnects, service grounding, interior components of service panels and sub panels, conductors, overcurrent protection devices, lighting fixtures, switches, and receptacles;
- Heating system such as installed heating equipments, vent systems, fuels, and chimneys;
- Air conditioning systems such as central and through-wall cooling equipment;
- Insulation and ventilation such as ventilation of attics and foundation areas, mechanical ventilation systems, and vapour retarders and insulation; and
- Fireplaces and solid fuel burning appliances such as system components, vent systems, fuels, and chimneys.

In each group of inspections, reports are required to clarify the conditions and problems of the systems and components under inspection. As there is no intention of specifying repairs, the *ASHI Standards of Practice* does not require inspectors to give suggestions about building diagnoses.

On the other hand, besides the regular building inspection, the buildings diagnosis need to focus on particular building performance based inspections. For example, the Nippon Kanzai Co., Ltd. [3] provides the services of buildings diagnosis relating to earthquake proof, equipment and facilities, environment, management and operation, energy, and information-oriented society, etc.; the Häring Co., AG [4] provides the services of buildings diagnosis in connection with the energy balance of facades of new buildings and redevelopments; the BSRIA [15] carries out both strategic analysis of building requirements and site-based monitoring and investigations of existing buildings and services focusing on mechanical, electrical and corrosion related failure investigations for building services products, including advising of the integration of renewable energy into conventional systems and buildings, energy and environmental audits, project appraisal and feasibility studies, performance testing of systems and components, and technical advice on photovoltaics, solar, heat pumps and other forms of renewable energy, etc.; the BRE [16] provides building diagnosis on the durability of existing buildings by determining the causes and effects of deleterious processes like sulphate attack, aggregate instability, frost damage, chloride ingress and reinforcement corrosion, which lead to the deterioration of concrete, masonry, steel and timber, and advice on remedies. The reviews of standards and practice have proved that the industry needs more reliable and efficient methods for building inspection and diagnosis.

Since late 1970s, various nondestructive inspection methods have been applied for effective building inspection and diagnosis [5], and it is recognized that the use of nondestructive inspection methods for building inspection and diagnosis are promising direction toward on-site practice. Previous research show that ultrasonic pulse method, image analysis, multi-sensing method such as differential thermal analysis and optical diffraction analysis, infrared thermography method [8], ES, and artificial neural network (ANN); etc. can all be effectively used as nondestructive inspection methods for building diagnosis. For example, in detecting the depth of visible cracks in reinforced concrete structures, the nondestructive method such as the ultrasonic pulse method can subsequently perform a safe inspection to cracked structures, even display cracks of various dip angles and lengths. However, it has to be noticed that problems related to the quality and the accuracy of measurement may lead to wrong interpretation of obtained measurements by using nondestructive inspection methods [6], although there are potentials to set up a correct correlation between the changes in data acquisition and signal processing, allowing to determine dynamic system characteristics with accurate process and data [7]. As a result, it is still in suspense to select a most appropriate method or to find new methods for each specific case in building inspection and diagnosis.

3 A remote expert system

The conceptual model of the remote ES for building diagnoses is set up based on several key components, including on-site data collection and basic decision support, and remote data analysis and superior decision support. Figure 1 illustrates the conceptual model of the remote ES for building diagnoses. For on-site data collection and basic decision support, property managers, technicians and data collection systems are required to work together in on-site building inspection and basic building diagnoses. In the meantime, for the remote data analysis and superior decision support, senior managers, experts and computer-based decision support system are all necessary to work collectively to provide remote decision-making supports such as superior building diagnoses and remedies for further actions.

As illustrated in Figure 1, property managers and technicians conduct building diagnoses on site by using relevant equipments such as sensor system and telepresence system. The process of on-site building diagnoses is used to fulfil the requirements of building maintenance or refurbishment, which is usually required by property managers, occupants, or governmental departments. For instance, whether the façade system of a building is still durable enough after several years of services or not, and whether the structural system of a building is still reliable enough after natural disasters or not, are all problems to be solved in building diagnoses.

To realize the conceptual model, the authors adopt the fundamental conception of the ASK centre, which is a product being developed by SchemNZ Ltd. in Wanganui, NZ, into the process of existing building diagnoses. As the ASK centre is a standalone system, potential utilizations of the proposed ES are expected from system rental service, especially for small and medium-sized enterprises involved in building diagnosis related business. Further developments will focus on more relevant inspection processes in building inspection to expand the conceptualization of the ASK centre and its theory.

In case defects occur in buildings, on-site managers and engineers may expect to use telephone and email to report the situation to remote headquarters, and to discuss about the problems with managers, engineers or experts working in headquarters. The weaknesses of these kinds of communications may limit remote experts from getting enough information from the front line; consequently, instructions from the headquarters may not be timely enough due to the lack of real-time information exchange. In order to overcome these weaknesses, the off-site section or the remote section of this building diagnosis system is designed to be integrated with the on-site section by connecting a telepresence terminal into a remote ES through the Internet. By this integration, remote experts can get real-time visual and audio information about building defects form the front line. Moreover, as there is a standalone ES inside the remote computer system, remote experts can thus confidently discuss and make decisions because on-site information and off-site knowledge are all available to support the process of building diagnosis.

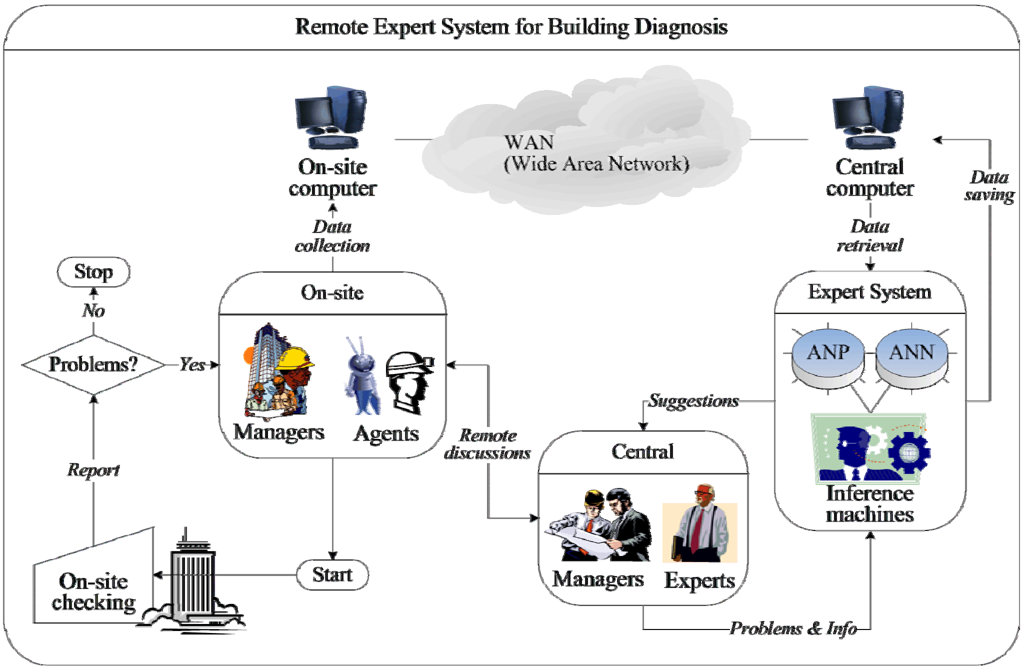

Fig. 1. The remote ES model for building diagnoses.

4 Key issues

Key issues related to realizing the conceptual model of remote ES for building diagnosis have been addressed on two sides, including the hardware integration and the software development. Major technical considerations focus on ES, telepresence, telecommunication and their integration.

4.1 Expert system

As illustrated in Figure 1, there are two inference machines currently used in developing the ES of building diagnosis, including an analytic network process (ANP) model and an ANN model.

The ANP is a multicriteria decision-making theory of relative measurement used to derive composite priority ratio scales from individual ratio scales that represent relative measurements of the influence of elements that interact with respect to control criteria [9]. An ANP model comprises two parts including a network of interrelationships among each two nodes or clusters, and a control network of criteria or sub-criteria that control interactions based on their interdependencies and feedback. Regarding how to use ANP for building diagnosis, a four-step ANP procedure is recommended [10], including model construction, paired comparisons, super-matrix calculation, and final assessment.

Experimental studies using ANP have been applied in building assessment [11] and façade assessment [12]. Based on these fundamental research, an ANP model for building diagnosis is under construction.

During model construction, questionnaire surveys are used to collect experts' opinions on specific questions, which can be regarded as a process of knowledge acquisition. Meanwhile, an ANN model is designed to integrate with the ANP model. The ANN is an approach of artificial intelligence and is widely used to set up ES. The novel integration of ANP and ANN can enable knowledge acquisition and reuse in an innovative way, which is practical and powerful than any separately use. The two decision-making models and their integration are under development.

4.2 Telepresence

Telepresence is the enabling of human interaction at a distance, creating a sense of being present at a remote location, and the telepresence technologies such as voice/data integration and video/data integration have been widely applied in tele-education, tele-dealing and telemedicine for remote operations and emergency access to expertise [13]. In the area of construction engineering and management, the telepresence is also particularly applicable where access to expertise and the dispersed and geographically remote nature of many construction sites makes management and the implementation of innovative practices challenging and time consuming [14], and potential applications of telepresence include remote site monitoring and surveillance, home and office security, and asset tracking, etc.

The term of 'remote expert' can be used to describe an expert in a particular area who provides advice or conducts work remotely. This involves both the remote collection of information required for the expert and the delivery of advice or services to a remote destination. The information that is required by the remote expert depends upon the discipline and the task involved. In the case of remote diagnosis of a control problem and re-programming of a programmable logic controller (PLC) for instance, it might be sufficient for the remote expert to have remote access to a single computer that contains trending information on the performance of a controller and programming software for the PLC. For more generalised and complex problems, it becomes critical for the remote expert to be able to see and hear the area of the process and equipment, environment etc. For this the remote expert requires a telepresence system of some form that can provide the visual and audio information required and can be moved, providing the remote expert with an image of whatever they need to see. Conversely, it also becomes critical for the remote expert to have hands on site to perform actions that simply cannot be performed by a computer or electronic system, for instance inserting an electrical plug back into its socket. What is required then is a telepresence system which can provide the remote experts with a visual and audio image of the process that can be moved at will and some means of performing physical actions at the site. The visual images and audio have to be sent to the expert and the actions have to be telegraphed back to the site.

Few telepresence systems have been introduced to the construction industry. A major example is using it in the area of security, where closed-circuit television can provide a telepresence for the security guard. For example, simple construction site security applications such as remote site monitoring and surveillance, home and office security [14] are possible with the additional benefit of random surveillance by managers, or equipment or material owners, from any location.

The reason why the telepresence technologies are not commonly used in construction engineering and management is in part due to the costs of equipment and communications; in addition, there is no way to provide for physical action and the cameras provide views from fixed points only. In this regard, sensor system will be adopted to collect relevant data from the front line and data will be transmitted through the Internet. Therefore, remote experts can use all kinds of information in building diagnosis.

4.3 The ASK centre

An Audio-visually Supported Knowledge (ASK) centre, set up by the SchemNZ (schemnz.com) in New Zealand, provides a framework within which individual solutions may be integrated to facilitate problem solving. The ASK centre is expected to provide a remote link between an on site technician who has sufficient hands-on skills to complete most physical tasks, and an expert who has access to any specialised knowledge required for the work required. The system can also provide a mechanism for a number of advanced techniques such as predictive maintenance, process design auditing, and data trending as the data communications can provide the live measurements and computational feedback necessary to run such schemes.

The ASK centre incorporates a telepresence system that utilises a wireless camera and audio link, the camera is worn by a technician on the scene and provides the remote expert with video information from the site of the problem. The expert is in full audio communication with the technician who can move the camera to the desired location and can provide the physical actions required by the expert. The video and audio signals are converted into whichever communications protocol is best suited for the application. In all conducted trials by the SchemNZ, the remote expert was able to instruct the technician at the front line without difficulty and receive ready confirmation from the video and audio that the actions had been performed. The impression reported by the remote experts was that the system was very natural to use.

5 A scenario of façade diagnosis

The envelope of buildings is a mediator between the interior and the exterior. The performance of building envelope is highly relied on materials and services conditions. At the design stage, materials are selected by architects to fulfill many sustainable visions, which require the building envelope should be energy-positive, adaptable, affordable, durable, environmental-friendly, healthy and comfortable, and intelligent [17]. As it is a complex systematical work for designers to select the most appropriate façade solution for new buildings, a multicriteria decision-making model called FaçadeChoice was therefore developed to support decision making in building envelope design [12]. The FaçadeChoice is an ANP based decision-making tool, in which experts' knowledge has been accumulated during model construction. To reuse the expertise of building envelopes design, the proposed remote ES can be employed to support the design. In other words, designers can use the FaçadeChoice tool via the Internet from their studios; meanwhile, real experts at the remote side, if they are there, can provide their real-time advices, just like a process of consultation. However, both designers and experts do not need to meet in one physical place. In addition, they can share information from remote sides in a digital way.

As mentioned in section 1, after construction, buildings are simultaneously ageing during the period of their services. In order to detect the deterioration of façades to maintain or to improve the level of building health, periodic inspections are required not only by occupants but also by the government [18, 19]. As a result of this requirement, façade audit has become a business service in the building professions. For example, the Diagnostech Pty Ltd. [20] provides consultation services in the diagnosis and remediation of commercial buildings and industrial buildings with one focus on façade condition audits; the Wiss, Janney, Elstner Associates (WJE), Inc. [21] is active in evaluating the facades and roofs of buildings by using hands-on inspection and testing to better understand existing conditions. It is noticed that the WJE Difficult Access Team employs rope-assisted climbing techniques to gain close up access where swing stages cannot be used. For high-rise buildings, the inspection of façade system is extremely hard due to the risky working condition; therefore, experts are usually difficult or even not able to personally inspect the façade. In this regard, the proposed remote ES can be used by remote experienced experts to get firsthand multimedia information from façade inspectors who work at the front line; meanwhile, embedded sensor system inside the building envelopes can also transmit the data of visual, thermal and acoustic conditions and related façade performance to supply real-time monitoring and audits being conducted by experts at the centre. The inference machines such as the ANP model and the ANN model can be used by experts at the centre in the meantime to make a quick decision regarding the maintenances and refurbishments of building envelopes. Under special condition, if experts at the centre feel it difficult to make a decision, they can invite other experts from outside the centre to log into the system and to work together for final decisions.

Based on these discussions, the authors think that the proposed remote ES is an innovative approach to building inspection and diagnosis, in which building professionals can to get many advantages from the application of modern information and communication technologies to achieve high-level reliability and efficiencies in the design and the operation of healthy buildings.

6 Conclusions

This paper presents the prototype of remote ES for building diagnoses. The model integrates several technologies, including the ES, the telepresence, and the telecommunication into a whole workable environment by conceptually utilizing the ASK centre system being developed by SchemNZ. Key issues are discussed for further realization. It is expected that the proposed system can facilitate the process of building diagnoses and therefore have appreciable potentials in the construction market.

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This paper discusses inspections into the context of an integrating framework called an ASK Centre, which is a product being developed by SchemNZ Ltd., Palmerston North, New Zealand.

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A Study on VOCs Emitted Characteristics of Air Exchange Effect from Building Materials in Local Climate of Taiwan - Plywood and Varnish for Example

Cheng-Chen,Chen[1] , C.M. Chiang [2] , W.C. Shao [2]

[1]Department of Architecture, National Cheng-Kung University, No. 1 University Road, Tainan, Taiwan, ROC
email: coolhas@archilife.ncku.edu.tw http://www.arch.ncku.edu.tw
[2]Department of Architecture, National Cheng-Kung University, No. 1 University Road, Tainan, Taiwan, ROC

Summary: *The research proposes a Building Materials VOCs Emission that suits the local Climate conditions based on Emission Model and Experimental (ASTM D5116-97) comparison and analysis methods according to local climate conditions such as Relative Humidity (30ºC-80%RH) and different Air Exchange Rate (0.5, 1.0, 1.5ACH). In addition, we approximate the concentration and rate of the volatility of constructional materials based on Emission Experience Model.*

Keywords: *Air Exchange Rate, Emission Model, Small Scale Chamber, VOCs, TVOC*
Category: *Materials for healthy buildings*

1 Introduction

Indoor Air Quality of buildings in Taiwan has been attracting attention in recent years;Indoor Air Quality may indeed directly or indirectly impact health of human body (Brooks et al., 1991) in accordance with the relevant study; it has been approved that respiratory tract & eyes disease, even nerve system disease have close relation with IAQ (Nielsen, 1988). This research may probe into indoor air pollution caused by VOCs emitted from indoor building materials.

In addition, because the local climate of Taiwan is different from country and region in high latitude, so, building may face serious challenge due to the high temperature and humid climate of Taiwan. (Fig. 1)

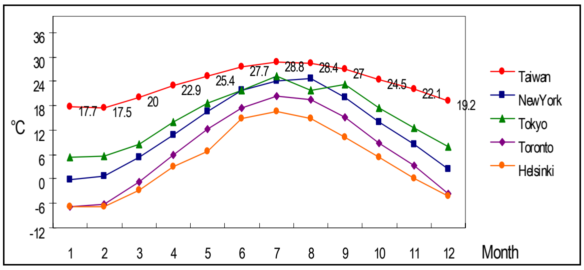

Fig. 1. The month-average temperatures of the cities in different regions.

The study shows that hazards of concentrations of formaldehyde and VOCs emitted from indoor building materials in Taiwan are 10 ~ 100 times higher than basic value of normal health risk (P.C. Wu et al , 2003), therefore, this Study will analyze existing indoor environment in Taiwan basing on current reference analysis, and also put forward emission model applicable to local environmental condition according to local climate factors of Taiwan (temperature, relative humidity and air exchange rate) with testing method of Small-Scale Chamber, (ASTM D5116-97,1997), probe into hazard of air pollution (VOCs) produced from building materials in indoor environment on basis of health risk assessment method (U.S.-EPA, 1994) so as to assess its impact and hazard on human body, put forward better air exchange rate as reference for future designers, constructors and users.

2 Methods

This research is finished with three methods including reference analysis, experimental analysis and statistic analysis, and test emission changes of VOCs from building materials such as paint and plywood building material basing on small-scale environmental chamber (ASTM D5116-97) and the standard testing method for VOCs of indoor air(ISO 16000-6). To monitor emission concentration & factor of building materials and to make regression analysis with mathematic decay model, we can set up emission decay model of building materials and assess its impact and hazard on health of human body.

2.1 Small Scale test Chamber

The Small Scale test Chamber is established in ASTM D5116-97 including Small Environmental Chamber (Volume=225L), Clean Air Generation System, Monitoring and Control System and Real-time Sampling and Analyzing System. (Fig. 2)

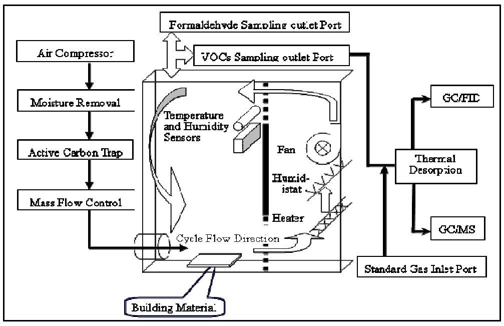

Fig. 2. The diagram of the environmental chamber VOC test system.

2.2 Analyzing Method

VOCs are measured with ISO 16000-6, namely, material TENAX-TA absorbs VOCs in air first, then analyze thermal desorption with ATD and GC/FID. The analyzing instruments include GC/FID, ATD, the analysis answers to ISO 16000-6. (Table 1)

Table 1 Specifications for Instrumentation used for the analysis of VOCs

Component	Specifications & Operating Parameter
Analytical Column	DB-624 GC 60m x 0.32mm x 1.8μm
Carrier gas	Helium
GC-FID Condition	Injector temp 20℃,Column temp program:35℃ ,10℃/min to 120℃ hold 10min , 10℃/min to 220℃ hold 10min
ATD Condition	Split ration 12:1,Tube desorption temp:280℃ hold 5min,Cold trap low temp:-20℃, Cold trap high temp:300℃ hold 5min

2.3 Design of the experiment

To test the emitted VOCs from small-scale building materials for 24 hours (varnish) and 48 hours (plywood) under different air exchange rates in common testing condition (25ºC, 50%RH) and local climate (30ºC, 80%RH) with indoor varnish and plywood in common use in Taiwan. To compare emission differences of standard condition and local climate of Taiwan basing on the emission results with regression analysis of decay model, also compare decay characteristics of building materials with changes of air exchange rates. This design of experiment is shown as Table 2:

Table 2. Design of the experiment

Building materials	Temp.	Relative Humidity	ACH	Loading Factor
Varnish	25℃	50%	$0.5h^{-1}$	$0.011\ m^2/m^3$
	30℃	80%	$0.5h^{-1}$	$0.011\ m^2/m^3$
	30℃	80%	$1.0h^{-1}$	$0.011\ m^2/m^3$
	30℃	80%	$1.5h^{-1}$	$0.011\ m^2/m^3$
Plywood	25℃	50%	$0.5h^{-1}$	$0.4\ m^2/m^3$
	30℃	80%	$0.5h^{-1}$	$0.4\ m^2/m^3$
	30℃	80%	$1.0h^{-1}$	$0.4\ m^2/m^3$
	30℃	80%	$1.5h^{-1}$	$0.4\ m^2/m^3$

3 Results and Discussion

This research probes into impacts of indoor environmental factors on VOCs and formaldehyde from building materials. So, this research studied impacts of experimental factors on emission of building materials according to variable factors of experiment such as temperature, relative humidity, surface wind speed and air exchange rate of chamber and establish emission decay model so as to assess effect and hazard of emitted pollution of building materials on health of human with small scale chamber testing method regulated by ASTM D5116-97, the researched results are as follows:

3.1 Effects of local environmental changes on volatile organic compounds

3.1.1 Emission changes of varnish in local climate

According to the tested results done in course of 24 hours, it is found that toluene is the main emitted material from varnish occupying 74.4%, which has great impact on emission changes of varnish. Ethyl-Benzene, m,p-xylene and o-xylene respectively occupy 9.64%, 9.54% and 6.40%.(Fig. 2)

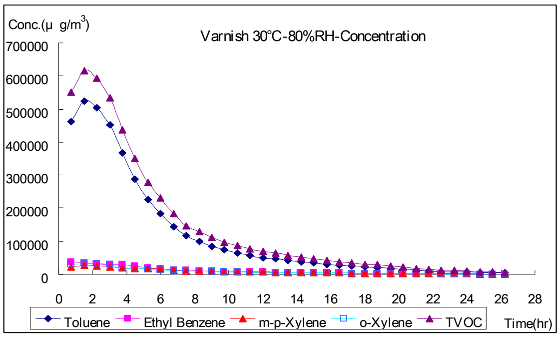

Fig. 2. The main emitted Compounds from Varnish

The emitted concentrations of TVOC and factors measured in high temperature and humidity of local climate (30ºC, 80%RH) are remarkably increased comparing with the standard state (25ºC, 50%RH), total emission concentrations of TVOC increased about 123%, (Fig. 3) the maximum concentrations increased by 5.1 ~7.2 times during middle periods of emission (measured point in 9.75 ~ 18.75 hour), emission factors of TVOC are divided into emission model of two stages, wherein the first stage exposed large quantity of emission characteristics (measured point in 3.75 hour of standard testing, measured point in 6 hour of local climate), and the emission slows down in the two stage, namely, the average factors of varnish are increased by 5.1 times in local climate, furthermore, its emission time is extended and decay slows down.

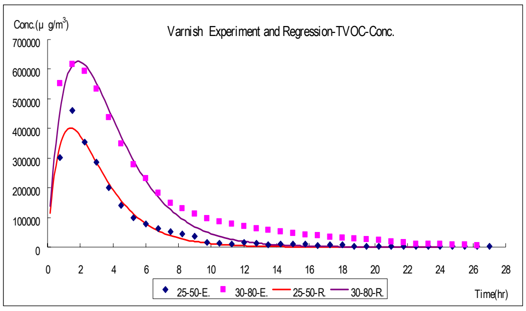

Fig. 3. Effects of local environmental changes on volatile organic compounds from Varnish

3.1.2 Emission changes of plywood building material in local climate

According to the tested results done in course of 48 hours, it is found that toluene is the main emitted materials from plywood occupying 56.33%, which has great impact on emission changes of plywood, o-xylene, ethyl-Benzene, m,p-xylene then occupy respectively 33.71%, 5.55% and 4.41%.(Fig. 4)

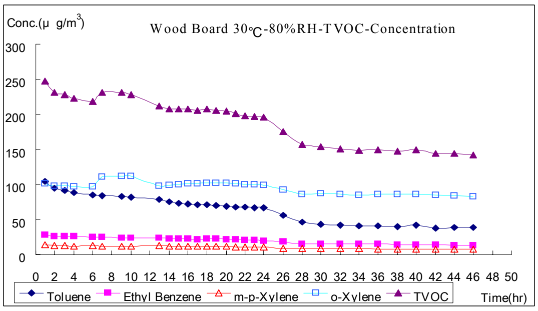

Fig. 4. The main emitted Compounds from plywood

The changes of TVOC emission concentrations and factors measured in high temperature and humidity of local climate (30ºC, 80%RH) are remarkably increased comparing with the standard state (25ºC, 50%RH), total emission concentrations of TVOC increased about 152%, the maximum of total emission concentrations increased by 1.50 ~ 1.91 times and 1.75 ~2.18 times during primary periods of emission (measured point in 6 ~ 12 hour) and middle periods(measured point in 18 ~26 hour), emission factors of TVOC averagely increased by 2.54 times. As to changes of emission concentrations, VOCs emitted from plywood are stable, decay is slowing down. (Fig. 5)

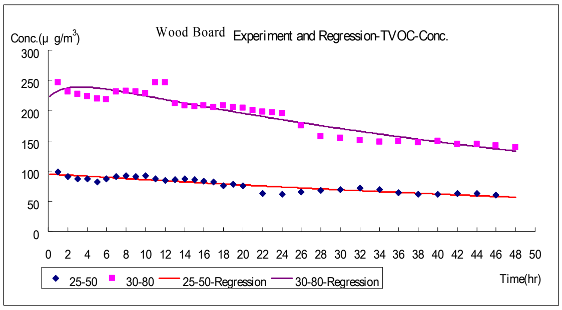

Fig. 5. Effects of local environmental changes on volatile organic compounds from plywood

3.2 Effects of Air Exchange Rate on the concentration of volatile organic compounds

3.2.1 Emission changes of varnish under different air exchange rates

According to the tested results of varnish under high temperature and humidity (30ºC, 80%RH) and different air exchange rates (0.5, 1.0, 1.5ACH), if TVOC concentration removal efficiency of varnish is promoted to 1.0ACH with 0.5ACH as contrast basis, the removal efficiency can be averagely increased by 43.6%, if promoted to 1.5ACH, may be averagely increased by 76%. Removal efficiency at primary stage 0 ~ 4.5 hour) of emission is about 34.4% (1.0ACH), 62.8% (1.5ACH), the maximum removal efficiency at middle stage (4.5 ~ 18 hour) is about 55.7% (1.0ACH), 92.8% (1.5ACH). Emission factors change greatly in the very beginning, when promoted to 1.0ACH, emission factors are 1.04 times, it is then 1.12 times as promoted to 1.5ACH and has two stages of emission model, wherein the first stage exposes large quantity of emission characteristics (measured point in 4.5 hour (0.5 and 1.5ACH condition), measured point in 6 hour (1.0ACH condition) starts changing), and the emission slows down in the two stage. All in all, as to air exchange rate of varnish, when air exchange rate is promoted to 1.5ACH, it may have more remarkable removal efficiency than promoting air exchange rate to 1.0ACH, especially on compound o-xylene, it may have better removal efficiency. (Fig. 6)

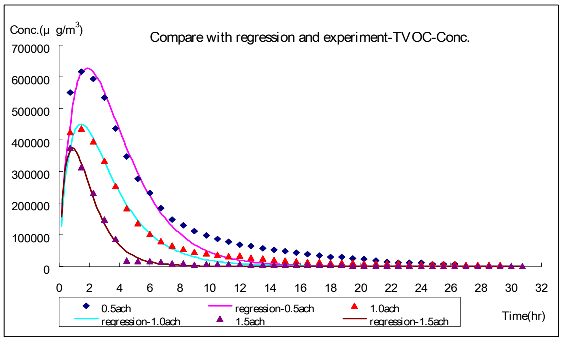

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Fig. 6. Effects of Air Exchange Rate on the concentration of volatile organic compounds from Varnish

3.2.2 Emission changes of plywood in different air exchange rates

According to the tested results of plywood under high temperature and humidity (30ºC, 80%RH) and different air exchange rates(0.5,1.0,1.5ACH) of local climate, VOCs concentrations of plywood are lower than the basic value of WHO(World Health Organization). Removal efficiency may be increased by 55.1% as promoted to 1.0ACH with 0.5ACH as contrast basis. If promoted to 1.5ACH, may be increased by 60%. Removal efficiency at primary emission (0 ~ 12 hour) is about 34.4% (1.0ACH), 62.8%(1.5ACH), the maximum removal emission at middle emission (12 ~ 24 hour) is about 59.5% (1.0ACH), 65.6% (1.5ACH). however, there is no remarkable removal effect as promoted to 1.5ACH at last emission (24 ~ 48 hour). Emission factors change greatly in the very beginning, when promoted to 1.0ACH, emission factors are 1.02 times, it reaches 1.65 times as promoted to 1.5ACH. Emission factors are variable due to changes of air exchange rates, however, it may be stable at last periods and keep step with changes of air exchange rates. Generally speaking, when air exchange rate is promoted to 1.0ACH, there is remarkable removal efficiency, however, there isn't distinctive removal effect as promoted to 1.5ACH, wherein there is no remarkable removal efficiency on compounds such as Ethyl-Benzene and m, p-Xylene. (Fig. 7)

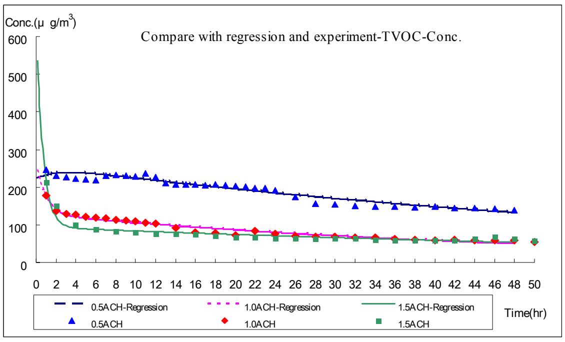

Fig. 7. Effects of Air Exchange Rate on the concentration of volatile organic compounds from Plywood.

3.3 Constructions of Emission Model for local Climate Varnish and VOCs Plywood concentration emission

3.3.1 Establishment of emission model of varnish under different air exchange rates

It is found that first decay chamber model in concentration decay is capable to describe emission from varnish in 1.0ACH ($R^2_{\text{1st-decay chamber model}} = 0.985$) and 1.5ACH ($R^2_{\text{1st-decay chamber model}} = 0.993$) after making model regression analysis on TVOC emission datum of varnish in local climate (30ºC, 80%RH) and different air change rates (0.5,1.0,1.5ACH) with statistic software Grapher.(Table 3).

Table 3. First decay chamber model in concentration of TVOC from varnish in 0.5, 1.0, 1.5 ACH.

model	1st Decay Chamber Model $C = L(EF_0)(e^{-kt} - e^{-Nt})/(N-k)$			
parameter	L	EF_0	k	R^2
0.5 ACH	0.011	82472864.14	0.5653	0.965
1.0 ACH	0.011	77993714.63	0.4413	0.985
1.5 ACH	0.011	103760900.6	0.781	0.993

* ASTM D5116-97

The regressed emission concentrations have close linear relation with the tested concentrations basing on the comparison between the assessments and the tested values of emission concentrations of decay model in different air exchange, as to real-time measured values and regressed assessments, the related coefficient of determination of them, R-Square is 0.992 in 1.0ACH (Fig. 8), however, R-Square is 0.968 in 1.5ACH so as to establish emission model of different "air exchange rate" in "local climate".

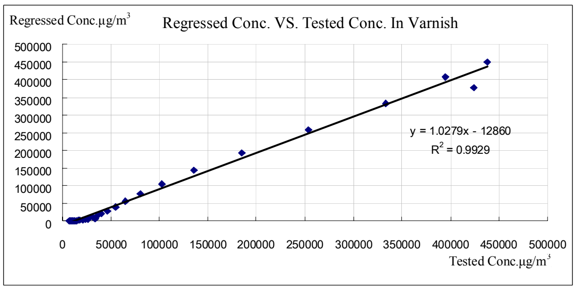

Fig. 8. Effects of Air Exchange Rate on the concentration of VOCs from Varnish

3.3.2 Establishment of emission model of plywood under different air exchange rates

It is found that power law model in emission factor changes of plywood is capable to describe emission of plywood in 1.0 ACH ($R^2_{\text{power law-decay model}} = 0.951$) and 1.5 ACH ($R^2_{\text{power law-decay model}} = 0.812$) after making model regression analysis on TVOC emission concentration datum of plywood in local climate (30ºC, 80%RH) and different air exchange rates (0.5, 1.0, 1.5 ACH) with statistic software Grapher. (Table 4).

The regressed emission factors have close linear relation with the tested emission factors basing on the comparison between emission factor values and the tested values of emission factor, as to real-time measured values and regressed assessments of emission factors, the related coefficient of determination of them, R-Square is 0.87 in 1.0ACH, however, R-Square is 0.817 in 1.5ACH so as to establish emission model of different "air exchange rate" in "local climate".

Table 4. Power Law decay model in Emission Factor of TVOC from Plywood in 0.5, 1.0, 1.5ACH.

model	Power Law Decay Model $EF = at^{-k}$		
parameter	*a*	*k*	R^2
0.5 ACH	531.16	0.284	0.816
1.0 ACH	571.222	0.364	0.951
1.5 ACH	802.402	0.388	0.812

* J.P. Zhu et al. (1999)

3.4 Health evaluations of Toluene within Building Materials

The health risk is evaluated in accordance with "The Risk Assessment Guideline of 1986" published by U.S.-EPA in 1986 and presented amendment report in 1988 and 1992. The risk assessment methods include hazard identification, dose-response assessment, exposure assessment and risk characterization, wherein risk assessment is composed of carcinogenic and non-carcinogenic materials. Carcinogenic materials to human body are usually indicated with carcinogenic hazard when determining harm on health. This research transferred emission factors of building materials to space concentration with mass balance (Matthews, 1986) according to the experimental results. The health hazard assessment is established under emission condition of exposed building materials assume that in one single room (5m x 4m x 2.75m) where temperature is 30ºC, relative humidity is 80%, air exchange rate is 0.5 ~ 1.5, Loading Factor is 0.4 m^2/m^3,the person is 60kg, breath air volumes are 12 m^3/day, his average exposure times are about 90% indoor, absorption rate is 80%, the results are shown as the table. 5.

Table 5. Health evaluations of Toluene within Building Materials

VOCs	Toluene			
evaluations	***Emission Factor of Varnish***	***Hazard Index of Varnish***	***Emission Factor of Plywood***	***Hazard Index of Plywood***
0.5 ACH	393.1	338.1>1	0.094	0.08<1
1.0 ACH	243.9	209.8>1	0.048	0.04<1
1.5 ACH	78.9	67.8>1	0.047	0.04<1

* Emission Factor Value is Measurement in 48hr

3.5 Discussion

Due to the high temperature and humidity in Taiwan, VOC concentrations of building materials are higher than nations in the north temperate zone, if tested with standard testing method, the emission concentration might be undervalued, cannot effectively control organic compounds emission of indoor building materials and maintain indoor air environment. When change air exchange rate to remove indoor pollution concentrations, should be divided into construction and application periods according to different emission characteristics of building materials. For example: solvent paint shall promote air exchange rate to 1.5ACH when constructing, and adjust air exchange rate to 1.0ACH as users enter into construction site so as to keep health capability of indoor air environment and save energy of air conditioner.

4 Conclusion and proposal

4.1 Conclusion

4.1.1 Impact of local climate on emission changes of VOCs from building materials

To study indoor climate such as local temperature, relative humidity (indoor 30℃, 80%RH in summer) with experimental model so as to test emission change of VOCs from building materials and make difference contrast with common testing standard(25℃、50 % RH), which indicates that total emission concentration of varnish tested increased by 123% than the standard state in local climate, however, total emission concentration increased by 152% on plywood tested, therefore, the emission concentration may be promoted along with increase of temperature and relative humidity as building materials in "local climate", and also harm health of person exposed there, especially, must control building material such as solvent paint so as to monitor quality of building materials and keep a healthy environment.

4.1.2 Impact of air exchange on emission concentration of VOCs from indoor building materials

In accordance with air exchange rate of common building, this research applies 0.5,1.0 and 1.5ACH as change factors to make TVOC testing on plywood and varnish in local climate, which indicates that if varnish promoted "air exchange rate", may remarkably remove organic compounds. In practical application, constructors can control the necessary air exchange rate in construction site according to the emission characteristics of such building materials in course of construction period, namely, it is 1.5ACH in the beginning of construction and keeps 1.0ACH in last period so as to maintain health safety of working environment; the resident would better maintain at least 1.0 ACH air exchange rate in local climate when applying such building material so as to have better indoor air quality.

4.2 proposal

This research mainly probes into impacts of "local climate" and "air exchange rate" on emission characteristics of VOCs from building material such as plywood and varnish. The effects are remarkable as to changes of air exchange rate, however, this research establishes a fixed value for change of "loading Factor", so, it lacks relevant discussion on "air exchange rate" and "loading Factor", therefore, we propose hereby that the follow-on research should base on this paper to study "change of loading Factor" of building materials.

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Guidelines to resolve indoor air quality and sick building syndrome complaints amongst office employees

K Heslop
University of the Western Cape, Department of Industrial Psychology, Private Bag X17, Bellville 7535, South Africa
email: kheslop@uwc.ac.za http://www.uwc.ac.za

Summary: *The National Environmental Management Bill (no. 62 of 2002) and related legislation, inter alia, the Atmospheric Pollution Prevention Act, the Health Act, National Buildings Regulations and the Occupational Health and Safety Act were promulgated with a view to establish parameters for environmental management in South Africa. This legislation, although in its fledgling state, attempts to provide guidelines with respect to ambient air quality standards, sets targets and objectives for reducing pollutant emissions. Notwithstanding the benefits of these statutory interventions, the enforcement and the concomitant prosecution of offenders appear problematic at present. This research provides a review of the literature, explores a range of alternatives and offers suggestions for collaborative efforts to improve the health, comfort and well-being amongst buildings' occupants.*

Keywords: *Indoor Air Quality (IAQ), Sick Building syndrome (SBS), Solutions*
Category: *Sick Building syndrome (SBS)*

1 Introduction

The National Environmental Management Bill, which amends the National Environmental Management Act (NEMA), 1998, establishes parameters for environmental management in South Africa (Resource, 2005a). In terms of this legislation, South Africans have a fundamental right to an environment which is not harmful to their health or well-being. Despite the promulgation of this legislation and related legislation (inter alia, the Atmospheric Pollution Prevention Act, the Health Act, National Buildings Regulations and the Occupational Health and Safety Act) with respect to ambient air quality standards, the enforcement and the concomitant prosecution of offenders appear problematic at present (Gansan *et al*., 2002). Although industrially developed countries have well developed programmes in place, most Industrially Developing Countries (IDCs), including South Africa, continue to grapple with effective monitoring and intervention programmes.

Whilst health, comfort and economic implications of sick building syndrome (SBS) amongst office employees are priorities in most developed countries (Djukanovic *et al*., 2002; Glas *et al*., 2004; Sepännen *et al*., 2003), there is a relative dearth of South African research into this problem compared to industrialised countries. Prior to 1992, no comprehensive survey of the SBS problem had been undertaken in South Africa, although an extensive project on indoor air quality (IAQ) had been conducted at the Carlton Centre as early as 1979. By 1992, 110 IAQ assessments were conducted by the Johannesburg City Health Department. Most South African research to date indicates that inadequate ventilation or thermal problems precipitate SBS complaints with an increased prevalence of certain symptoms in air-conditioned buildings. In comparison, by 1988, the National Institute for Occupational Safety and Health (NIOSH) in the USA had completed 529 IAQ investigations (Knöppel & Wolkoff, 1992).

Since these finding were released, the National Centre for Occupational Health has responded to requests for assistance, culminating in occupational hygiene surveys being conducted, and the Centre for Scientific and Industrial Research (CSIR) has since been applying American measurements of air quality in establishing the extent of SBS in South Africa. Similarly, Occutech, an accredited professional company carries out risk assessments at quarries in KwaZulu-Natal. More recently, Gardiner (2002) has proposed a framework for establishing air quality objectives and targets as part of an ISO 14001 programme. Similarly, Cairncross *et al.* (2003) are collaborating with international and local experts to adopt a methodology to develop an Air Pollution Index (API) for South Africa. Collectively these organizations have postulated the use of various modes to address problems emanating amongst building occupants.

2 Building audits

Although SBS complaints are not unmanageable, they can be contained by proactive and dynamic building management and regular audits. The main purpose of an IAQ audit is to establish benchmarks with respect to building environment issues to ensure acceptability and serve as a reference point for future changes in acceptability levels. Although these surveys are often reactive and frequently costly, preventative healthy building management, on the other hand, is cheaper and does not result in crisis management. Moreover, it enhances management's relationship with employees by demonstrating a genuine concern for employee well-being, and reduces the chances of litigation (Resource, 2005b; Truter & Terblanche, 1996).

As environmental concerns assume increasing importance, environmental auditing systems have been designed to allow industry to achieve and demonstrate good environmental practices. Compliance with these environmental audit systems allows organisations to assess their environmental performance against national or international standards (Gardiner, 2002). However, environmental audits need to be conducted within a structured management system, integrated with overall management activity and should address all aspects of desired environmental performance. A concerned building management approach could assist in reducing absenteeism as a result of SBS and hence may increase employee productivity (Glas *et al.*, 2004; Nilsen *et al.*, 2002).

3 Improved maintenance

Much of the research to date indicates that the prevalence of SBS symptoms is associated with characteristics of buildings and ventilation systems. Sepännen and Fisk (2002) indicate that one of the most important factors affecting IAQ is how the building is heated, ventilated and air-conditioned. The World Health organization (WHO, 2000), maintains that unacceptable environmental conditions frequently arise from faulty, dirty and / or inadequate heating, ventilation and air conditioning (HVAC) systems, and hence poor maintenance has been highlighted as one of the principal causes of SBS (Cairncross *et al.*, 2003).

HVAC systems should be designed, at a minimum, to meet ventilation standards in local building codes; however, many systems are not operated or maintained to ensure that these design ventilation rates are provided. In many buildings, IAQ can be improved by operating the HVAC system to its design standard (WHO, 2000).

Increasing ventilation rates and air distribution often can be a cost effective means of reducing indoor pollutant levels. For example, research by Wang *et al.* (2002) indicates that incorrect ventilation design can culminate in increased reporting of symptoms consistent with SBS. Their research highlights the fact that, by addressing the ventilation design, concomitant reductions in symptom reporting were noticed. Similarly, Hedge and McCarthy (1993) report in their research that altering an organisation's filtration system resulted in: a 55% reduction in sickness absence, a 94% employee reported increase in indoor air quality, and a 40% employee reported increase in productivity.

Consequently, priority must be placed on maintenance, cleaning and repair of HVAC systems as a step towards preventing SBS. Lagercrantz *et al.* (2000) propose maintenance and scheduled inspections are important procedures to be followed in order to avoid the occurrence of IAQ problems and to ensure a comfortable and productive workplace.

4 Indoor air quality programmes

Pivotal to reducing the potential health, comfort and economic impact of poor IAQ on occupants is an effective IAQ programme, which Bowman (2001), Gardiner (2002) and Resource (2005b) maintain should entail developing a sound environmental policy statement, establishing an effective environmental management system, formulating and wide distribution of environmental strategies that support the environmental policy statement and are consistent with environmental ethics, developing environmental objectives, plans, programmes and procedures, environmentally motivated training and regular meetings, and integrating environmental costs and cost reductions as a necessary point of an organisation's business plans.

In conjunction with this, a number of chemical, engineering, auditing and other South African firms have launched programmes of integrated environmental monitoring as part of their corporate environmental responsibility. This has sought to enlist the participation of management, engineers, other technical specialists, and less frequently the general workforce, in striving to improve the working environment. Accordingly, organisations such as

AECI, ESKOM, and Gencor and Times Media Limited, Sanlam and MultiChoice took steps to address questions of environmental responsibility (Truter et al., 1992). In common with developments overseas, there is an emphasis on teamwork between managers and employees, and more dissemination of information.

5 Employee Participation

According to Soine (1995), work environments which mitigate against the development of SBS are those which encourage a climate of concern and respect for employees, characterised by effective communication between employees and management; participatory decision-making structures; opportunities for social interaction among employees; and, a modicum of control over aspects of both the job tasks and physical environment in which those tasks are completed. With regard to the physical environment, employee input into decisions about temperature, humidity and related matters should assume precedence. Mechanisms for employee feedback about environmental conditions are also important. Employees should be able to routinely report instances of unacceptable environmental conditions and have confidence that these will be pursued (Soine, 1995).

Michaels (1984) proposes the extensive use of employees as environmental investigators. This entails training of employees to conduct on-going environmental evaluations and information-gathering activities, as part of management policy aimed at preventing and/or remedying SBS. Consultation with employees about possible workplace improvements is another possible avenue to explore, since employees may be aware of opportunities for improving workplace quality that have eluded management (Resource, 2005b).

One factor which is postulated to increase the sensitivity of staff in many modern buildings is that they are provided with highly centralised environmental control systems which are often enhanced by design features which reject the external world through the use of tinted glazing and sealed facades. In such buildings, occupants can have little opportunity to exercise control over their environment and so they are totally reliant on the building systems and those managing them to produce a satisfactory environment. In response, Kohonen *et al.* (2002) propose the use of customized environments, based on an integrated approach combining advanced air filter and air distribution technologies.

6 Pollutant Source Removal

A number of studies show that reducing pollutant sources decreases the number of people dissatisfied with air quality and the prevalence of SBS symptoms (Lagercrantz *et al*., 2000; van Beuningen *et al*., 1994; Wargocki & Fanger, 1997; Wargocki *et al*., 2002). The increased concern about SBS has prompted public demand for more healthy building materials and products, that is, materials with a low and harmless emission of pollutants. This has led to a need not only for the development of new and safer materials, but also of methods for measuring and evaluating the emission (Horn et al., 2003; Kumar & Little, 2003). Pollutant source removal or modification is an effective approach to resolving an IAQ problem when sources are known and control is feasible. Several of these options may be exercised at one time (Knöppel & Wolkoff, 1992). Examples include routine maintenance of HVAC systems, periodic cleaning or replacement of filters, replacement of water-stained ceiling tile and carpeting, institution of smoking restrictions, which is already mandatory, venting contaminant source emissions to the outdoors, storage and use of paints, adhesives, solvents, and pesticides in well ventilated areas, use of these pollutant sources during periods of non-occupancy; and allowing time for building materials in new or remodeled areas to emit pollutants prior to occupancy.

Some research (Nilsen *et al*., 2002) for example, reports a 12,5 % reduction in absenteeism rates in offices in which interventions via pollutant source removal and cleaning were emphasized. Similarly, research by Palomäki *et al.* (2002) showed that repairs to damaged flooring material resulted in the number of sick days leave due to respiratory symptoms consistent with SBS decreasing by 14% following the intervention.

7 Occupant Activities

According to LaBar (1992), one method of preventing IAQ problems is to restrict certain activities which are likely contributors to indoor air problems. Organisations can institute certain policies to control pollution in environments. In accordance with this, by 1993 clean-air policies had been implemented by several organisations and state departments in South Africa (Bothma, 1993). Several years ago, researchers proposed the institution of no-smoking policies (Salojee, 1993) or providing separate smoking lounges (Larsen, 1995; Lees-Haley & Brown, 1993).

While national policy imposes severe restrictions on smoking in communal areas, employers and organisations are being compelled to adopt a more proactive approach to management of indoor environments and monitoring of occupant activities. However, corresponding monitoring remains problematic in view of the concomitant logistical difficulties associated therewith (Resource, 2005a, Resource, 2005b).

8 Education And Communication

Education and communication are important elements in both remedial and preventive IAQ management programmes and requires a commitment and investment by management to work closely with maintenance employees and to upgrade their skills as technology evolves. When building occupants, management, and maintenance personnel fully communicate and understand the causes and consequences of IAQ problems, they can work more effectively together to prevent problems from occurring, or to solve them if they do (Arnold, 2001).

9 Air Cleaning

Air cleaning can be a useful adjunct to source control and ventilation but has certain limitations. Particle control devices such as the typical furnace filter are inexpensive but do not effectively capture small particles; high performance air filters capture the smaller, respirable particles but are relatively expensive to install and operate (Horn *et al*., 2003). Attempts to cure cases of SBS should start from the dual premise that many factors may be interacting to cause the problems (Kumar & Little, 2003). Hence, decisions about treatment should be informed having considered all the known risk factors and established ways of dealing with them. Where possible, the success of treatments should be verified by controlled pre and post surveys (Arnold, 2001).

10 Air Ionisation

Some research indicates that negative ions - especially in combination with an air cleaner can influence on productivity, efficiency, comfort and health. Beneficial effects of negative air ions on mood, performance and well-being have often been claimed (Sulman, 1980), and while conclusive evidence has yet to be assembled, Hawkins (1981) has shown the use of negative air ionisers in offices may reduce the incidence and severity of headaches, particularly among female employees. Charry and Hawkinshire (1981) have shown for certain types of employees, even short-term exposure to high concentrations of positive ions can impair performance and have a negative effect on mood. Investigations by other researchers showed either that negative ions had no effect in 'sick' buildings or that they had no measurable effect on human mood and performance (Hedge & Collis, 1987).

11 Bioremediation / Green Plants

Research studies by NASA and others have revealed that enclosed offices contain large amounts of harmful gases which are known to affect the health and performance of employees. However, further studies have proven conclusively that plant introduction removes many of these potentially damaging gases by natural processes - regenerating a healthier atmosphere and happier staff. The NASA research combined with an increasingly large amount of corroborating research indicates plants may improve IAQ, however, these studies were short-term laboratory experiments and there have been no reports on longer-term field trials. The results do, however, offer tentative evidence that the use of plants could be sufficient to maintain clean air (Lees-Haley & Brown, 1993).

12 Management/Organisational Factors

Among the factors which are commonly cited as a cause of SBS is the quality of management. Management can be seen as contributing to SBS if it does not act effectively to create a safe and healthy indoor environment to avoid symptoms. Poor quality management can lead to inadequate environmental conditions and contribute to the sensitivity of employees resulting in the reporting of symptoms even in environmental conditions which would otherwise be considered adequate (Djukanovic *et al*., 2002).

Instead of ignoring complaints, or dismissing them as imaginary, management should have the problems objectively assessed (Aupiais, 1991). As Lindvall (1985, p. 1) has noted, "in offices, perceived discomfort is a critical effect" because of the mental nature of office work. Therefore, levels of environmental parameters which are well within the recommended limits can still be "psychologically stressing, increasing the risk of cumulative effects".

It is commonly staff at clerical and secretarial grades who have the worst office environments, often without natural light and without environmental controls which are generally found in cellular offices. In such buildings, occupants can have little opportunity to exercise control over their environment and so they are totally reliant on the building systems and those managing them to produce a satisfactory environment (Wilson & Hedge, 1987).

13 Conclusion

While the issue of indoor air quality has moved from an 'alarmist' standpoint to one of identifying strategies for reconciling health and well-being with energy efficiency, most of these strategies have involved revised maintenance and operation procedures and, in some instances, the re-design of mechanical systems in problem buildings (Sepännen *et al*., 2003). Alternative solutions involving major architectural renovation and the implications of air quality concerns on new architectural design strategies have yet to be explored. Moreover, the design of ergonomic workstations to maximise employee comfort as well as individually controlled ventilation systems which employees can control to suit their unique needs and comfort level have been offered as potential solutions (Kohonen *et al*., 2002).

While several methods have been proposed to address IAQ problems and reduce SBS amongst office employees, sustained attention to and commitment from management is essential. Unless the necessary attention is accorded to such complaints Besch and Besch (1989, p. 13) contend that "the longer it takes to ... institute corrective action, the more likely the performance, productivity and morale of everyone ... will be unfavourably affected". In considering the desirability, efficacy and feasibility of instituting any environmental changes, however, the potential benefits must be weighed against long-term disadvantages, such as biological contamination, and the economic / energy cost should the intervention be perceived to be inappropriate.

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Outline of a Methodology for Construction of a Healthy Building

J. Gomes

Universidade Lusófona de Humanidades e Tecnologias, Av. Campo Grande, 376, 1749-024 Lisboa, Portugal
email: ip241783@ip.pt

Summary: *This work describes the outline of a methodology, which has been applied with success in several situations, for construction of a healthy building in terms of Indoor Air Quality (IAQ). This methodology aims to decrease or even eliminate, where possible, the emissions resulting from building materials and includes the following steps: the evaluation of available information and specifications on building materials and related products; discussions with manufacturers, analysis of samples, in situ inspections and final IAQ investigations. An outline of this methodology is presented in figure 1.*

Keywords: *indoor air quality, healthy building construction; sick building syndrome*
Category: *control strategies for IAQ*

1 Introduction

In industrialized countries inhabitants spend the most part of their time inside buildings. This is why Indoor Air Quality became such an important issue concerning public health, and Sick Building Syndrome (SBS) [1] is currently affecting several new office buildings. SBS can be observed when a new office building starts to be occupied, immediately after its construction. Frequently, new occupants claim complaints such as headache, nasty smells, as well as affections from skin and eyes. Looking for its causes is a very expensive and time consuming process which requires important resources at occupants expenses.

Some strategies [2], [3], to obviate this problem were already published elsewhere, stating the necessary precautions so that SBS would not be experienced. Furthermore, sound strategies should result in a set of checks to ensure that safe and recommended construction materials are, in fact, used when constructing the building itself.

This is quite an important issue, as builders frequently prefer to use other non recommended materials with which they are more frequently acquainted [4].

2 Methodology

The methodology used in the design of healthy buildings should include the evaluation of data available on materials and used construction products, discussion with producers, analysis of sample materials, in situ inspections and further investigations about IAQ after building completion.

Attention should be paid also on the information to be available to all parties in the process such as owner, and occupants, during the whole process. Acting this way, all players will gain confidence in the process itself and, in the end, occupants will rely that they will work in a safe and healthy environment.

This methodology develops in 5 consecutive steps as indicated in figure 1, and as described below.

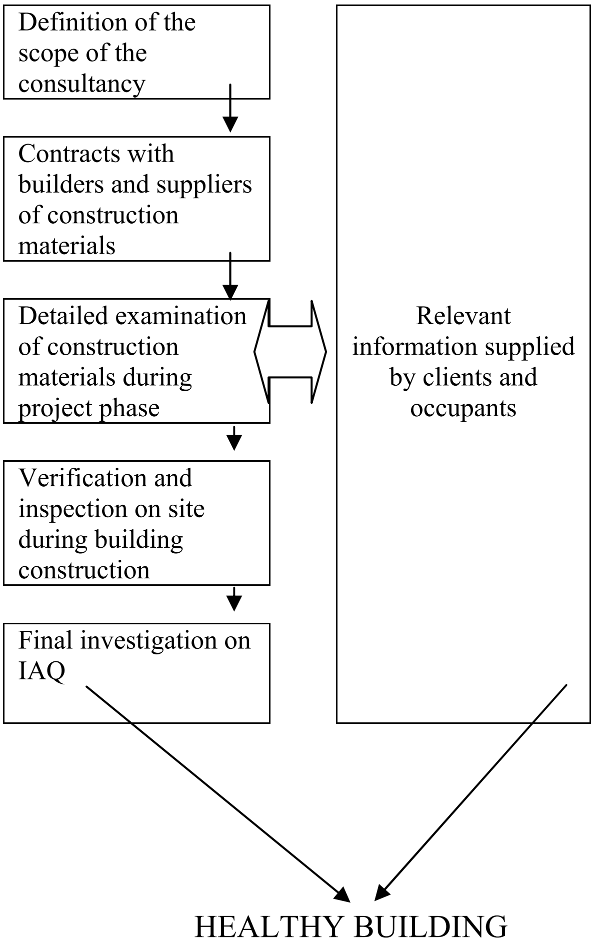

Figure 1. Description of the methodology

2.1 Definition of the scope of the intervention

Representatives of all parties should be present during project phase, which includes frequent meetings with clients, engineers, architects and future occupants.

This intervention may include general aspects on environmental protection such as the use of tropical timber or can be limited to IAQ only. All team members should be aware that the selection and use of construction materials and auxiliary products resulting in low emissions is an important part of the project itself.

2.2 Contracts with producers and construction companies

Traditional contracts with producers and construction companies should also include additional clauses referring to materials and products to be used in building construction divided in two different groups: all materials containing polycyclic aromatic compounds such as PCB, which are not to be used in any circumstance ; and another group including aromatic hydrocarbons such as solvents which are to be avoided as possible, but that can be used in exceptional circumstances.

The inspection entity should be informed if builders are planning to use any materials from this second group. However, the decision to use this type of products or not will depend on the amount and place of actual utilisation.

Apart from the fact that contractual clauses have juridical relevance, the attention of producers and builders should be directed to the importance of utilising materials that will not result in environmental problems. The type of clauses are indicated in table 1.

Table 1. Contents of contractual clauses

Non allowed materials (in any situation)	Non allowed materials without previous consent
Asbestos	Mineral fibres
PCBs	Wood preservatives
Pentachlorophenol	Insecticides
Lindane	Aromatic hydrocarbons
CFCs	Organic solvents
Formaldehyde	

2.3 Detailed examination of construction materials during project phase

This information should be asked to producers. They should also be consulted also on the existence of alternative materials. During this process confidentiality is to be maintained.

If necessary, producers should be asked to present samples of materials which are bound to act as significant IAQ pollution sources as indicated in table 2.

Table 2. Construction materials relevant to IAQ

Paints
Adhesives
Wood panels
Cork panels
Pavements
Mineral fibres

If necessary, data on the atmospheric emissions resulting from these materials, should be obtained. In that case, samples of the materials are placed in environmental test chambers at 25 ℃ and conditioned properly during 24 h. Volatile organic compounds (VOC) are sampled, in charcoal sorbent tubes or in Teflon bags, and analysed in the laboratory using an appropriated detector, such as HRGC/MS (high resolution gas chromatography using a mass spectrometry detector) for very low concentration levels of hazardous substances.

It should be noticed that the emission concentrations to be obtained in this test tend to be somewhat higher than the one to be obtained in real situations. Nevertheless, this information will be quite helpful to compare materials with each other and could be even organised as a ranking of emission potential which allows to select materials with lower potential.

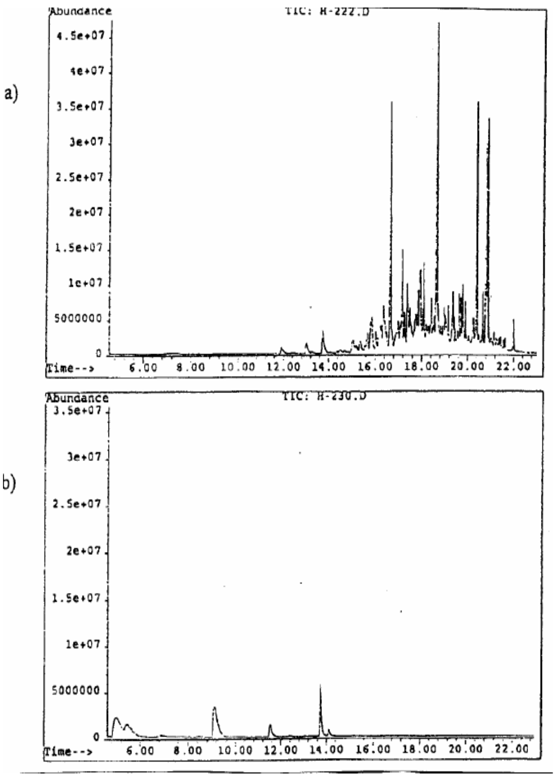

Figure 2. Chromatographs obtained from test samples

Figure 2 presents 2 chromatograms obtained when analysing tow different paint samples: figure 2a shows a type of paint having a high content of organic solvents, while figure 2b shows another type of paint where the emission potential of VOC is considerably reduced, and, therefore, should be selected as construction material for indoor surfaces.

Apart from this type of tests other assessment are to be done, such as sensorial evaluations by a panel of people similar to the future occupants of the building. The objective of this panel is to characterise qualitatively sensorial reactions such as intensity and type of smells that will result from the application of those materials.

This is quite an important evaluation as smells will affect very vividly the disposition of occupants. Table 3 resumes the main information to obtain related with construction materials.

Table 3. Necessary information on construction materials

Published information	Further investigations
Manufacturers information	Discussions with manufacturers
Data on emissions from construction materials	Emission tests in chamber
Material safety data sheets	Sensorial tests

2.4 Verifications and inspections during construction

During the construction phase several non programmed on-site inspections are to be made. During these inspection visits, samples of construction materials should be taken, and the exact location of materials application should be photographed. In certain cases, samples should be analysed to assess the use of hazardous substances. All samples should be preserved until IAQ investigations are concluded. This will allow the execution of confirmation tests and further evaluate the source unexpected contaminants in indoor environments.

2.5 Final investigation on IAQ

About 4 weeks after the completion of the building, final investigations on IAQ are to be made to assure the inexistence, at least, of the hazardous substances mentioned in table 4.

Table 4. Substances to be investigated on IAQ

Type of compound	Specific compound
Solvents	Aromatic hydrocarbons
Aldehydes	Alifatic hydrocarbons
Organics	Terpenes
Semi-volatiles	Other solvents
Inorganics	Formaldehyde
	Wood preservatives
	Mineral fibres

3 Results and discussion

Several buildings, already constructed, subjected to this methodology, showed that is possible to build healthy buildings without excessive costs.

The surveyed cases showed no complaints from occupants. Due to an adequate materials selection, smells and VOC concentrations were dully controlled. However, it should be noted that this methodology cannot prevent, by itself, the presence of any undesired chemical compound in indoor air.

But, from a practical point of view, the concentration of hazardous compounds in indoor air is significantly minimized.

Some psychological effects related with reactions of changing the work habitat still remain uncontrolled, but it should be noted that this type of scientific assessment could be used to minimize its effects.

It should be noted that the emissions referred to in this paper are mainly the primary emissions derived from construction materials. Secondary emissions are not fully considered here.

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Biological Activity of Spores from Eight Fungal Species Isolated From Building

H.M. Musa[1], K.E. Aidoo[2], C.A. Hunter[1]

[1] Centre for Research on Indoor Climate and Health, School of Engineering, Science and Design, Glasgow Caledonian University, Cowcaddens Road, Glasgow, G4 OBA.
[2] Department of Biomedical and Biosciences, School of Life Sciences, Glasgow Caledonian University, Cowcaddens Road, Glasgow, G4 OBA.
Corres. email: K.Aidoo@gcal.ac.uk
www.gcal.ac.uk

Summary: *Eight mould species isolated from building materials were used to determine their biological activity and cytotoxic potentials they may pose to humans. Aspergillus. parasiticus, A. ochraceus, A.versicolor, A. fumigatus, P. citrinum, Chaetomium, Phoma and Ulocladium were the mould species used on two human cell lines Hep-2 and Hfl-1. The influence of the extracts on the cellular methylthiazoltetrazolium (MTT)-cleavage activity was evaluated. The mutagenic effect of the fungal extracts was determined using the Muta-chromoPlate based on the reverse-mutation test using Salmonella typhimurium TA100 and TA98 as test strain. Aspergillus parasiticus, A. ochraceus, P. citrinum and Chaetomium showed a high cytotoxic effect on both cell lines with A. ochraceus having higher cytotoxic effect on both cell lines with an* IC_{50} *value of 2.48 and 1.25 using Hep-2 and Hfl-1 respectively. Chaetomium exhibited a high cytotoxic effect on both cell lines, though not much attention has being given to its presence in the indoor environment. This may pose a potential mycotoxic hazard to human. Extracts from A. parasiticus, A. ochraceus, A.versicolor and P. citrinum were also found to have mutagenic properties. Aspergillus fumigatus showed less mutagenic effect.*

Keywords: *Cytotoxicity, tetrazolium dye assay, mutagenicity, mould*
Category*: Biological contaminants*

1. Introduction

Condensation, dampness and subsequent microbial growth in indoor environment can increase the risk of adverse health effects on the occupants. Compounds produced by the microorganisms may be either immunogenic or toxic [1]. Microbial growth and the ability to produce toxic compounds on building substrates depend on whether these materials can serve as nutrients for the microbes [2-3]. Over 400 secondary metabolites (mycotoxins) from fungi have been identified and they are characterised by their low molecular weights and structural diversity. During the early stage of dampness formation in buildings, fungal genera such as *Penicillium* and *Aspergillus* are among the primary colonizers. Under suitable environmental conditions, especially high moisture content in the materials, other species, such *as Streptomyces, Ulocladium, Trichoderma* and *Stachybotrys,* may become dominant [4-5].The presence of these microbes on the building substrates is an indication of water damage in the building [6]. Fungal species such as *Stachybotrys, Aspergillus, Penicillium* and *Streptomyces* found on building substrates have been reported to produce toxins such as satratoxins, aflatoxins, ocharatoxins, citrinin, sterigmatocystin and valinomycin [2,3,7]. As a result of the large range of bioactive compounds originating from mould, determination of all harmful metabolites produced on building substrates seem difficult, but rather spore-induced cytotoxicity could be used as an index of the biological activity of microbial spores synthesized at different growth conditions [8] and the Ames test could be an essential test for predicting possible carcinogens. Eight fungal strains *Aspergillus parasiticus, Aspergillus ochraceus, Aspergillus fumigatus, Aspergillus versicolor, Penicillium citrinum, Chaetomium globosum, Phoma macrostoma* and *Ulocladium chartarum* isolated from building substrates were used for the cytotoxicity assay. The assay relies on the ability of the cells to reduce a water-soluble yellow dye3-4,5-dimethylthiazole-2,5-diphenyl-tetrazolium bromide (MTT), to a water-insoluble purple formazan product [9-10]. The relevance of genetic testing relies on its ability to detect genotoxic carcinogens employing endpoints other than neoplasia. The most popular and validated mutagenicity bacterial reversion screening test is the *Salmonella/raicmsoraa* test (Ames test) [11]. The *Salmonella typhimurium/raicmsorae* assay uses a number of Salmonella strain with pre-existing mutations that leave the bacteria unable to synthesize the required amino acid, histidine, and therefore unable to grow and form colonies in its absence. New mutations at the site of these pre-existing mutations, or nearby in the genes, can restore the gene's function and allow the cells to synthesize histidine [12]. The genotoxic potential of the six fungi species; *A. parasiticus, A. ochraceus, A. fumigatus, A. versicolor,* *P. citrinum* and *Chaetomium* was evaluated by the Ames fluctuation test on *Salmonella typhimurium* TA 100 and TA 98 with and without metabolic activation S-9. Both *Salmonella typhimurium* TA 100 and TA 98 are mutant strains, carrying mutations in the operon coding for histidine biosynthesis [11, 13]. When these bacteria are exposed to mutagenic agents, under certain conditions reverse mutation from amino acid (histidine) auxotrophy to prototrophy occurs. In the assay, the test agent can not diffuse into the bottom agar away from the bacteria held in the top-agar, since the concentration remains constant during the auxotrophic growth phase. This is advantageous when dealing with compounds which are mutagenic only at concentrations which are toxic or near toxic, where the received dose may be critical [14]. In this study, eight mould species isolated from buildings were used to determine their potentials to evoke cytotoxic effect on two human cell lines Hep-2 and Hfl-1 and *Salmonella typhimurium* TA 100 and TA 98 strains were used to determine their genotoxic effects.

2 Materials and Methods

2.1 Fungal Species

Bulk samples collected in dwellings (Air sample, swabs, wallpaper etc) were cultured on Malt Extract Agar (MEA) at 23°C for 1 to 2 weeks. Fungi were identified based on their morphology and production of secondary metabolites.

Eight fungal species *A. parasiticus A. ochraceus, A. fumigatus, A.versicolor P. citrinum, Chaetomium globomm, Phoma macrostoma* and *Ulocladium chartarum* isolated from building substrates tested were used for the cytotoxicity and mutagenicity assay. Samples were isolated from the building substrates and cultured on MEA at 23°C for 7 days and toxins extracted using 5ml methanol. Extracts were filtered through Whatman no.l, filter paper and then evaporated under nitrogen. The residues was reconstituted in 2ml growth medium Ham's F12 for (Hfl-1 analysis) and MEM for (Hep-2 cells analysis) and stored at 4°C until needed.

2.2 Maintenance of cell lines

Human foetal lung (Hfl-1) and HeLa-derived larynx epithelium (Hep-2) were both purchased from the European Collection of Cell Culture (ECC, Salisbury, UK). Hfl1 fibroblasts was cultured and grown in Ham's Fl2 medium while, Hep 2 was cultured in Minimum Essential Medium (MEM) containing Earls's salts and glutamine (MEM, BioWhittaker BE12-611F) both, supplemented with 1% (v/v)non-essential amino acids (BioWhittaker BE1-114E), 100 IU/ml Penicillin (Sigma, P-0906), 100 µg/ml Streptomycin (Sigma, P-0906), Amphotericin B (0.25µg/m1, BioWhittaker BE17-836E) and Foetal bovine serum (FBS, 10%, BioWhittaker). At the attainment of 80-90% confluence, 4ml of Trypsin/EDTA (0.05%/0.02%, v/v) solution (Gibco, Paisley UK) was used for cell detachment and washed twice using PBS for the removal of trypsin/EDTA and transferred into a fresh media and incubated at 37°C, 5% CO_2 incubator until needed.

2.3 Application of toxin extract onto cell line

Fresh growth media (Ham's F12 and MEM 2ml of each) was added to the toxin extract and 100µl of same media was suspended into a sterile cell well in triplicates with a serial dilution from 1:1 to 1:128 and 100µl of cells ($5x10^5$) in growth medium pipette into the various cell well. Ten microliter (10 µl) and 20 µl of Triton X were added into empty cell well in triplicate and 100 µl of the cell suspension added, this serves as the positive control. 200 µl of growth medium was placed in an empty cell well as background. Cell line was incubated for 24, 48 and 72hr at 37°C, in a 5% CO_2 incubator.

2.4 Evaluation of cytotoxicity of toxin extracts

After 24hrs, 48hrs and 72hrs of incubation, the cytotoxicity of the extract was determined using the MTT method as described by Robb *et al,* and Calvert *et al.,* [15-16]. Supernatants were removed from the wells and 80µl of (MTT) in PBS ($2mgml^{-1}$) added to each well and incubated at 37°C, 5% CO_2 for 4hrs. One hundred microliter (100 µl) of Dimethyl-sulfoxide (DMSO) was added to dissolve any intracellular formazan crystal and agitated for 15 min on a rotary shaker. An ELISA plate reader (Dyntech, France) was set at 570nm wavelength and the absorbance read to determine the survival ability of cell lines through MTT cleavage. In order to calculate the percentage cell death/survival (cytotoxicity), the mean optical density was used. The percentage of cytotoxicity was calculated as;

$$\%\ \text{cell survival} = \frac{[A-B]}{A} \text{ X } 100 \qquad (1)$$

Where A=mean optical density of untreated wells containing cells only, B= optical density of wells with mould extract.

IC_{50} concentration as an effective dose to determine the growth inhibition of the cells using mycotoxins was calculated from the linear interpolation of the 2 test points that correspond with the 50% inhibition, one point lower and one point higher (MCL-5 Metabo, Woburn Massachusetts). Using the formula;

$$IC_{50} = \frac{[(50\%\text{-Low}\%) \text{ x } (C_h - C_i)]}{(\text{High}\%\text{-Low}\%)} + C_i \qquad (2)$$

where: C_h= High concentration, C_i= Low concentration, High%= High percentage, low%= low percentage.

The IC_{50} value is a 50% inhibition of cell growth or metabolic cell activity.

2.5 Mutagenicity determination of the fungal extract

The mutagenicity of the fungal extract was determined using a commercial kit Muta-Chromplate [14]. Two mutant bacterial strains *Salmonella typhimurium* TA98 and TA100 maintained on a nutrient agar slant incubated at 40°C for 24 hours. Davis-Mingioli Salt, 21.62mL; D-glucose, 4.75mL; Bromocressol Purple, 2.38mL; D-Biotin, 1.19mL; and L-Histidine, O.OomL constituted the reaction mixture used for the analysis. Two standard mutagens; Sodium azide (NaN_3, 0.5 μg/100μL) was the standard mutagen for TA100 strain and 2-Nitrofluorene (2-NF, 30 μg/100μL) used with TA 98 strain. When S-9 was used, 2-Amino-Anthracene (2AA) replaced NaN_3 and 2-NF. All chemical and test strains used for the Ames test were purchased from Environmental Biodetection Products Inc (Brampton, Ontario, Canada).

2.6 Mutagenicity assay

The mutagenicity test was carried out as described by Ames *et al,*. [11] and Maron and Ames [13].Reagent mixture, fungal extract, distilled water and standard mutagen were prepared in sterile bottles as indicated in Tables 1. An over night culture broth of *S. typhimurium* (TA100 and TA98 each) was inoculated into the various mixture in the bottles at various concentration of *25\\L* respectively. Two hundred microliter of the mixture was dispensed into a 96-well microtitration plate using a multi-channel pipette. The plates was placed in an air tight sterile plastic bag to prevent evaporation and incubated at 37°C for 4 days. A mutagenic test was considered positive, if the compound induced a concentration dependent increase in revertant number.

2.7 Statistical analysis

Experiments were carried out in triplicate for the cytotoxicity assay and results were calculated on Prism GraphPad Software V. 3.0 (GraphPad Prism, Graph Pad Software, San Diego, USA). For each mutagenicity test plate, significant difference of number of positive wells compared to the background plate was determined statistically using Gilbert statistical table [17].

3 Results and Discussion

3.1 Cytotoxicity assay

Eight different fungal extracts from *A. parasiticus, A. ochracem, A. fumigatm, A. versicolor, P. citrinum, Chaetomium globomm, Phoma macrostoma* and *Ulocladium chartarum* isolated from homes with mould problem were tested for their cytotoxic effect using Hep-2 and Hfl-1 cells (Fig.l &2). Both the aspergilli and penicillia species used for the analysis have been reported as producers of different types of mycotoxins namely, aflatoxins, ochratoxin, sterigmatocystin, gliotoxin and citrinin [2, 3, 7]. The results of the study show the cytotoxic nature of both the *Aspergillus* and *Penicillium* spp. on both cell lines. Although not much has been reported about *Chaetomium globomm, Phoma macrostoma* and *Ulocladium chartarum,* extracts from these fungi showed some form of cytotoxic effect on the cells with time (Tables 2 and 3).

In their work Udagawa *et al.,* [18] and Sekitaet *et al.,* [19] both showed that *Chaetomium* produced decakitide sterigmatocystin which is a hepatotoxic precursor of Aflatoxin BI. The cytotoxic nature of *Chaetomium* could be attributed to the production of decakitide sterigmatocystin, which among other secondary metabolites produced by this fungus could be responsible for the cells death over time. *Aspergillus ochraceus* extracts was highly cytotoxic on both cells used with 100% cell death using a concentration of 100μl/ml at 24, 48, and 72 hr. The corresponding IC_{50} values (define as the extract concentration that results in 50% cell growth inhibition) was determined and the results are presented in Tables 1 and 2. From the result, *A. versicolor* extract had the least cytotoxic effect among all five known toxigenic fungi (IC_{50} 15.06 μl/ml on Hep-2 and 15.63μ/ml on Hfl-1) after 72 hr. The cytotoxic nature of all extracts on both cell lines was time dependent as the IC_{50} value increased with the amount of time the cells remained in the presence of the extracts.

In comparing both cell lines, Tables 2 and 3 shows that Hfl-1 was more susceptible to the extracts at a dosage lower than that observed on Hep-2 cells. The use of various fungal extract in the cytotoxicity analysis on both cell lines, showed the different effect exhibited by different fungi species. Antibiotics, penicillin and streptomycin, added to the cell culture medium to prevent bacterial contamination of the culture showed no measurable cytotoxic effects. Due to the polar nature of most mycotoxins, and their insolubility in cell culture medium, methanol was used for the extraction of mycotoxins from the fungi. Methanol only exhibited minimal or no effect on the cells after 24, 48 and 72hr and thus the cytotoxic effects in the assay can be attributed to the various mycotoxins produced by the fungal species used.

Table 1. Set-up fluctuation assay with and without S-9 activation

	Volume (ml)					
Treatment	Standard (NaN_3, 2NF or 2AA)	Fungal extract	Reagent mixture	S-9 mix	Water	Test Strain (TA 100 & TA 98)
Blank	-	-	2.5		17.5	-
Back Ground I	-	-	2.5		17.5	0.010
Back Ground II		-		2.0		0.010
Standard mutagens	0.1	-	2.5	-*	17.4	0.010
Test sample I	-	0.015, 0.025	2.5		17.5	0.010
Test sample Π		0.015, 0.025	2.5	2.0	15.5	0.010

* = Not Added, 2.0 ml S-9 when 2AA

Table 2. Concentration of mould extract required to achieve 50% inhibition (IC_{50}) of Hep-2 cells

	Time of incubation (hour)		
Fungi	24	48	72
	Concentration (µl/ml)		
A. fimigatus	nd	11.75	8.18
A. ochraceus	39.62	9.49	2.48
A. parasiticus	78.60	7.61	5.73
A. versicolor	nd	23.24	15.06
P. citrinum	nd	13.83	9.24
Chaetomium	nd	38.57	7.05
Phoma	nd	31.94	59.41
Ulocladium	nd	76.29	83.01

nd = not detected

Table 3. Concentration of mould extract required to achieve 50% inhibition (IC_{50}) of Hfl-1 cells

	Time of incubation (hour)		
Fungi	24	48	72
	Concentration (µl/ml)		
A. fimigatus	83.99	4.61	2.57
A. ochraceus	27.58	2.13	1.25
A. parasiticus	36.40	5.75	4.08
A. versicolor	nd	23.13	15.63
P. citrinum	75.95	6.89	4.45
Chaetomium	80.92	5.65	5.49
Phoma	nd	10.13	11.61
Ulocladium	nd	33.81	31.71

nd = not detected

Table 4. Salmonella *typhimurium* Ames test with *S. typhimunum* TA100 and TA 98 25µl of mould extract with and without S-9 activation.

Fungi	TA 100		TA98	
	+ S9 (%)	- S9 (%)	+ S9 (%)	- S9 (%)
A.parasiticus	7.3	100	6.3	75
A. ochraceus	9.4	100	12.5	70
A. versicolor	8.3	n.d	15.6	n.d
A. fiimigatus	11.5	n.d	13.5	n.d
P. citrinum	8.3	100	14.5	60.4
Chaetomium	5.2	78.5	12.5	55.8

n.d = not determined, + S9= S9 added,
- S9= S9 not added

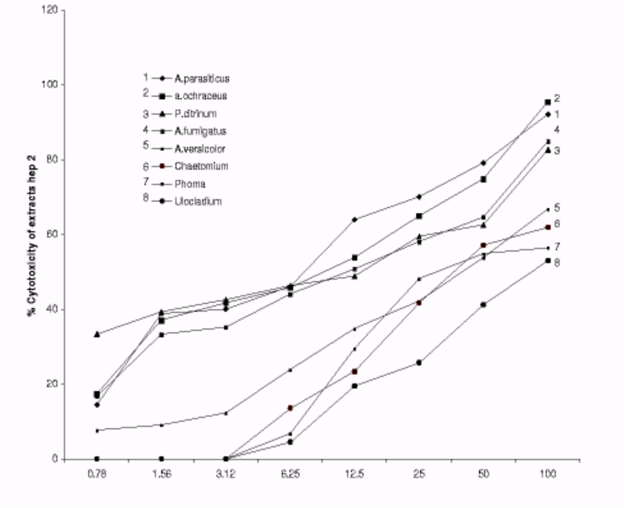

Fig.l. Cytotoxicity results of eight mould species isolated from indoor environment exposed to Hep-2 cells at 48hr.

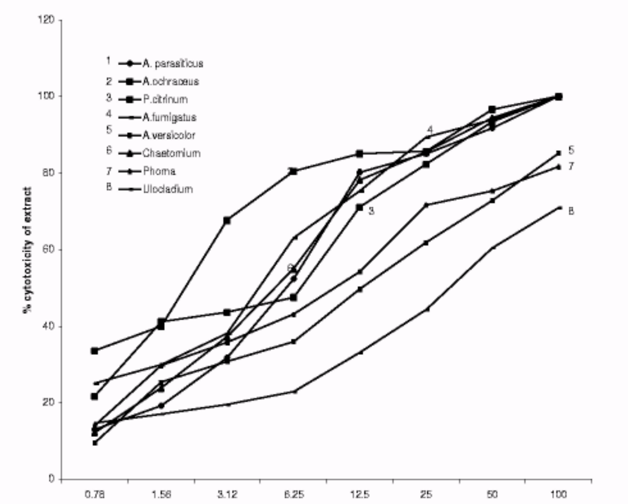

Fig.2. Cytotoxicity results of eight mould species isolated from indoor environment exposed to Hfl-1 cells at 48hr.

3.2 Mutagenicity assay

The result of the Ames test was read when the blank plate were purple indicating the assay was not contaminated. A statistical procedure was used to score the plates. A sample was considered mutagenic when it produced a reproducible, dose-related increase in the number of revertant colonies and weak when it produced a reproducible, dose-related increase in the number of revertant colonies but the number of revertants was not double the background number of colonies. The number of positive wells compared to background plate was determined statistically using Gilbert Statistical Table [15]. The result using the six species at 25µ1, showed that all the mould tested *(A. parasiticus, A. ochracem A. versicolor, A. fumigatm, P. citrinum* and *Chaetomium)* were weakly positive to the test strain TA 100 and TA 98 when no metabolic activation (S-9) was added. Four of the test mould species, *A. pamsiticus, A. ochmceus P. citrinum* and *Chaetomium globosum* selected for the analysis using same concentration of 25µ1 with the activation mix (S-9), the result showed both TA 100 and TA 98 *salmonella typhimurium* strains were highly mutagenic to the tested samples (Table 4). In general S-9 reduced toxicity and improved the test ability to detect mutagenicity of the extracts used.

4 Conclusions

All fungal extracts tested showed cytotoxic effect on the two cell lines, *A.ochraceus* extract showed much higher cytotoxic effect on both cell lines. *A. parasiticus, A. fumigatus, P.citrinum, A. versicolor, Chaetomium, Phoma* and *Ulocladium* showed cytotoxic effects on both cell lines in a descending order, with and IC_{50} range of 2.48 to 83.01 using Hep-2 and 1.25 to 31.71 using Hfl-1 cells. Human foetal lung fibroblasts (Hfl-1) showed higher cytotoxic response to all extracts as compared to HeLa-derived larynx epithelium (Hep-2). Mould extracts used for the mutagenicity test were weakly mutagenic on both test strains TA 100 and TA 98 without the activation mix (S-9) and the four test samples tested with the S-9 activation mix were highly mutagenic. The mutagenic result indicates that, the extracts requires activation even when present in an individual body and the human liver is a good source of activation which can help to activate the mutagens in the body.

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TXIB-Emission from Floor Structure and Reported Symptoms before and after Repair

P. Metiäinen[1], H. Mussalo-Rauhamaa[2] and M.Viinikka[1]

[1] City of Helsinki, Environment Centre, P.O.Box 510, FIN-00099 City of Helsinki, Finland
email: pertti.metiainen@hel.fi [2] Helsinki University Central Hospital, Departments of Dermatology and Allergic Diseases, Finland

Summary: *A small scale study was conducted in order to find out how the repair of flat's floor structure would effect the emissions from the floor structure and reported symptoms of the residents. 16 flats with a PVC-carpet on concrete floor were studied. Residents of all flats reported symptoms before being aware that there was anything wrong in their flat, for example they did't complain about any odors. Volatile organic compounds were measured by the GC/MSD system. Unusually high concentrations of 2,2,4-trimethyl-l,3-pentanediol di-isobutyrate (TXIB) in indoor air were detected. Subsequently, all flats were repaired. The old PVC-carpets and glue were removed; room air temperature and ventilation rate were increased for a couple of weeks in order to air out organic compounds from the floor structure. A new low-emitting Ml-labelled PVC-carpet was glued on the floor. From one to six months after finishing the repairs, a new questionnaire was mailed and IAQ measurements were repeated. The consentrations of TXIB decreased dramatically and 74% of the residents reported significant or slight decrease in their symptoms. Our results of this study indicate that these findings could potentially be of major importance to public health.*

Keywords: *TXIB, PVC, VOC, symptoms, floor structure, repair*
Category: *Materials as sources for indoor pollutants*

1 Introduction

There is an increasing body of evidence indicating that poor quality of indoor air increases the frequency of skin, mucosal and upper respiratory tract symptoms. Low rates of ventilation and air exchange seem to enhance the effects of indoor air pollutants [1]. Previous studies have found an increased prevalence of asthma among subjects with domestic exposure to newly painted surfaces [2]. Plastics (PVC) and textile wall materials also appear to have a role in the development of asthma and bronchial obstruction in young children [3].

Higher concentrations of TXIB in indoor air seem to increase the risk of symptoms like nose and eye irritation, throat symptoms and "heavy head". The number of asthma diagnosed by a doctor was high in one of the target blocks of flats. Symptoms may be a direct result of TXIB exposure. Alternatively, TXIB may act as a marker for another PVC component [4]. Correlation between TXIB-emission and eye and nose irritation has also been reported [5].

The storage capacity of concrete for decomposition products of PVC-carpet and glue is a critical factor concerning future emissions from the floor, since up to one half of the decomposition products can be transported downwards and stored in the concrete. The organic compounds stored in the concrete can, if conditions change, be emitting to the indoor air over a long period [6]. High quantities of 2,2,4-trimethyl-1,3-pentanediol di-isobutyrate (TXIB) were still emitted from floor structures that were over ten years old [4].

The idea for this study came from City of Helsinki Environment Centre. It was important to find out how repair of the floor structure would change emissions and symptoms reported by the residents.

2 Methods

Health effects were investigated by a cross sectional study. Indoor Air Quality (IAQ) measurements were conducted during the home calls. The inspector of City of Helsinki Environment Centre conducted an interview, an overall study based on sense perception, ventilation rate measurements and checked the moisture condition of the structures (from the surface). Later on air samples for volatile organic compounds (VOC) measurements were collected.

In this study 16 flats were selected from the City of Helsinki database. These flats had an unusually high concentration of TXIB in indoor air and the residents would stay in their apartment after repair. The source of TXIB was a low quality PVC-carpet on concrete floor. These flats located in eastern parts of Helsinki and some were in semidetached houses or in a block of flats. The main frame in these buildings was made of reinforced concrete and the floor structure mentioned above was made of PVC-carpet, glue, screed and concrete slab. The flats were built between 1990 and 1994.

The old PVC-carpets and glue were removed; room air temperature and ventilation rate were increased for a couple of weeks in order to air out organic compounds from the floor structure. A new low-emitting Ml labelled PVC-carpet was glued on the floor with low-emitting Ml labelled glue [7]. The repair work was done in 2000-2002.

Ventilation rate was estimated by measuring air flow through outlets (TSI Veloci Calc 8388). Moisture condition of the structures were estimated from their surface (Gann Hydromette UNI 1). The VOCs were collected on Tenax TA from indoor air (from the middle of the living room and bedroom, 1.2 m above floor level). VOCs were thermally desorbed from sampling tubes into a GC/MSD system (Hewlett Packard 6898). TVOC concentration in indoor air was verified by SCAN-method. TXIB concentration in indoor air was verified by SIM-method. The first measurements were conducted in 1999-2002 and the second measurements after the repair work in 2001-2002.

The first questionnaire was mailed to all residents before repair (2000-2002). The questionnaire included questions about the residents' symptoms, medical history and living conditions. The response rate was around 100%. The questionnaire used in this study was the Örebro (MM-40-FIN) questionnaire where a few questions from the Finnish Tuohilampi questionnaire were added. The residents were asked to report symptoms occurred during the last three months and diseases occurred during the last twelve months. The parents reported on behalf of children younger than 14 years old.

The second questionnaire was mailed one to six months after repair (2001-2002). This questionnaire was very simple and it included questions about any changes in reported symptoms and IAQ (included only in 2002 questionnaire) and any possible complaints of the repair work. The parents reported on behalf of children younger than 14 years old. All residents responded to this questionnaire.

3 Results

Volatile organic compounds (VOC)

TVOC concentrations in indoor air varied before repairs between 150 - 630 µg/m^3, the median was 305 µg/m^3. After repair TVOC varied between 100 - 705 µg/m^3, the median was 270 µg/m^3. In figure 1 the TVOC concentrations in indoor air are presented for each flat before and after repair.

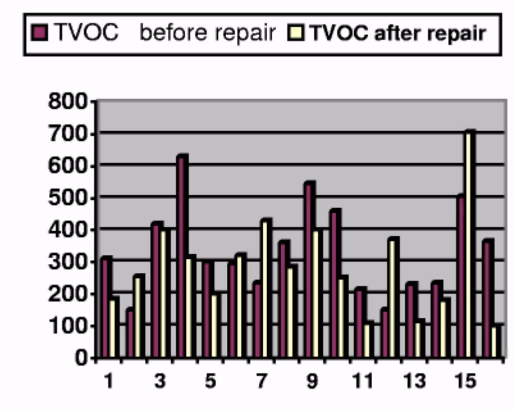

Figure 1. TVOC-concentration in indoor air (µg/m^3) before and after repair

TVOC concentrations in indoor air decreased or increased very randomly after repair. This could be explained by acknowledging that there are many factors affecting TVOC concentration, like the lifestyle's of the residents.

TXIB concentrations in indoor air varied before repairs between 31 - 183 µg/m^3 (2.6 - 15.4 ppb), the median was 54 µg/m^3 (4.5 ppb). After repair, TXIB varied between 2 - 16 µg/m^3 (0.2 - 1.3 ppb), the median was 7 µg/m^3 (0.6 ppb). In figure 2 the are TXIB concentrations in indoor air are presented for each flat before and after repair.

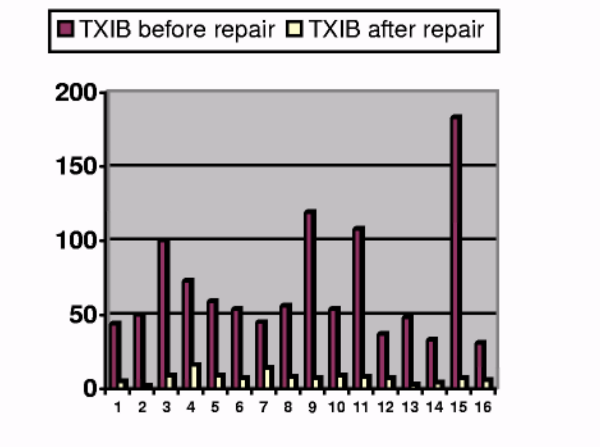

Figure 2. TXIB-concentration in indoor air (µg/m^3) before and after repair

This repair method had a great effect on TXIB concentration in indoor air. TXIB concentration decreased in all flats to a fraction of its previous values after repair. This was a result of airing out VOCs from the concrete slab and using a new low-emitting (labelled Ml [7]) PVC-carpet.

Results from questionnaires

There were a total of 35 residents living in the flats, 16 males and 19 females, ages varied between 0 - 61 years old and the mean being 19 years.

Table 1. Some results from the questionnaires

	Amount of answers N = 35
Development in health a symptom or illness	
improved significantly	20 (57%)
improved sligthly	6 (17%)
remained the same	6 (17%)
worsened sligthly	3 (9%)
worsened significantly	-
not applicable (always in good health)	-
Indoor air quality*	
improved significantly	6 (26%)
improved sligthly	12 (52%)
remained the same	-
worsened sligthly	-
worsened significantly	-
no responce	5 (22%)
Reported quality of repair work	
good	23 (65%)
some complaints	9 (26%)
no responce	3 (9%)

*This question was included only the questionnaires send in 2002, amount of answers N = 23.

A majority (74%) of the residents reported significant or slight improvement in their health Also a majority (78%) of the answers from the questionnaire of 2002 reported significant or slight improvement in indoor air quality. 65% of the residents reported that the quality of the repair work was good and 26% reported some complaints about the quality or refinements of the repair work.

Table 2. Development of reported symptoms or illnesses. Residents reported one or more symptoms.

Symptom or illness	Amount of answers N = 35
Healed/disappeared/improved	
Skin symptom	4
Throat symptom	5
Cough	6
Headache	6
Runny nose/blocked nose	5
Sneezing	1
Eye symptom	1
Ear infection	1
Asthma	1
Did not specify which symptom was improved	10
Worsened slightly	
fever	3
cough	1
depression	1

The residents reported significant improvement in many different symptoms like cough, a sore throat, nose symptoms and headache.

4 Discussion

In a recent study on odor and chemesthesis from brief exposures to TXIB it had claimed that some odor could be sensed at 1,2 ppb and chemically stimulated symptoms could occur only concentrations of 2,1 ppm or more [8]. In this study test subjects were exposed to clean TXIB vapor of different concentrations for many hours through a headspace. In our case some residents had been living in their flat for many years. We don't know how high the concentrations of TXIB in indoor air there had been in the beginning. In addition TXIB doesn't exist only as clean vapor in indoor air, but as adsorbed into dust particles or into the surfaces. Small children often crawl on the floor and they are hence exposed more than adults to TXIB and other possible compounds evaporating from a PVC-carpet. The mechanism and the harmful substance(s) triggering symptoms are still unknown, but studies show that the TXIB concentration in indoor air and symptoms have a relation [4][5]. Our suggestion is either that TXIB has a significant relation with symptoms or the other unknown substance is in the same proportion as TXIB in indoor air and TXIB would be a marker for it.

5 Conclusion

In our study we found out that it is possible to reduce significantly TXIB-concentrations in indoor air, following in a reduction in the amount of symptoms reported by the residents. The method used in the repairs included airing out concrete floor for a couple of weeks and installing a new low-emitting PVC-carpet.

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Predicting Spatial Distribution of Infection Risk of Airborne Transmission Diseases in a Hospital Ward

Hua Qian[1], Yuguo Li[1], Peter V. Nielsen[2], Xinghuang Huang [3]

[1]Department of Mechanical Engineering, The University of Hong Kong, Hong Kong SAR, China.
Email: keenwah@hkusua.hku.hk
[2]Department of Building Technology and Structural Engineering, Aalborg University,
DK-9000 Aalborg, Denmark
[3]Department of Mechanical Engineering, Shanghai Jiaotong University, Shanghai, China

Summary: *This study attempt to integrate the Wells-Riley equation and computational fluid dynamics for analyzing the risk of airborne transmission diseases in a building. The new method can predict the spatial distribution of the infection risk of the airborne transmission diseases in a large hospital ward, while the Wells-Riley equation alone can only predict the overall infection risk in the whole building assuming a uniform distribution of the droplet nuclei concentration. This new method is applied to analyze the transmission risk in the well documented 8A ward SARS outbreak in a Hong Kong hospital in 2003.*

Keywords: *Wells-Riley equation, SARS, airborne transmission of diseases, CFD*
Category: *Communicable diseases indoors: SARS, legionellosis and other*

1 Introduction

Avian flu has become a new threat as we just escaped from the terror of the 2003 SARS outbreak. Considerable attention has been paid recently on the potential high-risk transmission of infectious diseases in public areas such as hospital wards, schools, airplanes etc. Furthermore, there still exists the risk of outbreak of airborne transmission diseases, such as measles, chickenpox, TB and so on. It was estimated there were up to 8.8 million new cases and 3 million deaths annually on the worldwide only for TB, which contributed to 6% of all deaths [1]. Analyzing the outbreak case and accurately estimating the infection risk of infectious diseases can help us understand the transmission route of infectious diseases and take method to decrease it.

This study focuses on the prediction of spatial distribution of infection risk of airborne transmission of infectious diseases. It is well known that the droplet nuclei are the vehicles to transmit airborne transmission diseases [2]. Droplet nuclei, the residuals of dried-out droplets, are small in size of generally less than 5 μm in diameter. The settling velocity for the particles less than 5 μm in still air is less than 1 m/h, which make its distribution pattern in the air close to that of gaseous pollutants. In order to estimate the risk of airborne transmission diseases, Wells (1955) introduced the concept of quantal infection [3]. A quantum is the dose which is necessary to cause infection to a new susceptible, and a quantum may be one or more airborne pathogens, which can attach in the droplet nuclei.

The most successful prediction model for the infection risk of an airborne transmission disease is the so-called Wells-Riley equation which is based on the concept of quantal infection [4]:

$$P = \frac{C}{S} = 1 - e^{-Iqpt/Q} \tag{1}$$

where p is the pulmonary ventilation rate of each susceptible per second (m^3/min); Q is the room ventilation rate (m^3/min); q is the quanta produced by one infector (quanta/min); and t is the duration of exposure (min).

The Wells-Riley equation works well when droplet nuclei of infectious particles were randomly distributed in the room air, which means that the air is fully mixed in the enclosed space and the average concentration is Iq/Q. It implies that the chance of infection is equal spatially indoors.

The largest nosocomial SARS outbreak in Hong Kong occurred in 8A ward in a public hospital in 2003. The spatial distribution of infection cases was not even and it was related to airflow pattern in the 8A ward [5, 6]. The traditional Wells-Riley model cannot interpret the spatial distribution of the infection cases in a large space in spite that it may interpret the temporal distribution. Li et al (2005) showed the relationship between the infection cases and airflow pattern using computational fluid dynamics simulations and field measurement [5]. Li et al. (2005) did not predict the infection risk distribution in the space. We propose a method here to integrate the Wells-Riley model into CFD. The new model can calculate the spatial risk distribution in a large space.

2 Integrating Wells-Riley equation into CFD

The viability of airborne organisms differs under different environmental conditions (temperature, humidity, UV etc). Dunklin and Puck (1948), Ferry et al. (1958) and Riley and O'Grady (1961) noted that when organisms were atomized into air, the rate of their death was at first rapid and then subsequently slowed down [7,8,9]. The first rapid decay (high death rate) occurred within a very short time, which also means that the rapid decay only occurred within close vicinity from the infector's exhaled mouth or nose. In order to simplify the model, the first rapid death is dealt with the source and the death rate of microorganism at any given condition in the pasteurizing range can be treated as proportional to the number of living cells present [10], the viability of the airborne organisms in a closed space can be written as:

$$\frac{dN}{dt} = -kN \tag{2}$$

Where N is the concentration of the quanta (quanta/m^3)

Airborne organisms are assumed to be attached in particles or in droplet nuclei, which are very fine particles or the residual of dried-out droplets. The governing equation for the airborne organisms transport in indoor air can be written as following:

$$\frac{\partial(\rho N)}{\partial t} + \nabla \bullet (\rho (V + V_s) N) = \nabla \bullet (\Gamma \nabla N) - k\rho N \tag{3}$$

The above equation is based on a drift-flux particle model [11]. Vs is the settling velocity for the particles.

Equation (3) allows us to estimate N, the number concentration of quanta in an indoor space after the airflow field is obtained. The infection risk of one susceptible can then be estimated as:

$$P = 1 - e^{-pNt} \tag{4}$$

The total predicted the number of infected cases, C, for S susceptible who may be located at different locations with different quanta concentration N_i will be:

$$C = \sum_{i=1}^{S} (1 - e^{-pN_i t}) = S - \sum_{i=1}^{S} e^{-pN_i t} \tag{5}$$

The escape possibility for one susceptible exposed with different quanta generation for different time duration can be written as:

$$\text{Escape possiblity} = e^{-p\sum_{j=1}^{n} N_j t_j} \tag{6}$$

The total predicted cases for S susceptible at different locations with different quanta concentration N_i and different time duration can be calculated as below:

$$C = \sum_{i=1}^{S} (1 - e^{\sum_{j=1}^{n} -pN_{ij} t_j}) = S - \sum_{i=1}^{S} e^{\sum_{j=1}^{n} -pN_{ij} t_j} \tag{7}$$

3 Ventilation parameters and infection distribution patterns in Ward 8A

A total of 39 beds were placed in 4 main semi-enclosed cubicles, each with a dimension of 7.5m× 6m×2.7m, and 2 beds was placed in the isolation cubicle in the ward 8A with overall dimension 24m×18m×2.7m during the period of SARS outbreak there. The ventilation rate was measured on July 17, 2003 when the operation parameter of ventilation system was set as close as possible to that during SARS outbreak. The measured air change rate for the whole ward 8A was 7.8 ACH including 70% recirculated air. The measured airflow rate for each supply diffuser, return, and exhaust outlets and the floor plan of ward 8A during the period of SARS outbreak in 2003 was shown Figure 1, and more details can be found in [5]. The temperature and relative humidity of supply air were at 14^{o}C and 100% respectively and those of return air were at 22 ^{o}C and 75% respectively.

The index patient was admitted into Ward 8A on March 4 and was placed in bed 11 until March 12. His cough was suspected as the main pathogen source [5,6]. Wong et al (2004) and Li et al (2005) studied the infected medical students who examined patients at bed-side with relatively unchanged position during the time [5,6]. They also provided the epidemiological features, spatial distribution pattern among the medical students. Among 16 of 66 medical students developed SARS, there are 10 out of 27 students who reported to enter the index patient's cubicle while 8 of 18 students who could not recall whether they entered the cubicle and 1 out of 20 never entering the cubicle. The relative risk of the same cubicle as the index patient was 7.4 [(10/27)/(1/20)], which clearly describe the association between the infection and position of susceptible. Among all medical students, a group of 20 third-year students was particularly worthwhile for further studying because none of them visited ward 8A for assessment after March 7 or contacted with other SARS patients after their March 6 or 7 visits. The positions of this group of medical students during their bedside clinical assessment are shown in Figure 1, which excluded the ill student who had an unusually long incubation period (onset on March 23). The time schedule of the clinical assessment of the 19 medical students is shown in Table 1.

Those medical students were assessed by 11 assessors, among which 5 assessors on March 6, 5 on March 7 and only 1 evaluated on both days. The five assessors on March 6 only all developed SARS while three of five assessors for March 7 only developed SARS and the one presented on both days also developed SARS. The infection cases of the group of third-year medical students accessed on March 6 and 7 are chosen here to analyze the infection risk of medical students.

4 Results and Discussion

Calculation quanta generation by the Wells-Riley Equation

In order to calculate the risk of the medical students, some assumptions should be made. We first assume that the pulmonary ventilation for each patient is 6 l/min. The total airflow rate of the ventilation system is 77.4 m^3/min or 7.9 ACH. There are no data on the fine particle (droplet nuclei) removal efficiency of the filter in the air conditioning system and the survival rate of virus as they pass through the ductwork or filter. If the combined filtration efficiency (considering the virus death rate) is 0%, 50% and 100%, the equivalent airflow rate from outdoor is 23.22, 50.31 and 77.4 m^3/min respectively. We assume that the quanta generation is steady and same for each day. The results of quanta generation are also summarized in Table 1. We use the obtained quanta generation to estimate the infected cases in assessors, which results were shown on Table 2. The predicted results agreed very well with the real cases.

Integrate the Wells-Riley Equation into CFD analysis

There are no data of the spatial distribution of the medical students for each session or each day. The locations of 19 medical students on March 6 and March 7 are shown in Figure 1. We assume the quanta generation during the whole examining period is a constant. As we cannot find any data on the viability of SARS Co-virus in air, the death rate of SARS Co-virus here is assumed to be zero. The process of droplet evaporation is also ignored and the size of droplet nuclei size was assumed to be same as the gaseous pollutant. Due to no data on the efficiency of filters installed in Ward 8A, we calculated risk with three filter efficiencies and compared the results.

The calculated risk of each medical student was summarized in Table 3. The spatial risk distribution for three ventilation systems is shown in Figure 2. The data agreed well with the infection cases for three ventilation efficiencies. The predicted spatial risk distribution at high efficiency filter seems agree better than the lower ones. A low filter efficiency make the risk distribute more even in the hospital ward. It should be noted here that the calculated spatial risk distribution is based on each calculated quanta generation. At same quanta generation, the risk for a high efficiency filter is obviously greater than that for a low efficiency filter.

5 Conclusions

The classical Wells-Riley model is a powerful tool for analyzing and predicting the infection risk of airborne transmission diseases in spite of that it cannot predict the spatial distribution of risk in a room. Integrating the Wells-Riley equation to CFD can predict the spatial distribution of infection risk of airborne transmission diseases. Using a SARS outbreak in a large hospital ward, we demonstrated that such an integrated method can predict the infection risk distribution of airborne transmission diseases in a large space when the susceptible is at relative unchanged locations, such as a hospital ward or an air plane.

Acknowledgements

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Table 1: Calculated quanta generation using the Wells-Riley equation and the cases of medical students (Those highlighted in gray color means the calculated results)

NO. of infected cases (*C*)	**No. of susceptible involved (*S*)**	**C/S**	**Filter efficiency**	**Equivalent airflow rate (m^3/min)**	**Exposure period (min)**	***Iqpt/Q***	***q* (quata/min)**
7	19	0.37	0	23.52	40	0.010q	148.2
			50%	50.96	40	0.005q	96.3
			100%	78.4	40	0.003q	44.5

Table 2: Predicted number of infected cases of assessors using the quanta generation in Table 1

Filter efficiency	**Equivalent airflow rate (m^3/min)**	**Exposure period (min)**	***Q* (quata/min)**	***Iqpt/Q***	**No. of susceptible involved (*S*)**	**Predicted infected cases**	**Actual infected cases**
0	23.52	160	44.5	1.84	10	8.4	8
50%	50.96	160	96.3	1.84		8.4	8
100%	78.4	160	148.2	1.84		8.4	8

Table 3 Calculated risk of each medical student and the predicted total infected cases (those in brackets are the actual infected cases)

Cubicle	**Close to Bed No.**	**Filter Efficiency =100% *q*=148.2**	**Filter Efficiency =50% *q*=96.3**	**Filter Efficiency =0% *q*=44.5**
Same Cubicle	12a	0.82	0.73	0.59
	12b	0.9	0.82	0.66
	12c	0.94	0.87	0.7
	9	0.58	0.53	0.47
	14	0.57	0.52	0.47
	15a	0.44	0.43	0.42
	15b	0.57	0.52	0.47
	16	0.66	0.57	0.5
	16xa	0.52	0.48	0.45
	16xb	0.54	0.5	0.46
	16xc	0.68	0.61	0.52
	Total infected cases	7.22(9)	6.58(9)	5.71(9)
Adjacent Cubicle	24a	0.29	0.34	0.38
	24b	0.31	0.35	0.39
	17xa	0.35	0.37	0.4
	17xb	0.39	0.4	0.41
	17xc	0.4	0.41	0.41

	Total infected cases	1.74(0)	1.87(0)	1.99(0)
Distance Cubicle	25x	0.18	0.27	0.35
	30	0.1	0.23	0.34
	4	0.12	0.24	0.34
	Total infected cases	0.4(0)	0.74(0)	1.03(0)
The entire ward	Total infected cases	9.36(9)	9.19(9)	8.73(9)

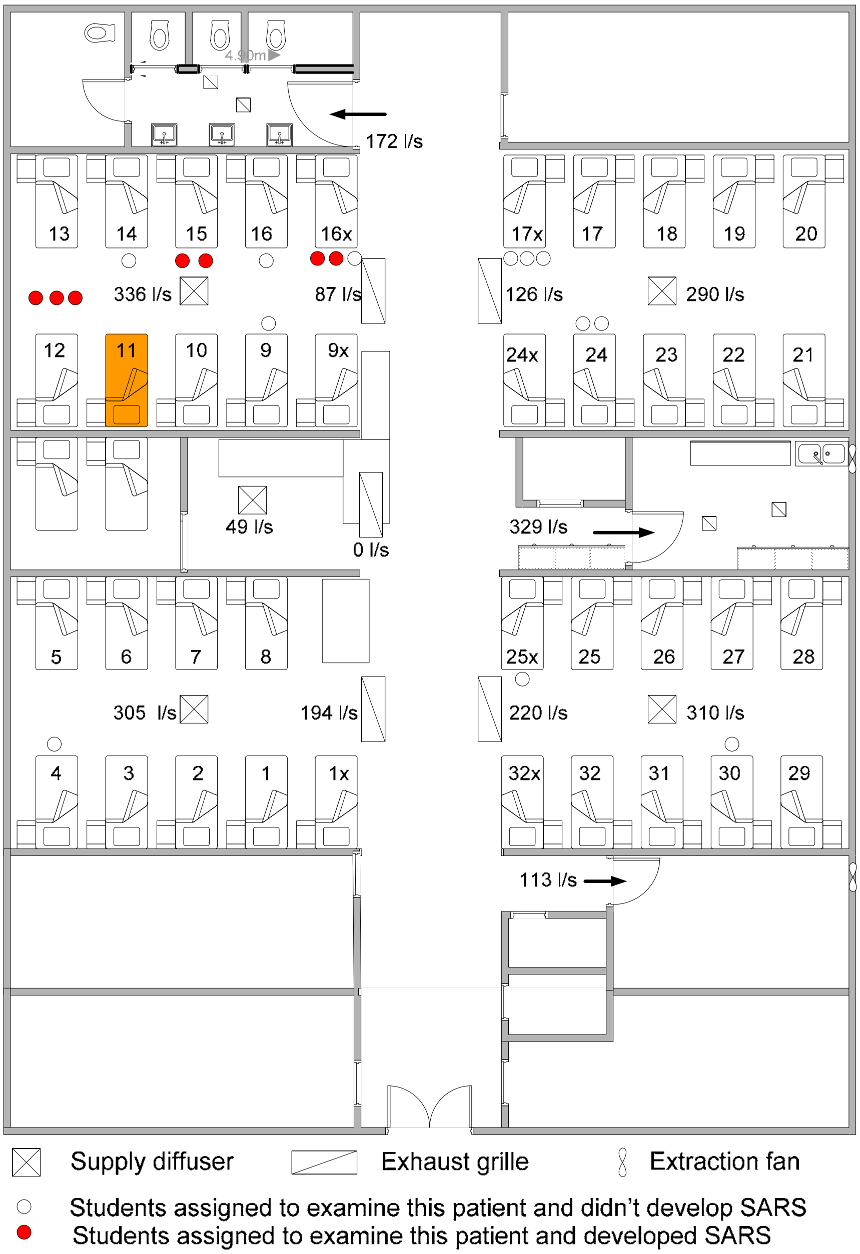
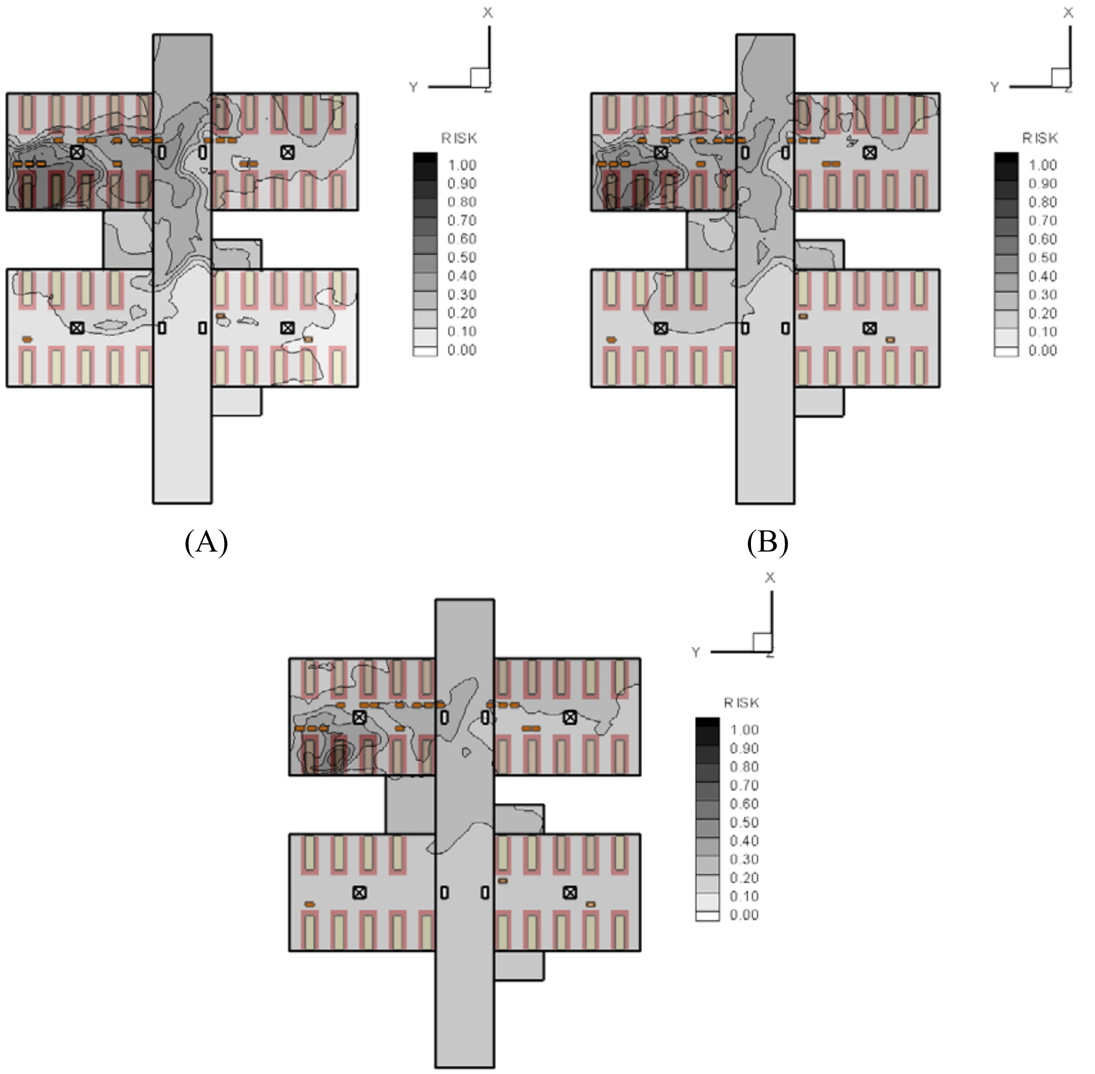


Figure 1 Floor plan of Ward 8A at the time of outbreak in March 2003. Measured supply and exhaust flow rates are also given. The bed no.11 where the index patient stayed is highlighted. The locations of the 19 medical students who attended the 40-min bedside clinical assessments are also highlighted. (Modified from [5]) .



(A) (B)

(C)

Figure 2 Predicted spatial risk distribution in Ward 8A. (A) Filter Efficiency = 100%, *q* =148.2 (quanta/min) (B) Filter Efficiency = 50%, *q*=96.3(quanta /min) (C) Filter Efficiency = 0%, *q*=44.5 (quanta /min).

An Evaluation of a Smoking Ban Ordinance in Bars in Austin, TX

M. S. Waring[1], J. A. Siegel[1] and P. Huang[2]

[1]University of Texas, Civil, Architectural, and Environmental Engineering, C1752, Austin, Texas 78712, USA
email: jasiegel@mail.utexas.edu
[2] Health Promotion Unit, Texas Department of State Health Services, Austin, TX 78756, USA

Summary: *On September 1, 2005, the city of Austin, TX, USA instituted a smoking ban in most indoor public places. In this paper, we present the results of the effects of this ban on indoor air quality and indicators of exposure to environmental tobacco smoke (ETS). We report measurements of* $PM_{2.5}$*, CO,* CO_2 *concentrations, number of smokers, and number of occupants taken at seventeen venues during the month-long periods before and after the ban. Additionally, VOCs were monitored before and after the ban at three venues. The results show a statistically significant decrease* ($P < 0.05$) *in* $PM_{2.5}$ *and CO concentrations after the ban in all compliant venues, except for one venue that was exempt from the ordinance. We found no significant change in the overall number of patrons before and after the ban.*

Keywords: *Environmental tobacco smoke (ETS), smoking ordinance, hospitality venues, indoor air quality*
Category: *IAQ and related health policies and legal issues; Environmental Tobacco Smoke (ETS)*

1 Introduction

Environmental tobacco smoke (ETS) has been determined to be a health hazard [1-5], and although smoking has been banned in all federal buildings in the United States, states and municipalities are left with the responsibility of controlling ETS in public spaces. On September 1, 2005, the city of Austin, TX, USA enacted an ordinance that banned smoking in public places, city buildings, enclosed areas in workplaces, and within 15 feet from an entrance or operable window of an enclosed area in which smoking is prohibited [6]. Bans such as this one are often controversial because owners of bars and restaurants claim to suffer economic losses due to a decrease in patronage. In Austin, this ban has been particularly contentious because the city prides itself on its live music and nightlife scene, and citizens worry about the effect of the ordinance on local bar and nightclub operation and culture. Thus, if municipalities are going to institute smoking bans, the effectiveness of a smoking ban ordinance in reducing exposure to ETS as well as the occupancy effects must be well understood.

In certain localities where indoor smoking bans have been instituted, researchers have been able to measure pre- and post-ban indicators of ETS exposure in the air in one or a sample of venues. Ott *et al.* [7] measured respirable suspended particles (RSP) in a large tavern in Menlo Park, CA, USA 26 times during the two-year period before a smoking ban and 50 times during the one-year period afterwards and found a drastic decline in indoor RSP concentrations after the ban took effect. Repace [8] conducted pre- and post-ban measurements of RSP and particulate polycyclic aromatic hydrocarbons (PPAH) in six bars, a casino, and a pool hall in Wilmington, DE, USA, and he concluded that ETS contributed to 90% – 95% of the RSP indoor air pollution and 85% – 95% of the carcinogenic PPAH when smoking was allowed. Mulcahy *et al.* [9] investigated the effectiveness of a total indoor smoking ban in Ireland and sampled nine pubs for $PM_{2.5}$ and PM_{10} in Galway City, Ireland. The authors found a post-ban decrease of 75 – 96% for $PM_{2.5}$ concentrations and 47 – 74% drop for PM_{10} concentrations relative to pre-ban levels.

This study evaluates the effect of the smoking ban ordinance in Austin, TX on reducing exposure to ETS by measuring indicators of ETS in hospitality venues around the city before and after the smoking ban took effect. The goal of this research is to quantify the indoor air quality benefits of the indoor smoking ban and to provide this information to decision makers.

2 Methods

Indicators of ETS exposure and indoor air quality were measured at 17 Austin-area bars during the month-long period before the ban was enacted and again on the same day of the week and approximately the same time of day during the month-long period after the ban. The venues surveyed were a sample of convenience, were selected over a geographic range in Austin, TX, and were assessed by two different field teams. Eight venues (Venues 1 – 8) scattered throughout the city were evaluated by the first field team, and nine venues (Venues 9 – 17) located in an entertainment hub in the downtown area of the city were evaluated by the second field team. One selected venue (Venue 5) remained a smoking establishment after the ban because of a variance from the ordinance due to a recently upgraded ventilation system. Venue information and indicators of ETS exposure that were measured for this study were: room volume, mean number of occupants, mean number of lit cigarettes, temperature, relative humidity (RH), and $PM_{2.5}$, CO, and CO_2 concentrations. Additionally, at Venues 6, 7, and 8, volatile organic compound (VOC) concentration measurements were conducted before and after the smoking ban.

The room volume was estimated by visual and scaling methods for Venues 1 – 8 and with a Strait-Line Sonic Laser Tape ultrasonic ruler as well as with visual and scaling methods at Venues 9 – 17. The number of occupants and number of lit cigarettes were counted upon entry, then every fifteen minutes, and again upon exit. Occupancy levels were tested for statistically significant changes ($P < 0.05$) with regards to both pre- and post-ban mean occupancy over all venues and the percent change in occupants at each venue.

The temperature and RH in all venues were measured with a TSI Q-Trak. The TSI Q-Trak malfunctioned during the pre-ban testing of Venues 9 – 11, so any pre-ban measurements utilizing this instrument were not recorded for these venues. The $PM_{2.5}$ concentrations were measured with a TSI Dust-Trak by the first field team at Venues 1 – 8 and with a TSI Side-Pak by the second field team at Venues 9 – 17. The CO and CO_2 concentrations in all venues were also measured with the TSI Q-Trak. The TSI Q-Trak was calibrated according to the manufacturer's instructions for both CO and CO_2 before use. Data were collected every 30 seconds outside for five minutes before entering each venue, and then within each venue for at least 30 minutes and, in some cases, up to 90 minutes.

To quantify the effect of the indoor smoking ban on indicators of exposure to ETS, the $PM_{2.5}$ and CO data were analyzed to determine if there was a statistically significant decrease ($P < 0.05$) in concentrations after the ban. Due to the small sample size, the Behrens-Fisher test of the hypothesis that the mean $PM_{2.5}$ and CO concentrations were the same before and after the ban was conducted for each venue. Given that Jenkins *et al.* [10] has shown that the TSI Dust-Trak and Side-Pak overcount particulate matter concentrations, the $PM_{2.5}$ data were analyzed with three different correction factors from their study. The first method involved conducting the significance tests using the raw data from the instruments, which was taken as the upper bound of the particle concentrations. The second method of data analysis was to correct only the pre-ban data, using a correction factor of 4.41, obtained from chamber tests. This second method provided the smallest difference between pre- and post-ban particle measurements and is a lower bound. Finally, the third method was our best estimate and used correction factors of 3.24 for the pre-ban data and 2.57 for the post-ban data, which were determined from tests in smoking and non-smoking areas of hospitality venues. For Venue 5, the post-ban lower bound and best estimate used correction factors of 4.41 and 3.24 respectively, since this venue was approximately equally smoky before and after the ban.

The VOC samples were taken with a SKC Air Check Sampler (model 224-PCXR8) at a flow rate of 1 L/min for 60 minutes onto activated carbon sorbent in two stage tubes, extracted with CS_2, and analyzed with GC/MS. All concentration, temperature, and RH data were collected as close to the center of the main area of each venue as possible.

Finally, the air exchange rate was estimated for each venue with the following mass balance for CO_2 that assumed a well-mixed space and that the only sources of indoor CO_2 were due to the ambient outdoor levels, occupants, and lit cigarettes in the venue.

$$V\frac{\mathrm{d}C}{\mathrm{d}t} = QC_0 - QC + E \qquad (1)$$

where V is the volume of the venue (m^3), Q is the ventilation flow rate (m^3/h), C_0 and C are the outdoor and indoor concentrations of CO_2 (mg/m^3) respectively, and E is the emission rate of CO_2 (mg/h), which is comprised of CO_2 emissions from both people and burning cigarettes. Equation 1 was assumed to be at steady state, and rearranged to yield an estimate of the ventilation rate in air changes per hour, λ (h^{-1}).

$$\lambda = \frac{E}{V(C - C_0)} \qquad (2)$$

Assuming a typical human breathing rate is 0.78 m^3/h [11] and 4% of exhaled air is CO_2 [12], the typical human emits 51.9 g CO_2/h. Also, assuming that a typical cigarette emits 300 mg CO_2 [2] and that it takes on average 6.5 minutes to smoke a cigarette [13], a typical cigarette emits 2.77 g CO_2/hr. Given the assumptions inherent to Equation 2, particularly the assumptions of complete mixing and steady-state conditions, it should be regarded as an approximate estimate of the ventilation rate.

3 Results

A wide range of sizes of venues was sampled, and the range of volumes was 280 to 2500 m^3. The pre-ban range of occupants for all venues was 20 to 230 people, and the post-ban range was 20 to 307 people. The pre-ban range of lit cigarettes was 3.3 to 13 cigarettes, and the post-ban range was 0 to 1.3 cigarettes, excluding for Venue 5 which had an average of 9 smokers after the ban. Other than Venue 5, the lit cigarettes observed during the post-ban assessment were at Venues 3, 13, 14, and 17, where there were occupants who did not comply with the ban. The pre-ban range of temperatures was 21 to 28 °C, and the post-ban range was 21 to 30 °C. The pre-ban range of RH was 41 to 59%, and the post-ban range was 40 to 55%. The mean temperature and RH did not change significantly after the ban. Table 1 lists the volume and number of occupants and lit cigarettes for all 17 venues sampled. Over all of the sites, the occupancy showed no significant difference before or after the ban when considering either the total number of occupants or the percentage change at each venue.

Table 1. Venue information, including volume, mean number of occupants and lit cigarettes.

		Occupants (No.)		Lit Cigarettes (No.)	
Venue	Vol. (m^3)	Pre	Post	Pre	Post
1	284	23	20	5.0	0
2	1164	73	70	10.8	0
3	377	44	23	7.3	0.7
4	379	38	25	5.3	0
5	467	72	81	7.0	9.0
6	1167	89	54	9.4	0
7	826	69	53	9.2	0
8	419	20	25	4.0	0
9	351	204	195	8.8	0
10	532	90	131	7.2	0
11	816	99	106	3.3	0
12	626	230	237	9.7	0
13	521	190	202	9.7	1.0
14	1995	187	307	10.0	0.3
15	677	186	150	13.0	0
16	886	79	55	7.3	0
17	2508	105	108	12.0	1.3

In all of the $PM_{2.5}$ and CO concentration summary statistics reported below, Venue 5 is excluded because it was exempt from the ordinance. For the lower bound, the respective pre-ban $PM_{2.5}$ concentration mean and standard deviation for all venues were 111 and 49 $\mu g/m^3$, and the respective post-ban mean and standard deviation were 29 and 33 $\mu g/m^3$. For the best estimate, the respective pre-ban $PM_{2.5}$ concentration mean and standard deviation for all venues were 151 and 67 $\mu g/m^3$, and the respective post-ban mean and standard deviation were 11 and 13 $\mu g/m^3$. For the upper bound, the respective pre-ban $PM_{2.5}$ concentration mean and standard deviation for all venues were 488 and 216 $\mu g/m^3$, and the respective post-ban mean and standard deviation were 29 and 33 $\mu g/m^3$. Excluding all venues with post-ban smoking, the respective best estimate pre-ban mean and standard deviation for the $PM_{2.5}$ concentrations were 144 $\mu g/m^3$ and 72 $\mu g/m^3$, and the post-ban mean and standard deviation were 6 $\mu g/m^3$ and 5 $\mu g/m^3$. Figure 1 shows the best estimate of the mean pre- and post-ban $PM_{2.5}$ concentrations measured in all 17 venues, and the error bars represent the standard deviations for each sampled venue. $PM_{2.5}$ concentrations decreased for all venues except Venue 5, which had approximately equal concentrations of $PM_{2.5}$ before and after the ban because it had approximately the same number of smokers before and after the ban.

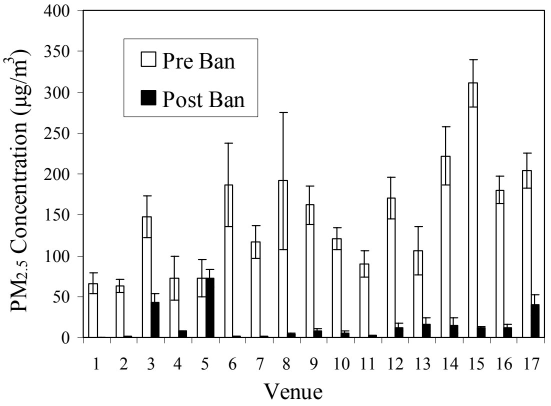


Fig. 1. Best estimate $PM_{2.5}$ concentrations for all venues. * represents occupant non-compliance, and + represents venues that did not have to comply with the ordinance.

There was a statistically significant decrease ($P < 0.05$) in $PM_{2.5}$ concentrations for all cases except for the lower bound case for Venue 3, which had occupant non-compliance after the ban, and all cases at Venue 5, which remained a smoking venue.

The respective pre-ban mean and standard deviation for the CO concentrations, again excluding Venue 5, were 5.9 and 2.2 ppm, and the respective post-ban mean and standard deviation were 2.5 and 2.0 ppm. Excluding all venues with post-ban smoking, the respective pre-ban mean and standard deviation for the CO concentrations were 5.8 ppm and 2.2 ppm, and the post-ban mean and standard deviation were 1.8 ppm and 1.0 ppm. CO concentrations decreased significantly ($P < 0.05$) after the smoking ban for all venues except Venues 5 (which retained its smoking status) and 17. Even though Venues 3, 13, and 14 had non-compliant occupants, there were fewer burning cigarettes than before the ban, so there was still a statistically significant decrease.

Table 2 lists the results for the pre- and post-ban concentrations of VOCs that were detected at Venues 6 – 8. Compounds listed in bold in Table 2 are all known to be emitted from sidestream tobacco smoke [14]. For the three tested venues, all of the compounds that cigarettes are known to emit, with the exception of acetone and limonene, decreased to below the detection limit after the ban. Though not listed in the table, ethanol was also detected at breakthrough levels at all venues before and after the ban.

Table 3 lists the outdoor and indoor concentrations of CO_2 for the venues, as well as the estimated ventilation rates in air changes per hour (h^{-1}). Outdoor and indoor CO_2 concentrations were not measured during the pre-ban testing for Venues 9 – 11, and consequently, those venues could not have ventilation rates estimated for the pre-ban sampling. The mean estimated ventilation rate for all venues was 2.4 h^{-1} before the ban and 3.8 h^{-1} after the ban, excluding Venues 9 – 11.

Table 2. VOC concentrations detected before and after the ban. Bolded compounds are known to be emitted from sidestream tobacco smoke [14]. b.d. indicates below the detection limit (8.3 μg/m^3).

	Venue 6		Venue 7		Venue 8	
VOC (μg/m^3)	Pre	Post	Pre	Post	Pre	Post
1,2,4-Trimethyl benzene	8.3	b.d.	b.d.	b.d.	10	b.d.
1,4-Dichloro-benzene	12	132	b.d.	b.d.	b.d.	b.d.
2-Propanol	45	73	18	28	b.d.	60
α-Pinene	10	12	b.d.	10	b.d.	b.d.
Acetone	45	25	47	32	250	b.d.
Benzene	32	b.d.	30	b.d.	32	b.d.
Ethyl Acetate	55	47	52	87	87	38
Heptane	13	b.d.	b.d.	b.d.	8.3	b.d.
iso-Butanol	13	b.d.	10	15	17	b.d.
Limonene	217	200	67	83	283	85
m/p-Xylene	27	b.d.	25	b.d.	25	b.d.
Methyl ethyl ketone	15	b.d.	17	b.d.	18	b.d.
Tetrachloro-ethylene	b.d.	b.d.	b.d.	b.d.	12	b.d.
Toluene	58	b.d.	53	b.d.	60	b.d.

Table 3. Outdoor and indoor CO_2 concentrations (in ppm) and estimated ventilation rates for each venue.

	Outdoor CO_2		Indoor CO_2		Ventilation (h^{-1})	
Venue	Pre	Post	Pre	Post	Pre	Post
1	468	452	2255	2538	1.3	1.0
2	457	502	2279	1895	1.0	1.2
3	453	423	2235	1208	1.9	2.2
4	417	480	1017	699	4.8	8.5
5	450	463	1251	1414	5.4	5.2
6	452	436	2256	1854	1.2	0.9
7	457	480	1889	3104	1.7	0.7
8	520	552	2057	1041	0.9	3.5
9		477		1605		13.9
10		478		2005		4.6
11		788		2979		1.7
12	716	446	3356	1821	3.9	7.8
13	736	442	2328	1297	6.5	12.8
14	722	419	5388	3838	0.6	1.3
15	668	437	5294	2647	1.7	2.8
16	767	589	2333	1038	1.6	3.9
17	654	533	1990	1563	0.9	1.2

4 Discussion

Given that neither this study nor two others that were similarly conducted [7,9] found evidence of a decrease in occupancy levels, a ban on smoking in hospitality venues does not appear to cause reductions in patronage. Further, all venues were visited at the same day of the week and time of day during the pre- and post-ban testing in an effort to minimize occupancy variations. Thus, this study found that a smoking ban may not, in fact, be detrimental to local business, as is often the prevailing public belief.

The effects of the ban on reducing the indicators of ETS exposure measured in the air in bars are clear. There was much less smoking after the ban, and four venues had minor issues with occupant non-compliance. Since the $PM_{2.5}$ data were analyzed with the three different sets of correction factors from Jenkins *et al.* [10] to account for instrument overcounting and there was a statistically significant decrease for all cases over all venues in which there was no smoking after the ban, it is clear that the smoking ordinance is effectively reducing the concentrations of indoor fine particles, a common indicator of ETS exposure.

Additionally, the statistically significant decrease in CO concentrations also bolsters the case that the ordinance is effectively reducing public exposure to ETS. However, Venue 17 exhibited an anomalous and inexplicable increase in CO concentration. Regarding the VOC concentrations, in the three tested venues all but two VOCs emitted by cigarettes—acetone and limonene—that were detected during the pre-ban sampling decreased to below detection levels in the post-ban sampling. Furthermore, acetone decreased by a factor of approximately 2 after the ban in Venues 6 and 7 and to below detection level in Venue 8. Also, limonene is an extremely common terpene found in many cleaning agents and consumer products besides ETS so its presence after the ban is unsurprising.

Thus, all indicators of ETS exposure that this study measured decreased considerably in nearly all venues after the ban, and by these air quality standards of $PM_{2.5}$, CO, and VOC concentration reduction, the smoking ban ordinance can be judged a clear success at reducing exposure to ETS. Furthermore, because three separate indicators of ETS exposure decreased after the ban, one can be more certain that the reduction of each individual indicator is due, in fact, to the smoking ban.

Other studies have judged the effectiveness of smoking bans on reducing public exposure to ETS by examining indicators not related to direct indoor air quality monitoring. For example, Sargent *et al.* [15] surveyed hospital admissions before and after an indoor smoking ban to determine if there was a change in the monthly number of hospital admissions for acute myocardial infarction, a form of heart disease for which there is an increased risk associated with exposure to ETS. The ban and subsequent study occurred in Helena, Montana, a geographically isolated community with one hospital to serve approximately 68,000 people. During the six months for which there was a ban on indoor smoking, the number of monthly admissions for acute myocardial infarction fell significantly from a mean of 40 admissions to 24 admissions per month.

The results of our study and other similar studies show that a smoking ban ordinance is an effective way to reduce indicators of ETS exposure. However, since a sizeable percentage of the public is often opposed to a ban, it is useful to examine the effectiveness of the smoking ban in the context of other ETS control strategies.

Ventilation is a commonly employed strategy used in attempts to control ETS. However, this method is not as effective as a smoking ban, and a clear example of the relative ineffectiveness of ventilation to control ETS concentrations is Venue 5. This particular venue was an enclosed upstairs bar in a local restaurant and will retain its smoking status until 2012 because of its separate ventilation system. Venue 5 had an estimated ventilation rate of just over 5 h^{-1}. It had a pre-ban $PM_{2.5}$ concentration of 72 $\mu g/m^3$, approximately one-half of the pre-ban mean over all venues of 151 $\mu g/m^3$. Furthermore, Venue 5 had a post-ban concentration of 73 $\mu g/m^3$, which is approximately seven times the post-ban mean over all venues of 11 $\mu g/m^3$. Though Venue 5 did have a pre-ban mean concentration that was less than the pre-ban mean across all venues, the lower $PM_{2.5}$ concentration afforded by the ventilation system appears considerably less effective when compared to the reduction in $PM_{2.5}$ concentrations due to the smoking ban. Furthermore, the 94% average reduction in $PM_{2.5}$ concentrations is considerably more than can be explained by the 37% average increase in estimated ventilation rate, indicating that the reduced smoking is the dominant contributor to the decreased indoor $PM_{2.5}$ concentrations.

Other studies have similarly noted the ineffectiveness of ventilation to control exposure to ETS. In their study of 60 UK pubs, Carrington *et al.* [16] noted that for pubs with non-smoking areas the median concentration of fine particulate matter is reduced only by 34% of that in the smoking areas. Kolokotroni *et al.* [17] evaluated the effectiveness of ventilation and partitioning to mitigate the effects of passive smoking and determined that ventilation strategies alone, though they do reduce ETS levels somewhat, are generally not sufficient to reduce ETS migration into a non-smoking space.

Since the ban is not viewed favorably by the entire population, the next question to examine is whether the ban provides more protection to the public than is actually necessary. In other words, would ventilation strategies be effective enough? Repace and Lowrey [18] looked at this very question and found that to lower the risk of contracting fatal lung cancer due to ETS exposure in the workplace below acceptable levels (1-in-100,000 chance over a 40 year worker lifetime), impractical amounts of ventilation would be required. They concluded that the only practical controls are complete physical separation or smoking prohibition. Thus, since in most venues complete separation with independent ventilation systems are either not physically or economically feasible, an indoor smoking ban is the only certain way to reduce exposure to ETS and ensure that the health of workers and the public is optimally protected in all hospitality venues.

As an added public health benefit, bans on indoor smoking such as the one in Austin also help encourage people to quit smoking. Hopkins *et al.* [19] surveyed the effectiveness of various interventions to reduce both pubic exposure to ETS and general tobacco use. Based on their survey, the authors "strongly recommend" the use of a smoking ban as an effective tobacco exposure and usage intervention. Of the ten sampled investigations of exposure and tobacco use after a smoking ban intervention, the authors reported that eight of the studies noted reductions in daily tobacco consumption and that three studies observed increases in tobacco use cessation. A report by the Surgeon General [20] on reducing tobacco use concluded that an additional benefit to clean indoor air regulations may be a reduction in smoking prevalence both among the workers and the general public. Moreover, the report also states that a smoke-free environment is required for the optimal protection of both nonsmokers and smokers.

In conclusion, this study assessed the effectiveness of an indoor smoking ban in Austin, TX at reducing public exposure to ETS. The study concluded that there was not a statistically significant decrease in occupancy, but that indicators of ETS exposure did decrease significantly. The best estimate $PM_{2.5}$ concentrations in the venues decreased 71 – 99% relative to the pre-ban levels, which was similar to other studies of the same type; CO decreased significantly in all but one venue; and concentrations of VOCs known to be found in cigarettes measured in three venues decreased to below detection levels for all but two common compounds. Moreover, the reduction in ETS exposure due to the smoking ban was examined in the context of other smoking ban studies and ETS control strategies. Due to the reduction in ETS indicators after the smoking ban and the ETS-related health effects described in the literature, Austin's comprehensive ban on indoor smoking can be judged effective at and necessary for reducing public exposure to ETS and improving public health.

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Laboratory Chamber Measurements to Simulate the Effect of Secondary MVOC Sources

W. Lorenz[1]. D. Guenther[1], R. Esbach[2], H.Richter[2] and R. Keller[3]

'Institute for Indoor Diagnostic, Marconistr. 23, D 40589 Dusseldorf, Germany
email: lorenz@mail.isis.de http://www.infid.de
[2]XInstitute Fresenius, Zur Wetterwarte 10, D 01109 Dresden, Germany
'Univ. Luebeck, Institute of Medical Microbiology and Hygiene, Ratzeburger Allee 160, D 23538 Luebeck, Germany

Summary: *As published the emission rate of MVOC out of microbial sources is very low. At field work higher MVOC concentrations are measured as they can be theoretically expected and they decrease slowly after removing the microbial sources. Chamber measurements were made to investigate the role of secondary sources. Two chambers were equipped identically. In one chamber a mould damage was simulated. Another chamber was contaminated with MVOC loaded air out of the damage-chamber. The MVOC concentrations increase in the first two month. After 4 month flooding with fresh air the decrease of MVOC was not completed. New damages can be overseen measuring MVOC, and renovation can not be controlled by MVOC measurements. Old damages should be indicated well.*

Keywords: *MVOC, sink effect, chamber measurements, secondary sources*
Category: *Modelling and simulation*

1 Introduction

As published by other investigators the emission rate of MVOC out of microbial sources is very low [1]. At field work we measured higher concentrations as they can be expected, looking at the results of these investigations.
We observed in practice:

A) In empty rooms without furniture, textiles, or carpets remarkably lower MVOC concentrations are measured than in furnished rooms.

B) In sanitary rooms, where walls and floor are plated with ceramics, very low MVOC concentrations were measured even if relevant hidden mould damages are present.

C) After complete removing of the mouldy materials during renovation the MVOC concentrations decrease, but very slowly.

These observations lead to the assumption that organic materials adsorb MVOC in a relevant manner. Beside the mould damaged materials, as primary sources, the contaminated sources will act as secondary sources. Such secondary sources are necessary to get a remarkable quantity of MVOC at air measurements.

To investigate the effect of secondary sources, chamber measurements were made in laboratory.

2 Experiments

Two identical glass chambers (with a volume of 200 1 each) were chosen for the experiments (chamber A and chamber B). On the bottoms of both chambers a polystyrene layer, a chip board layer, and carpeting were fitted. Three "walls" in each chamber were covered with gypsum board, and wall paper.

MVOC measurements were made in both chambers to control if MVOC are emitting out of the fitted materials (day 0).

After that a mould damage was simulated in chamber A. Water was filled in and mould spores were added (a few gram of moldy wall plaster taken from a damaged wall in a building).

Using a pump the air out of chamber A was flooded through chamber B with 100 1/h ("phase of contamination"). Between chamber A and chamber B the air was dried with silica gel.

The MVOC concentrations were measured in both chambers, first after 30 days (day 30) and then nearly every week with Anasorb tubes.

After 85 days the MVOC concentration did not increase. Then the chamber B was flooded with 100 1/h fresh air ("phase of decontamination") and the MVOC concentrations were measured after 20 days (day 105), then weekly over 3 ½ month (day 113 to 200), and finally after one more month with Anasorb tubes and Tenax tubes (day 230).

Sampling was made with SKC air samplers. Two different analyzing methods were used:

- 50 1 of air was drawn over active carbon tubes (Anasorb-tubes from SKC) with 1.0 1/min. Analyses were made with solvent desorption, liquid injection and gaschromatography using the ion-trap-method [2].
- 7.5 1 of air was drawn over tenax tubes with 0.2 1/min. Analyses were made with thermodesorption and gaschromatography.

At air sampling for MVOC analyses, also temperature and humidity were measured in the chambers.

The MVOC sum concentration was calculated *by* addition of the concentrations of the single substances 3-methylfuran, 2-pentanol, 3-methyl-l-butanol. dimethyldisulfide, 2-hexanone, 2-heptanone, 1-octen-3-ol, and 3-octanone.

3 Results

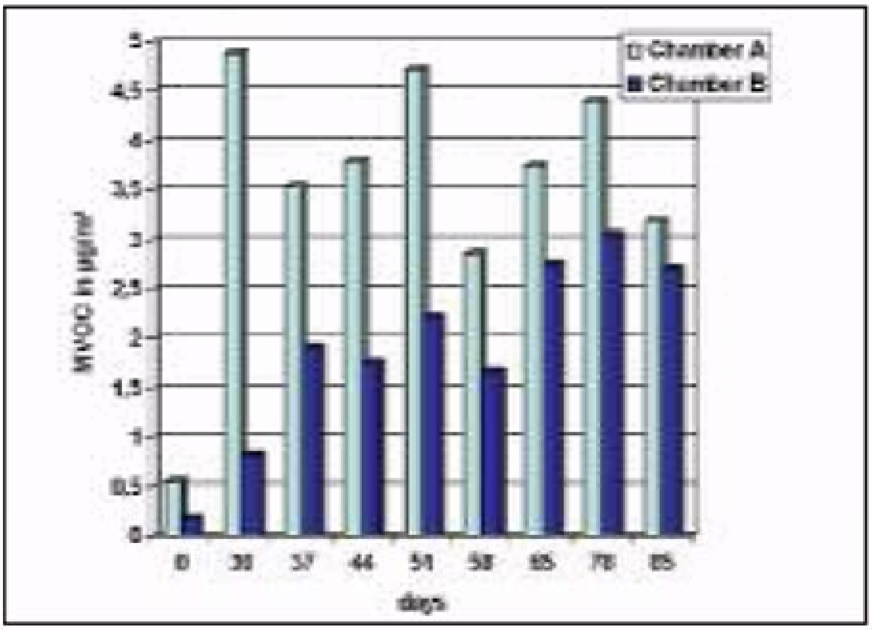


Fig. 1. MVOC sum concentrations in Chamber A and B during "phase of contamination"

Table 1. Temperature in °C and humidity in %

	Chamber A (mould damage		Chamber B (contaminated	
day	°C	%	°C	%
0	20	38	20	38
30	20	86	20	41
37	19	96	20	40
44	20	90	20	40
51	20	92	20	42
58	25	100	25	41
65	21	91	21	34
78	19	90	19	30
85	21	95	21	32
105-230	-	-	19-23	37-50

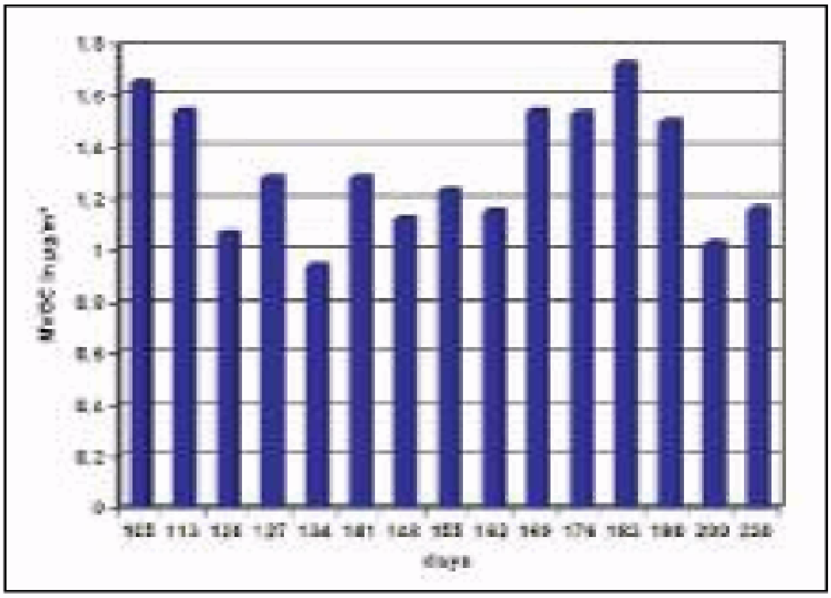


Fig. 2. MVOC concentration in Chamber B. The chamber was flooded with fresh air ("phase of decontamination").

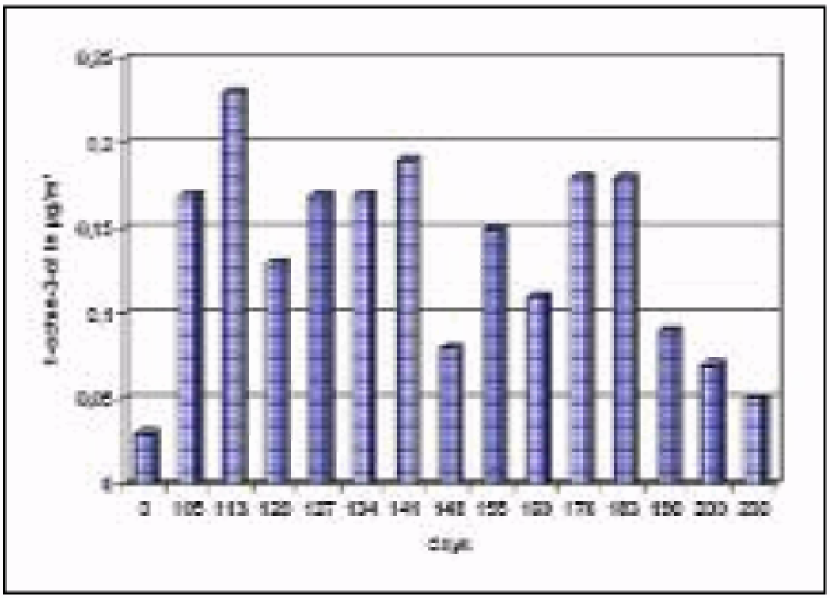
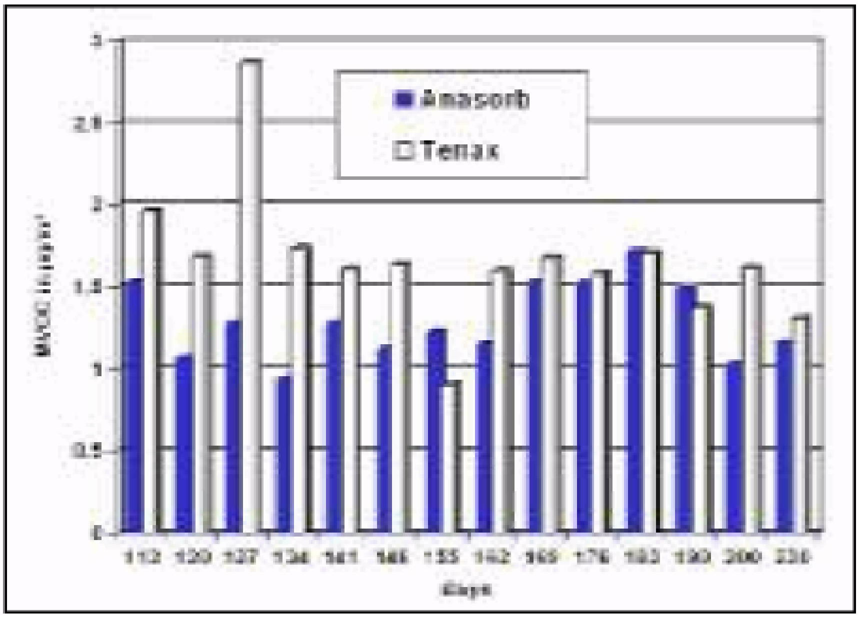


Fig. 3. l-octen-3-ol in Chamber B. The chamber was flooded with fresh air (phase of decontamination").



Fig, 4. Chamber B. MVOC measured with Anasorb tubes (solvent desorption), and with Tenax.tubes (thermo desorption) during "phase of decontamination"

4 Discussion

As expected, the MVOC concentration in Chamber B increase slowly, see Fig. 1. The MVOC will be adsorbed in the first 60 days by the fitted organic materials. In chamber A the highest MVOC concentration was measured after 30 days. Afterwards the concentration decreased in "waves". If this effect is true and not caused by unknown disturbing parameters, it may be an interesting phenomena, which should be investigated.

In the "phase of decontamination" (=flooding chamber B with fresh air) the MVOC concentration decrease not remarkably over 145 days (day 85 to 230). This shows a strong effect of secondary sources. Therefore we conclude, that MVOC measurements should not be used for controlling the success after renovation of mould damages.

Comparing the results of the solvent desorption analyses and the thermodesorption analyses it can be seen (Fig. 4), that the values are tendency higher after sampling with Tenax tubes and analyzing with thermodesorption.

Obviously after sampling with Anasorb tubes and analyzing with solvent desorption the values are "more stable". With Tenax tubes and thermodesorption the measured values will possibly show a wider distribution.

We assume, that fluctuations of the air flow during sampling will have a less effect on the measured values, if a higher air volume is sampled over a longer time.

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A Study on Dampness and its Associations with Asthma and Allergies among 20103 Young Children in Sweden, Bulgaria and Singapore

Zuraimi MS[1], Naydenov K[2], Hägerhed-Engman L[3,4], Tham KW[1], Bornehag[2,3,5] C-G and Sundell J[2]
[1]Department of Building, National University of Singapore, Singapore
email: bdgzms@nus.edu.sg http://www.bdg.nus.edu.sg
[2]International Centre for Indoor Environment and Energy, Technical University of Denmark, Denmark
[3]Department of Building Physics, Swedish National Testing and Research Institute, Sweden
[4]Department of Building and Environmental Technology, Lund University, Lund, Sweden
[5]Public Health Sciences, Karlstad University, Karlstad, Sweden

Summary: *Large international multi-center studies have shown significant differences between regions with respect to prevalence and severity of asthma and allergies. In a multitude of studies from different countries adverse health effects among children have been associated with exposure to dampness in homes. Since countries differ in climate, culture, socioeconomic factors, housing characteristics and indoor air pollution sources, these diversities are likely to cause important differences in exposures to dampness. Results from studies in three different countries and climates (Sweden, Bulgaria and Singapore) using mainly the same questionnaire and investigation techniques are compared. There were major differences in prevalence of asthma and allergic symptoms among the 3 countries – doctor-diagnosed asthma, 4.4 to 7.7%; rhinitis, 11.1 to 28.0%; eczema, 12.7 to 18.7%. We also found large variations in the frequencies of dampness indicators (visible damp stains and mold) – Sweden, 1.6%; Bulgaria, 35.5%; Singapore, 6.5%. Despite these large variations, associations (adjusted odds ratio) with asthma and allergies symptoms appear to be quite close for the three countries -- doctor-diagnosed asthma, 1.21 to 1.67; rhinitis, 1.38 to 2.07; eczema, 1.25 to 1.40.*

Keywords: *Dampness; Mold; Asthma and Allergies; Bulgaria, Sweden and Singapore; Nordic, Temperate and Tropical Climates*

Extended Abstract

There are significant differences between countries with respect to prevalence and severity of asthma and allergies among children as shown in e.g. the ISAAC (International Study of Asthma and Allergies in Childhood) studies [1]. In numerous studies from different countries, it has been shown that various health effects have been attributed to damp or moldy indoor environments with asthma and allergic symptoms most often studied [2].

In this work questionnaire data from three countries regarding reports of asthma and allergic manifestations and reports of dampness are analyzed. The objective of the present analysis was to investigate the associations between housing characteristics related to dampness, and airway, nose and skin symptoms among children from these countries.

Three multidisciplinary cross-sectional studies on the home environment and children's health were conducted in Sweden (Cold), Bulgaria (Temperate) and Singapore (Tropical) basically using the same questionnaire. Questionnaire responses were gathered from parents of 10851 Swedish, 4138 Bulgarian and 4759 Singapore preschool children with an age range between 1 to 8 years. Questions regarding current wheeze, rhinitis and eczema among the children together with questions on doctor diagnosed (Dx) asthma and rhinitis were included. Information on dampness indicators in the parents and children's bedroom were also solicited. Associations between dampness and symptoms were estimated using multiple logistic regression controlling for the influence of confounders.

There were major differences in reported asthma and allergic symptoms among children in the 3 countries (Table 1). Wheezing and rhinitis were highest in Bulgaria, and Singapore had the highest prevalence of doctor diagnosed (Dx) asthma and rhinitis. Current eczema were more prevalent among Swedish children

The common dampness problem for the 3 countries is visible damp stains and visible mold. The frequency of visible damp stains or/and mold were highest in Bulgaria, followed by Singapore and Sweden. In Sweden, however, there is reported more of "hidden mold" in building constructions [3]. This could be due to hidden mold in Swedish buildings which have insulated multi layer wall structures (in walls, foundations and roof-structures) as opposed to concrete structures in Singapore and Bulgaria. Other indicators of dampness may apply for some countries only. For example, condensation on the window panes would only occur under cold conditions in Sweden and Bulgaria, but not in tropical Singapore.

Table 1 Prevalence of symptoms and frequency of dampness exposure (%)

	Sweden	Bulgaria	Singapore
Symptoms			
Asthma Dx	5.4	4.4	7.7
Rhinitis Dx	2.2	7.7	10.1
Current Wheeze	18.9	29.7	15.8
Current Rhinitis	11.1	28.0	25.6
Current Eczema	18.7	12.7	12.7
Dampness Exposure			
Dampness (visible mould or/and visible damp stains)	1.6	35.5	6.5
Water leakage	17.8	4.4	NA
Floor moisture	8.3	21.2	NA
Condensation on window	14.3	19.3	NA

There were large differences in the type of housing characteristics in the three countries (Table 2). The majority of houses in Bulgaria and Singapore is multi-family apartments (made of either concrete or bricks – 83.4 to 100%). On the contrary, there were more single-family houses in the Swedish study where the homes incorporate walls with insulation materials (multi-layers of wood, insulation, wind-barrier, diffusion barrier, gypsum) where hidden mold growth may exist.

Table 2 Prevalence of different housing characteristics and dampness description (%)

Housing Characteristics	Sweden	Bulgaria	Singapore
Single-family	70.4	14.6	4.8
Multi-family	18.1	82.0	93.2
Others	8.8	3.4	N/A

In all three countries there are significant associations between dampness (visible damp stains or/and visible mould) and symptoms (Table 3). For the association with current wheeze, the adjusted odds ratio (aOR) was lowest in Sweden while the levels were almost similar between Singapore and Bulgaria. For doctor-diagnosed (Dx) asthma the association was only significant in the Bulgarian study.

For the logistic regressions used to control the influence of covariates, different factors were utilized in the 3 countries. For the study in Singapore, the covariates include age, gender, socio-economic status, housing types, parental atopy, food allergy, ETS exposure, respiratory infections. For the Swedish study, the factors include age, gender, asthma, rhinitis or eczema symptoms among parents, smoking, type of dwelling and construction period; and for the Bulgarian study, these include age, gender, asthma, rhinitis or eczema symptoms among parents, smoking and town.

Table 3 Associations between dampness and symptoms among children

Adjusted[1] odds ratio (95% confidence interval)			
	Sweden	Bulgaria	Singapore
Asthma Dx	1.67 (0.96-2.91)	**1.51 1.09-2.09**	1.21 (0.73-2.01)
Rhinitis Dx	**2.70 (1.36-5.35)**	**1.42 (1.10-1.83)**	1.56 (0.88-2.78)
Current Wheeze	**1.15 (1.02-1.31)**	**1.39 (1.20-1.62)**	**1.41 (1.00-1.97)**
Current Rhinitis	**2.07 (1.41-3.05)**	**1.38 (1.19-1.60)**	**1.59 (1.18-2.14)**
Current Eczema	1.25 (0.86-1.81)	**1.40 (1.15-1.72)**	1.36 (0.95-1.96)

[1] Adjusted for factors given in the text.

The aORs for the association between dampness (visible damp stains or/and visible mould) and current rhinitis for the three countries range from 1.46 to 2.07 where all three studies displayed significant associations. The association was highest in Sweden despite the low dampness frequency. On the other hand, Bulgaria and Singapore displayed almost similar aORs. Current eczema was significantly associated with dampness (visible damp stains or/and visible mould) only among Bulgarian children but again the aORs appear to be relatively similar.

The aORs range from 1.15 to 1.42 for current wheeze and 1.21 to 1.67 for doctor-diagnosed (Dx) asthma are comparable to the results of the review made by Bornehag et al [2]. A basic question is why are the associations between dampness and wheeze about the same in the three countries in spite of the large differences in exposure frequencies between the included countries. Bornehag and Sundell [4] have indicated that these could be because the causative agents have not yet been identified. Till now, there have been few suggestions on the role of these potential agents. Suggested causative agents in damp buildings are given below.

Mite exposure has been shown to increase the risk of sensitization and allergic disease. In most of the studies where adjustment for mite exposure had been performed, the association between dampness and health remained significant although the effects were reduced. The OR for the association between dampness and health seems to be almost the same all over the world with very different climate conditions and prevalence of mite infestation [5]. Again, mite exposure alone cannot explain all health effects related to damp buildings.

The literature is not conclusive on the possible role of microbes/moulds as a causative agent for dampness-related health effects. The prevalence of sensitization to mould allergen is low; however, Zock et al [6] has reported that the strength of association between asthma and dampness was stronger among individuals that are mold-sensitized. Furthermore, there is a possibility of yet unrecognized fungal allergens and that agents of microbial origins may act as odorous, irritant and toxic substances.

A recent hypothesis has implicated virus as a causal agent for dampness related health effects [7]. However, in this Singapore study, the associations remained significant after the influence for respiratory infections were controlled for in the multiple regressions (for the Swedish and Bulgarian studies, respiratory infections was not a confounder). Therefore, the 'viral pathway' appears to be inconclusive.

Most studies have investigated microbiological agents and very few discuss the role of chemical agents related to dampness. For example, the hydrolysis of phthalate esters from PVC floorings under high humidity can release the odorous and irritating VOC 2-ethyl 1-hexanol. In a recent report, Bornehag et al [8] has documented an association between asthma and allergic symptoms and PVC flooring material in combination with water leakage, but not PVC alone.

Conclusion

In general, the conclusions on an association between dampness and asthma and allergies among preschool children accord well with the scientific review [2]. This study has provided some further insights on the associations of dampness with asthma and allergic symptoms among preschool children in three countries – Sweden, Bulgaria and Singapore. Despite the differences in climate and building types and more importantly in the prevalence of dampness, the associations appear to be somewhat similar.

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Indoor Residential Chemical Exposures as Risk Factors for Asthma and Allergy in Infants and Children: a Review

MJ Mendell

Lawrence Berkeley National Laboratory, Indoor Environment Dept., 1 Cyclotron Rd., Berkeley, CA 94720, USA
email: mjmendell@lbl.gov

Summary: *Most research into effects of residential indoor air exposures on asthma and allergies has focused on exposures to biologic allergens, moisture and mold, endotoxin, or combustion byproducts. This paper briefly reviews reported findings on associations of asthma or allergy in infants or children with risk factors related to indoor chemical emissions from residential materials or surface coatings. Associations, some strong (e.g., odds ratios up to 13), were reported. The most frequently identified risk factors were formaldehyde, aromatic organic compounds such as toluene and benzene, plastic materials and plasticizers, and recent painting. Exposures and consequent effects from indoor sources may be exacerbated by decreased ventilation. Identified risk factors may be proxies for correlated exposures. Findings suggest the frequent occurrence of important but preventable effects on asthma and allergy in infants and children worldwide from modern residential building materials and coatings.*

Keywords: *indoor air quality; phthalates; volatile organic compounds; formaldehyde; asthma; allergy*
Category: *allergy and other sensitivity reactions*

1 Introduction

Concerns about recent increases in the incidence of asthma and allergies worldwide have stimulated a variety of scientific research, much focused on exposures in residences, where children spend the majority of their time. Most research into the effects of indoor residential exposures on asthma and allergies has focused on exposures to biologic allergens, moisture and mold, endotoxin, or combustion byproducts [1]. A growing body of research from outside the U.S., however, suggests that *chemical emissions* from common indoor materials and finishes have a variety of adverse effects on respiratory and immune health. The identified risk factors include specific organic compounds such as formaldehyde, benzene, and phthalates, indoor materials or finishes such as carpet, flexible flooring, paint, and plastics, and indoor activities related to these materials.

Although some recent review articles have included aspects of this larger picture [1-7], they have not considered the full range of available evidence linking indoor chemical emissions and health effects. This review summarizes current findings from studies in the peer-reviewed scientific literature on associations between indoor residential chemical emissions, or materials or activities associated with such emissions, and asthma and allergies in infants or children.

2 Methods

We searched the published biomedical literature, using the online site PubMed for relevant studies, and also searched selected conference proceedings. From the identified reports, we selected and summarized studies which met the following eligibility criteria: publication in scientific peer-reviewed journals or scientific conference proceedings; investigation of associations between health effects related to asthma or allergy in human infants or children (up to age 16) and either indoor residential chemical exposures, or materials or activities considered to be risk factors for chemical exposures; and a cross-sectional, case-control, cohort, panel, quasi-experimental, or controlled experimental design. Findings on adult populations, on school or ambient exposures, and on risk factors related to combustion byproducts or bedding were excluded.

For the eligible findings, we first describe the health outcomes, subjects, and designs in reported studies, separately for risk factors of measured concentrations and potential sources (materials or activities). We then summarize the reported associations between risk factors and health outcomes as odds ratios (ORs). The disease process of asthma may involve inflammation, infection, and allergy. We have roughly categorized the reported associations in two broad categories of health outcomes: asthma and lower respiratory effects (e.g., diagnosed asthma, asthma symptoms, lower respiratory symptoms, obstructive or chronic bronchitis, bronchial obstruction, adverse changes in lung function assessed by spirometry, lung inflammation assessed by exhaled nitric oxide, house dust mite sensitization, or pulmonary infections) and allergic effects (e.g., atopy by skin prick tests, allergic symptoms, diagnosed rhinitis, or diagnosed eczema).

3 Results

We identified 20 studies meeting the selection criteria (Tables 1 and 2): 12 investigating effects of indoor chemical concentrations, including formaldehyde, aromatic compounds, aliphatic compounds, and total volatile organic compounds (VOCs) as well as phthalates in dust; and 10 (with some overlap) investigating effects of indoor chemical sources, including plastics, recent painting, new furniture or particleboard, new synthetic carpets, textile wallpaper, and maternal cleaning activity.

Two of the studies, published in 1989 and 1990, were from the U.S. and focused on formaldehyde. All other studies, published between 1999 and 2005, were from western Europe, Russia, or Australia. Reported study designs and analyses included five cohort or panel, eight case-control, and nine cross-sectional, with some studies including multiple approaches. Nineteen were published in peer-reviewed journals, and one in a scientific conference proceeding.

Indoor chemical concentrations

Higher concentrations of chemical compounds measured in air or dust in residences were associated in numerous studies with health effects related to asthma or allergy in infants or children. (See Table 1 for information on study designs, subjects, and health outcomes, and Table 3 for estimated associations.)

Table 1. Description of studies on associations between *indoor chemical concentrations in air or dust* and asthma or allergy in infants and children*

Effect	Subject Age	Design	Ref
Asthma dx	6 mo–3 yr	Case-control	[8]
Asthma dx;, Persistent allergic symptoms; Rhinitis dx; Eczema dx	1-6 yr	Cross-sectional	[9]
Asthma dx and respiratory symptoms in past yr; Atopy (skin prick tests)	7-14 yr	Cohort/ Cross-sectional	[10]
Asthma, emergency treatment for	6 mo-3 yr	Case-control	[11]
Asthma dx; Chronic bronchitis dx; Peak expiratory flow; Respiratory symptoms	6-15 yr	Cross-sectional	[12]
Exhaled nitric oxide; Spirometry	6-13 yr	Cross-sectional	[13]
Obstructive bronchitis; Eczema;	3 yr	Case-control	[14]
Excess variability in PEFR; Respiratory. symptoms	< 16 yr	Cross-sectional	[15]
Asthma symptom severity	10-16 yr	Panel	[16]
Persistent wheezing	9-11 yr	Case-control	[17]
Pulmonary infections	6 wk	Case-control	[18]
IgE sensitization to foods; Total IgE	6 mo–3 yr	Cohort/ Cross-sectional	[19]

* see Abbreviations listed at end of paper

Table 2. Description of studies on associations between *indoor chemical sources* and asthma or allergy in infants and children*

Effect	Subject Age	Design	Ref
Pulmonary infections at 6 wk; Wheezing at 1 yr	6 wk and 1 yr	Case-control	[18]
Obstructive bronchitis, within first or second year	0-2 yr	Cohort	[20]
3+ wheezing episodes >3 mo of age, and either use of inhaled steroids or BHR symptoms	1-2 yrs	Case-control	[21]
Persistent wheeze; Late-onset wheeze; Transient early wheeze	0-3.5 yr	Cohort	[22]
Lower respiratory symptoms; Cough, phlegm; Asthma	1-7 yr	Cross-sectional	[23]
House dust mite sensitization	8 yr	Cohort	[24]
Bronchial obstruction	0-2 yr	Case-control	[25], [26]
Current asthma; Asthma-like symptoms; Current wheezing; Any allergy	8-12 yr	Cross-sectional	[27]
Persistent allergic symptoms	1-6 yr	Cross-sectional	[9]

* see Abbreviations listed at end of paper

For formaldehyde, associations were reported with increases in asthma [11, 12], asthmatic symptoms [10, 17], chronic bronchitis [12], exhaled nitric oxide (an indicator of lung inflammation) [13]; adverse changes in lung function [12, 15], and atopy [10]. For aromatic organic compounds such as toluene, benzene, and dichlorobenzene, associations were reported with increases in diagnosed asthma [8], obstructive bronchitis [14], pulmonary infections (associated with asthma attacks) [18], IgE sensitization to foods and total IgE [19], and eczema [14]. Aliphatic organic compounds such as hexane and decane were associated with increased IgE sensitization to foods [19]. Total VOC concentration was associated with increased asthma diagnosis [8], but not with persistent wheezing [17].

Specific plasticizers (phthalates), which are in the class of semi-volatile organic compounds, were associated with increases in persistent allergic symptoms and diagnoses of rhinitis, eczema, and asthma, with some dose-response relations [9].

Table 3. Summary table: odds ratios (ORs) for asthma, lower respiratory outcomes, and allergy in infants and children associated with *indoor chemical concentrations* and for *indoor source materials or activities*

Risk Factors	Health Outcomes	
	Asthma and Lower Respiratory OR	Allergy OR
Indoor Chemical Concentrations		
Formaldehyde	1.4* [11]; 1.8* [13]; 8.0*, 2.0*, * [12]; * [15]; 1.4 [17]	4.1 [10]
Aromatics		
toluene	1.3* [8]	13.0*, 16.0* [14]; 3.3*, 11.2* [19]
benzene	1.9*/8.0* [8]; 10*[14], 2.4*[18]	---
styrene	6.4* [14], 2.1* [18]	---
m-p-xylene	10.0* [14]	8.0* [19]
dichlorobenzene	1.2* [8]	---
chlorobenzene	---	5.9* [19]
4-ethyltoluene	---	3.0*, 9.3* [19]
Aliphatics		
decane	---	8.1* [19]
hexane	---	9.6* [19]
Total VOCs	1.3*/4.0* [8]	---
Phthalates (in dust)		
BBZP	1.9 [9];	2.0*, 2.6*, 3.0* [9]
DEHP	2.9* [9]	---
Indoor sources or activities		
Plastic materials	1.1, 1.4*, 1.4* [27]; 1.9* [26]; 1.5, 3.4* [23]; 2.9, 12.6* [25]; 2.1* [24]	1.3* [27]; 1.6* [9]
Recent painting	1.9*, 5.6* [18]; 1.1, 1.2, 1.3 [27]; 1.7*, * [21]; 4.1*, 4.1* [20]	1.2* [27]
New furniture or particleboard	1.3, 1.3, 1.6* [27]; 1.3, 1.4, 0.6 [27]	1.4*; 1.5* [27]
New synthetic carpets	1.7*, 1.8, 1.9* [27]	1.4* [27]
Textile wallpaper	1.6 [26]; 1.7, 3.7 [25]	---
Housecleaning by mother	2.0, 2.3* [22]	---

* p-value ≤ 0.05 (* with no OR indicates that p-value was reported without OR)

Effects were evident at relatively low levels of some exposures. Examples related to diagnosed asthma follow: In an Australian cross-sectional study, in categories with peak indoor formaldehyde concentrations of less than 20, 20-50, and greater than 50 $\mu g/m^3$ (study median=26 and maximum=140 $\mu g/m^3$), the proportions of diagnosed asthmatic children were 16%, 39%, and 44% [10]. In an Australian case-control study, risk of emergency treatment for asthma rose by an estimated 3% per 10 $\mu g/m^3$ increase in indoor formaldehyde concentrations over the range measured, from below 10 to about 200 $\mu g/m^3$ (median =30 $\mu g/m^3$) [11]. In this study, categorical analysis showed that, relative to the lowest indoor formaldehyde concentrations below 10 $\mu g/m^3$, evident risk only increased at concentrations above 50 $\mu g/m^3$, with a statistically significant (39%) increased risk of asthma at concentrations over 60 $\mu g/m^3$ [11]. A cross-sectional study in the U.S. reported that asthma prevalence was more than three times higher in children with kitchen formaldehyde levels greater than 73 $\mu g/m^3$ (60 ppb), which were found in 7% of the study homes [12].

An Australian case-control study found increased risks of new asthma diagnoses in children with increased indoor concentrations of VOCs, with the following significant ORs per 10 $\mu g/m^3$ increase: benzene, 2.9; toluene, 1.8; dichlorobenzene, 1.6; and total VOCs, 1.3 [8]. Adjusted risks for newly diagnosed asthma for children living in houses with above median concentrations were, for benzene, eightfold, and for total VOCs, fourfold. Median and maximum indoor concentrations (in $\mu g/m^3$) in the study houses were: benzene, 20 and 82; toluene, 17 and 154; dichlorobenzene, 17 and 202; and total VOCs, 55 and 622 [8].

In a Swedish cross-sectional study, children at the highest quartile of dust concentrations of two phthalate plasticizers had elevated risks for asthma diagnosis: for di(2-ethylhexyl)phthalate (DEHP), a significant OR of 2.9, and for n-butyl benzyl phthalate (BBzP), an OR of 1.9 [9]. Median dust concentrations in mg/m^3 were, for DEHP, 0.770, and for BBzP, 0.135.

Indoor sources or activities

Types of indoor residential materials and coatings, as well as renovation or cleaning activities, were associated with health effects related to asthma or allergy in infants or children. (See Table 2 for information on study design, subjects, and health outcomes, and Table 3 for estimated associations.) Interior plastic surfaces such as floors or wall coverings were associated with increases in current asthma, asthma symptoms, wheezing, and allergy [27], asthma, persistent wheeze, cough, and phlegm [23], bronchial obstruction [25, 26], and persistent allergic symptoms [9], but not lower respiratory symptoms [23]. Recent painting was associated with increases in current asthma, asthma symptoms, and allergy [27], recurrent wheezing [21], pulmonary infections at 6 weeks [18], and wheezing at 1 year [18], while redecoration (painting, new carpet, or new furniture) was associated with increases in obstructive bronchitis [20]. Textile wallpaper was associated with increased bronchial obstruction [25, 26]. New furniture, new particleboard, and new synthetic carpet were each associated with increases in current asthma, asthma symptoms, wheezing, and allergy [27].

Housecleaning by the mother was associated with persistent wheeze in young children [22].

Low outdoor air ventilation

One study found that lower ventilation rates in homes were associated with increased prevalence of asthma and allergic symptoms in children, with a dose-response trend [28]. Another study found no direct association of residential ventilation on recurrent wheezing in infants [29]. A third study found that outdoor air ventilation rates were not directly associated with risk of bronchial obstruction in infants [25]; however, lower ventilation rates *synergistically increased* the risk of bronchial obstruction associated with indoor sources such as plasticizer-containing surfaces, textile wallpaper, and environmental tobacco smoke. For instance, for risk of bronchial obstruction among infants living in homes with plasticizer-containing surfaces compared to those in homes without, the OR over all study homes was 2.9, while in analyses restricted to homes with low ventilation rates, the OR was 12.6 [25].

4 Discussion

Synthesis of findings

The reviewed studies found many associations, some strong, between risk factors for indoor residential chemical emissions and asthmatic and allergic effects in infants or children. Reported statistically significant ORs ranged to high levels: for painting, from 1.2 to 5.6; for formaldehyde, from 1.4 to 8.0; for aliphatic chemicals, from 8.1 to 9.6; for plastics and plasticizers, from 1.3 to 12.6; and for aromatic chemicals, from 1.2 to 16.0. Elevated risks were also reported for renovation and cleaning activities, new furniture or particleboard, and carpets or textile wallpaper. Findings from one study suggested that low ventilation rates may exacerbate risks from indoor sources by increasing indoor exposure concentrations.

Limitations

All the studies reviewed were observational, with the potential biases and limitations inherent in such studies; however, research on these risks in humans will of necessity be largely observational. Alternate explanations for the findings reviewed here include: recall bias related to past activities reported (although not in prospective studies); errors in measurement that are systematically biased in a direction that creates spurious relationships; confounding by other risk factors, such as outdoor-produced pollutants, not involving indoor chemical emissions; and chance positive associations resulting from large numbers of statistical comparisons but no true relationships. Even if the risk factors identified in these studies were not the result of bias, they may not directly indicate true causal factors. For instance, the aliphatic chemicals may be proxies for other exposures emitted from the same sources. Also, indoor benzene, although emitted from some products and appliances, may primarily be an indicator for indoor tobacco smoke, with its large number of toxic components.

While the reviewed studies contained very few reports of lack of association between the studied risks and outcomes, it is well recognized that negative results, or entirely negative studies, are less likely to be reported or published [30].

This brief summary does not provide details on the design of studies, or on their measurement methods for risk factors and health outcomes. Nor does it critique the findings or synthesize them by specific risk factor or outcome. For instance, this paper does not distinguish health outcomes of causation and exacerbation of asthma, and the specific findings for each. This important distinction and others will be made, to the extent possible, in a future more detailed review paper.

Although this review includes many single, unreplicated findings, it also includes repeated findings for some risk factors and similar health outcomes. The most frequently identified risk factors include formaldehyde, aromatic compounds such as toluene and benzene, plastic materials or plasticizers, and recent painting. The finding in one study that lower ventilation rate increased the risks associated with indoor chemical sources is consistent with the well-understood process by which both sources and removal processes determine indoor concentrations.

Related findings

Associations have been reported between indoor chemical emissions in homes and altered immune parameters in children, which may be related to development of asthma or allergy [19, 31]. After homes, children spend most time in schools, but little research is available on the effects of chemical exposures in schools on children's health. One study reported an OR of 2.9* for asthma and exposure to formaldehyde in schools [32]. Numerous studies have reported associations of indoor chemical emissions and emission sources with respiratory and allergic effects in adults [33-39]. Studies have found that, for some chemicals identified as risk factors in indoor air, higher concentrations in *outdoor* air are health risks for asthma severity in children: ORs were, for formaldehyde, 1.4 [40]; for benzene, 5.9, for toluene, 5.0, and for m-p-xylene, 3.6 [16]. A substantial body of research shows increased risk of various asthma and respiratory outcomes associated with synthetic bedding materials, although this increased risk, also found for sheepskin bedding, currently seems likely to be due to enhanced growth of dust mites [41] rather than to chemical emissions.

Interpretation and implications

At this time, it is not clear through what mechanisms inhalation of relatively low levels of chemicals such as formaldehyde, aromatic and aliphatic compounds, other components of paint, and plasticizers could increase asthma or allergies. Animal models and other evidence suggest that either inflammation, or increased sensitization without inflammation, may be involved [42-44].

Long term indoor chemical emissions in the home, where infants and children spend most of their time, may result in substantial cumulative exposures during a period of relatively high susceptibility. There is biologic plausibility for at least some of the associations summarized here. The risk factors reviewed here are nearly ubiquitous in modern homes, and it seems likely that use of the associated source materials will increase, leading to increased emissions. Furthermore, as average ventilation rates continue to decrease in houses in the U.S. [45] and presumably in other countries in order to increase energy efficiency, concentrations of indoor pollutants will increase even if levels of indoor emissions remain unchanged.

Available findings thus suggest the possible large-scale occurrence, and future increase, of important yet preventable adverse respiratory effects in infants and children worldwide, related to modern residential building materials and coatings and exacerbated by decreased ventilation. Where necessary, research should confirm risk factors, identify specific causal exposures, and elucidate mechanisms. For risk factors with sufficient documentation, research should quantify risk/response relations, estimate the magnitude of public health impacts, and evaluate effective preventive actions.

ABBREVIATIONS

BBzP	n-butyl benzyl phthalate
BHR	bronchial hyperresponsiveness
DEHP	Di(2-ethylhexyl)phthalate
dx	diagnosis, diagnosed
HR	hyperresponsiveness
IgE	immunoglobulin E
mo	month
OR	odds ratio
PEFR	peak expiratory flow rate
PVC	polyvinyl chloride
VOC	volatile organic compound
wk	week
yr	year

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Living Conditions of Patients with Fragrance Allergies

M. Fischer[1,2], B. Blömeke[2], H.F. Merk[3], H. Niggemann[1], W. Dott[1] and G.A. Wiesmüller[1]

[1]Inst. of Hyg. and Environ. Medicine, RWTH Aachen University, Pauwelsstraße 30, 52074 Aachen, Germany
Email: ga.wiesmueller@post.rwth-aachen.de http://www.hygiene.ukaachen.de
[2]Dept. of Ecotoxicology and Toxicology, University Trier, Am Wissenschaftspark 25-27, 54296 Trier, Germany
[3]Dermatological Clinic, RWTH Aachen University, Pauwelsstraße 30, 52074 Aachen, Germany

Summary: *Dependence of questionnaire-obtained living conditions on patients with fragrance allergy (PFA) and controls were statistically exploratively analyzed. Compared to the controls, the PFA showed significantly more impairments in everyday life (p=0.043), lesser smoking habits (p=0.025), more susceptible reactions to deodorant products (p=0.003-0.046), fewer amalgam fillings (p=0.044), more dental prostheses of gold (p=0.037), platinum (p=0.014), or synthetic materials (p=0.014), at home more gas as fuel (p=0.019), more plants in potting soil (p=0.020), more supply protections (p=0.037), more moulds eliminations (p=0.033) and more leisure activities in the garden (p=0.008). Relevance of exposure conditions and genetic susceptibility to fragrance allergies must be clarified.*

Keywords: *fragrance allergies, living conditions, indoor air*
Category: *case-control study*

1 Introduction

Fragrances are widespread in our environment and contained in many products of cosmetic, food and chemical industry [6, 7]. About 2,500 substances are available for perfume composition, including ca. 100 known contact allergens [3]. In allergologic diagnostics, mainly the following substances are covered in patch tests:

- cinnamon alcohol, cinnamon aldehyd, alpha-amyl-cinnamon aldehyd
- eugenol, isoeugenol
- hydroxyl citronellal
- geraniol
- oak moos

These fragrances can be found in 15 to 100% of all cosmetic products [1, 3], mostly in different combinations. About 10% of the patients suffering from eczema show sensitizations to one or more of these substances. Prevalence of fragrance allergy is estimated between 1.7% and 4.1% [5].

Symptoms of fragrance allergies are not only restricted to the skin, because in solved or atomized form fragrances can also induce allergic contact reactions in the respiratory tract and the eyes [1, 2].

However, there is no valid knowledge available about the living conditions, especially at home, of patients with fragrance allergy.

Study aim

Therefore, the aim of our study was, to analyze the living conditions of patients with fragrance allergy in comparison to patients without fragrance allergy but other allergies (controls).

2 Patients and Methods

For the present investigation a standardized questionnaire was used, which was developed by seven departments of the University Hospital Aachen for studies about the relevance of genetic predispositions and environmental factors on different human diseases [10]. This questionnaire focuses on living habits and living surroundings and includes 75 questions, 25 of which scrutinize the home related living conditions.

Patients with fragrance allergy (n = 44) and the controls (patients without fragrance allergy but with other allergies; n = 46) were recruited in the outpatients' Unit of Allergology of the Dermatological Clinic of the RWTH Aachen University. Moreover, patients with fragrance allergy from the previous two years, who were diagnosed and treated by the clinic, were contacted and asked to participate in the study.

Data management was performed using Microsoft® Access and Excel.

Data were exploratively analyzed using the statistical program Stata® 8.2. Living conditions of the fragrance allergy group and the control group were described by percentages. Dependence of questionnaire-obtained living conditions on patients with fragrance allergy and controls (patients without fragrance allergy but with other allergies) were analyzed using Pearson's χ^2 and Fisher's exact test

3 Results

The fragrance allergy group consisted of 25 women and 19 men, the control group of 29 women and 17 men.

Compared to the controls, the fragrance allergy group showed significantly more impairments in everyday life (p=0.043) and lesser smoking habits (p=0.025).

Patients with fragrance allergy stated in the questionnaire more susceptible reactions to deodorant spray, deodorant stick and deodorant roller, lotions, and make-up (Table 1) than the controls.

Table 1. Percentages of susceptible reactions to personal hygiene and cosmetic products in patients with fragrance allergy (FA) and controls (Fishers' exact test).

Personal hygiene and cosmetic products	FA-patients	Controls	p-value
Deodorant spray	(n = 40) 60.0%	(n = 41) 36.6%	***0.046***
Deodorant stick	(n = 33) 48.5%	(n = 36) 13.9%	***0.003***
Deodorant roller	(n = 36) 50.0%	(n = 39) 18.0%	***0.006***
Lotions	(n = 35) 51.4%	(n = 40) 15.0%	***0.006***
Make-up	(n = 30) 33.3%	(n = 30) 6.7%	***0.021***
Other products	(n = 33) 27.3%	(n = 34) 11.8%	0.132

Furthermore, the fragrance allergy group had fewer amalgam fillings and more dental prostheses of gold, platinum, or synthetic materials (Table 2) compared to the controls.

Table 2. Percentage of dental filling materials in patients with fragrance allergy and controls (χ^2 test).

Dental material	FA-patients	Controls	p-value
Amalgam	(n = 36)	(n = 41)	***0.044***
Yes	55.6%	61.0%	
Not yet, but in the past	41.7%	22.0%	
No, never	2.8%	17.0%	
Gold	(n = 33)	(n = 37)	***0.037***
Yes	69.7%	40.5%	
Not yet, but in the past	6.1%	5.4%	
No, never	24.2%	54.1%	
Platinum	(n = 21)	(n = 29)	***0.014***
Yes	19.1%	0%	
Not yet, but in the past	0%	0%	
No, never	80.9%	100%	
Palladium	(= 14)	(n = 24)	0.185
Yes	7.1%	0%	
Not yet, but in the past	0%	0%	
No, never	92.9%	100%	
Synthetic materials	(n = 31)	(n = 14)	***0.014***
Yes	83.9%	51.4%	
No yet, but in the past	0%	8.6%	
No, never	16.1%	40.0%	

At home, patients with fragrance allergy used significantly more gas as fuel, had more plants in potting soil, more supply protections, more moulds eliminations and did more leisure activities in the garden than the controls (Table 3).

Table 3. Percentage of home and living conditions of patients with fragrance allergy and controls (χ^2 test (a), Fishers' exact test (b)).

Home and living conditions	FA-patients	Controls	p-value
Fuel	(n = 42)	(n = 45)	***0.019 (b)***
Oil	19.1%	46.7%	
Gas	71.4%	48.9%	
Coal	2.4%	2.2%	
Electricity	7.1%	2.2%	
Plants in potting soil	(n = 38) 94.7%	(n = 34) 73.5%	***0.020 (a)***
Supply protections	(n = 43) 25.6%	(n = 45) 8.9%	***0.037 (b)***
Supply protections against mould	(n = 44)	(n = 46)	***0.033 (b)***
Yes, often	4.6%	0%	
Yes	18.2%	4.4%	
No, never	77.3%	95.7%	
Leisure activities in the garden	(n = 42) 76.2%	(n = 44) 47.7%	***0.008 (b)***

Characteristics of the fragrance allergy group with p-values between 0.051 and 0.1 were more special nutrition habits (p=0.056), living more in single/family houses (p=0.064), longer ago movement in the present home (p=0.057), lesser location of home nearby traffic loaded roads (p=0.083), more usage of gas for cooking (p=0.070), fewer electrical boiler (p=0.079), more birds as pets (p=0.053), more employability (p=0.095), more working hours per week (p=0.084), lesser alternate shift-work (p=0.052), more light exposure at work (0.068), more hazardous substance exposure at leisure time (p=0.071) and more traveling (0.070) than the controls.

Questionnaire variables without significantly different distribution in the fragrance allergy and control group are: patient's cause suspection of their health disorders, stress at work, in the family and in the circle of friends, reactions on patient's health disorders of people in the family, neighborhood and at work, regularity of daily activities, flatemates, sportive activities, drug use, body height, body weight, intake of vitamins and/or mineral nutritions, drinking of alcoholic beverages, coffee, tea and/or coke, size and age of the home, previous renovation, financial burden, previous home type, window type, usage of ventilation systems and/or humifidifiers, kind of heating, damp and/or mouldy walls, previous mould exposure, chipboard, carpeted floor, wood preservative treated wood, maximum one year old furniture, suits and/or mattress, usage of toilet stones, toilet cleaners, disinfectants, sanitary cleaners, universal cleaners, leather impregnation products and softeners, professional pest control in the last year, changes at home because of health disorders, well-being at home, disturbing factors in the home surroundings, well-being in the home surroundings, graduation, professional training, actual employment, contact to different noxas at workplace, means of transportion to the workplace, transfer time to the workplace, wearing of protecting clothes at workplace, workplace with regulation of harmful substances, company medical care, working indoors, working in air-conditioned rooms, self-arrangement of work, pressure of time at work, satisfaction with colleagues, superiors and job, average yearly gross income, leizure acitivities, possible contact to noxas during leizure acitivities, travel habits.

4 Discussion

The observation that patients with fragrance allergy stated in our questionnaire more impairments in everyday life in comparison to the controls might be an indirect indicator of the wide spread of fragrances in our environment.

However, the results of the present study did not point out a general avoidance reaction to environmental factors of patients with fragrance allergies as it can be usually seen in patients with environment-related health disorders [9, 11].

The reported susceptible reactions to personal hygiene and cosmetic products are characteristic for patients with fragrance allergies [1, 4, 6, 8,] and therefore not otherwise expected.

As mentioned in the introduction, patients with fragrance allergies suffer not only from skin reaction, but also from symptoms of the respiratory tract [1, 2]. This can explain the higher frequency of stated susceptible reactions to deodorant spray in contrast to other deodorant products, because the spray reach better the respiratory system than the other deodorant products.

Fragrance induced respiratory symptoms could also be the reason that the patients with fragrance allergies showed lesser smoking habits than the controls. Another explanation may be the content of fragrances in tobacco smoke and in consequence a causal reaction to these substances.

Interestingly, the patients with fragrance allergies had more dental materials of gold and platinum than the controls. In allergic patients, dental materials with lesser allergic potential, like synthetic materials, would be expected. Actually, there is now explanation for this observation available.

The detected significant differences in home and living conditions between cases and controls can actually only be explained by chance. A disease characteristic exposure or living profile becomes not apparent in our study.

The same is true for the characteristic differences between the fragrance allergy and control group with p-values between 0.051 and 0.1. Altogether, the patients with fragrance allergies seem not withdraw from the social live as it is usually seen by patients with environment-related health disorders [9, 11].

In the interpretation of our results some study limitations must be taken into account. First at all, the number of cases and controls might be too small to observe further significant differences between both groups. Additionally, not every question was answered by every patient. Another problem might be the selected control group. Clinically, fragrance allergies and other allergies could have resulted in equal environment-related reaction as well as adaptation of the living conditions, especially at home. Therefore, in further investigation of exposure and living conditions in patients with fragrance allergies greater collectives as well as an additional control group of patients without allergies should be considered.

5 Conclusions

In conclusion, exposure conditions of patients with fragrance allergy must be investigated in greater collectives.

Furthermore, a control group of persons without allergies must be considered.

Last but not least, the relevance of exposure conditions and genetic susceptibility to fragrance allergies must be clarified.

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Housing characteristics and young children's respiratory health in tropical Singapore

MS. Zuraimi[1], KW. Tham[1], FT. Chew[2] and PL Ooi[1,3]

[1]Department of Building, National University of Singapore, 4 Architecture Drive, Singapore (117566)
email: bdgzms@nus.edu.sg http://www.bdg.nus.edu.sg
[2]Department of Biological Sciences, National University of Singapore
[3] Disease Control Branch, Ministry of Health

Summary: *There have been a large number of studies that documented associations with indoor housing characteristics with prevalence of respiratory symptoms in children. However, there have been very few studies from tropical Singapore where the majority live in concrete multi-house buildings and large proportions of the bedrooms are air-conditioned without provisions for fresh air. The aim of this study is to evaluate the association of housing characteristics and children's respiratory health and allergies in Singapore. Respiratory health and allergies, and housing variables were determined for children ages 1-6 living in Singapore. Multiple regression analysis examined the relationships between the housing characteristics and health outcomes. It was found that dampness, mold, ETS, traffic density, installations of wall-papers, air-conditioning were significantly associated with some health outcomes.*

Keywords: *Young children; Respiratory health; Housing characteristics; Indoor air; Tropics*

1 Extended Abstract

There have been reported studies that documented associations with indoor housing characteristics with prevalence of asthma, allergies and respiratory symptoms in children [e.g 1, 2, 5, 6]. However, there is a paucity of information from the tropics. A cross sectional study using a comprehensive questionnaire was completed by 4759 (response rates 70%) parents of young children (age: 1 and 6 years-old) attending child care centers (CCC) living in Singapore. Through the questionnaire, we solicit information on housing characteristics such as dampness, mold, painting, renovations, traffic proximity, pets, ventilation, cooking fuel use, pets keeping, ETS exposure, building material use and cleaning frequency and, respiratory health and allergy and demographic conditions (see Tables 1 and 2). The questionnaire data were initially analyzed by cross-tabulation and evaluated where appropriate, using the $\chi 2$ test. Multiple regression analysis was used to control for potentially confounding factors. The prevalence ratios (PR) and 95% confidence Interval (CI) were determined by Cox proportional hazard regression model with assumption of a constant risk period as recommended for cross-sectional studies [3, 4].

The current prevalence of symptoms among the children - 4.4% had current doctor diagnosed asthma, 15.8% had current wheezing and 25.6% had current allergic rhinitis. The prevalence of respiratory symptoms range from 21.8 to 69.3%. 21.7% of the parents reported that their children have current lower respiratory illness (either bronchitis, bronchiolitis, pneumonia, croup).

Table 1 Prevalence of asthma and allergy of respondents

Asthma and allergy symptoms	Nos	%
Wheeze in past 12 mths	749	15.8
Doctor-diagnosed asthma	206	4.4
Wheezy after exercise	161	3.5
Had a dry cough past 12 mth	1280	28.2
Rhinitis past 12 mths	1214	25.6
Rhinoconjuctivitis past 12 mths	367	7.8
Eczema past 12 mth	602	12.7
Flexural rash	520	81.3
Respiratory symptoms		
Cough with cold/flu in past 12 months	3214	69.3
Cough with cold/flu most days past 12 months	889	25.1
Full of phlegm w cold/flu past 12 months	1871	40.7
Full of phlegm w cold/flu most days past 12 mth	602	21.8
Gets attack of cough > 1 week past 12 months	1185	26.2
Lower Respiratory Illness in past 12 months	839	21.7

Table 2. Personal and other characteristics of the respondents

Variable		nos	%
Gender	male	2474	53.6
Age	2 yr	561	12.5
	3 yrs	962	21.5
	4yrs	1139	25.4
	5 yrs	1199	26.7
	6 yrs	622	13.9
Race	chinese	3778	81.9
	malay	393	8.5
	indian	233	5.1
	others	209	4.5
Type of housing	Subsidized multi-house	3832	82.7
	Private multi-house	580	12.5
	Single house	221	4.8
Total monthly income	<$2K	804	18.0
	$2-4K	1463	32.7
	$4-6K	967	21.6
	>$6K	1236	27.7
Food allergy		264	5.7
Avoidance behaviour		1295	27.7
Respiratory infections		3214	69.3
Maternal atopy		626	14.1
Paternal Atopy		557	12.6

Prevalence for dampness and mold exposures in the children's bedroom were 5.0 and 3.1% respectively. Table 3 shows the associations of dampness and molds with asthma, allergies and respiratory infections among the children. After adjusting for potential confounding effects, home dampness was significantly associated with current symptoms of rhinoconjunctivitis (PR 1.53, 95% CI : 1.00-2.33), full of phlegm (PR 1.36, 95% CI : 1.10-1.67), cough attacks (PR 1.48, 95% CI : 1.16-1.89) and LRI (PR 1.35, 95% CI : 1.00-1.82). The visible presence of mold was significantly associated with asthma (PR 2.16, 95% CI 1.15-4.08), current symptoms of rhinitis and rhinoconjunctivitis (PR 1.55 and 2.38), phlegm symptoms (PR 1.54, 95% CI : 1.02-2.34), cough attacks (PR 1.47, 95% CI : 1.08-2.00) and LRI (PR 1.70, 95% CI : 1.18-2.43).

Table 3 Association of home dampness and mold with asthma and allergy of children

	Prevalence Ratio (PR)	
	Dampness	Mold
Asthma and allergy symptoms		
Wheeze in past 12 mths	1.14 (0.82-1.58)	1.34 (0.91-1.96)
Doctor-diagnosed asthma	0.94 (0.45-1.93)	**2.16 (1.15-4.08)**
Wheezy after exercise	1.10 (0.53-2.28)	1.86 (0.89-3.89)
Had dry cough past 12 mth	1.11 (0.85-1.46)	1.20 (0.87-1.64)
Rhinitis past 12 mths	1.27 (0.98-1.65)	**1.55 (1.16-2.07)**
Rhinoconjuctivitis past 12 mths	**1.53 (1.00-2.33)**	**2.38(1.51-3.75)**
Eczema past 12 mth	1.23 (0.85-1.76)	1.28 (0.83-1.97)
Flexural rash	1.01 (0.69-1.50)	0.89 (0.54-1.46)
Respiratory symptoms		
Cough with cold/flu in past 12 months	1.13 (0.95-1.34)	1.09 (0.88-1.35)
Cough with cold/flu most days past 12 months	1.06 (0.75-1.48)	1.35 (0.93-1.97)
Full of phlegm w cold/flu past 12 months	**1.36 (1.10-1.67)**	1.21 (0.92-1.58)
Full of phlegm w cold/flu most days past 12 mth	1.23 (0.89-1.76)	**1.54 (1.02-2.34)**
Gets attack of cough > 1 week past 12 months	**1.48 (1.16-1.89)**	**1.47 (1.08-2.00)**
Lower Respiratory Illness in past 12 months	**1.35 (1.00-1.82)**	**1.70 (1.18-2.43)**

[a] Values in bold are statistically significant

Prevalence for smoking mothers and fathers were 4.2 and 28.0% respectively. Smoking in the presence of children (ETS exposure) occurs in 13.5% of the population. Table 4 shows the associations of different ETS exposure variables with asthma, allergies and respiratory symptoms among children. ETS exposure was significantly associated with asthma (PR 1.54, 95% CI 1.01-2.36), current symptoms of wheeze (PR 1.52, 95% CI : 1.21-1.91), doctor diagnosed asthma (PR 1.52, 95% CI : 1.09-2.11) and nocturnal cough ((PR 1.35, 95% CI : 1.14-1.61), rhinitis (PR 1.54, 95% CI : 1.32-1.81), rhinoconjunctivitis (PR 1.98, 95% CI : 1.46-2.68), phlegm symptoms (PR 1.18, 95% CI : 1.01-1.37), severe phlegm symptoms (PR 1.41, 95% CI : 1.106-1.81) and cough attacks (PR 1.24, 95% CI : 1.02-1.50). Smoking mothers result in higher risk to the asthma, rhinitis and respiratory symptoms of children compared to smoking fathers. With the exception of eczema symptoms, a dose-response pattern among children with different numbers of smokers in their homes (reference group is homes without any smokers) for asthma, rhinitis and respiratory symptoms.

Table 4 Association of parents smoking with asthma and allergy of children

	Prevalence Ratio (PR)[a]		
	Father	Mother	Both
Asthma and allergy symptoms			
Wheeze in past 12 mths	**1.22 (1.01-1.47)**	**1.71 (1.16-2.51)**	**1.67 (1.09-2.56)**
Doctor-diagnosed asthma	1.29 (0.90-1.84)	1.94 (0.97-3.87)	1.83 (0.85-3.97)
Wheezy after exercise	**1.50 (1.01-2.22)**	1.07 (0.39-2.96)	0.96 (0.30-3.08)
Had a dry cough past 12 mth	1.09 (0.95-1.26)	1.07 (0.78-1.46)	1.02 (0.72-1.44)
Rhinitis past 12 mths	1.14 (0.99-1.32)	**1.64 (1.23-2.19)**	**1.64 (1.20-2.24)**
Rhinoconjuctivitis past 12 mths	1.11 (0.85-1.46)	1.71 (0.98-2.97)	1.57 (0.85-2.91)
Eczema past 12 mth	0.93 (0.75-1.16)	1.17 (0.72-1.92)	1.10 (0.63-1.91)
Flexural rash	1.01 (0.80-1.29)	1.22 (0.71-2.07)	1.26 (0.70-2.29)
Respiratory symptoms			
Cough with cold/flu in past 12 months	1.01 (0.92-1.11)	1.01 (0.81-1.25)	0.97 (0.77-1.23)
Cough with cold/flu most days past 12 months	1.08 (0.91-1.29)	1.18 (0.81-1.73)	1.24 (0.83-1.87)
Full of phlegm w cold/flu past 12 months	1.08 (0.96-1.22)	1.06 (0.80-1.40)	0.98 (0.72-1.33)
Full of phlegm w cold/flu most days past 12 mth	1.12 (0.91-1.38)	1.17 (0.70-1.29)	1.21 (0.72-2.06)
Gets attack of cough > 1 week past 12 months	1.01 (0.87-1.17)	1.22 (0.86-1.73)	1.05 (0.70-1.56)
Lower Respiratory Illness in past 12 months	1.01 (0.84-1.22)	1.18 (0.77-1.83)	1.09 (0.67-1.78)

[a] Values in bold are statistically significant

In this study, 47.5% of the children sleep in air-conditioned rooms (100% recirculation without any fresh air provisions) with the children sleeping in rooms that rely on open windows for ventilation and thermal comfort. The use of air-conditioning in the children's sleeping room was significantly associated with current rhinitis (PR 1.14, 95% CI : 1.00-1.31) and rhinoconjunctivitis (PR 1.32, 95% CI : 1.03-1.69).

Those reporting high traffic densities outside their children's house (10.8%) had significant associations with current rhinitis (PR 1.27, 95% CI : 1.00-1.62), rhinoconjunctivitis (PR 1.56, 95% CI : 1.06-2.30) and phlegm symptoms (PR 1.16, 95% CI : 1.01-1.34).

Wall papers in the children's bedroom is significantly associated with increased risk for current rhinitis (PR 1.65, 95% CI : 1.07-2.55) and current eczema (PR 2.26, 95% CI : 1.34-3.81). Installation of carpet is protective for current rhinitis (PR 0.32, 95% CI : 0.10-0.99) while increasing the risk of asthma (PR 2.81, 95% CI : 1.02-7.68).

Conclusion

This study shows that housing characteristics such as exposure to home dampness, mold, ETS, traffic density, installations of wall-paper, air-conditioning are important determinants of respiratory health and allergies among young children in tropical Singapore.

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Living Conditions at Home of Patients with self-reported Multiple Chemical Sensitivity (sMCS), Fragrance Allergies or Nasal Polyps

Ch. Brülls[1], H. Niggemann[1], W. Weißbach[1], W. Dott[1], M. Fischer[1,2], B. Blömeke[2],
H.F. Merk[3], J. Isselstein[4], J. Ilgner[4], M. Westhofen[4] and G.A. Wiesmüller[1]

[1]Inst. of Hyg. and Environ. Medicine, RWTH Aachen University, Pauwelsstraße 30, 52057 Aachen, Germany
Email: ga.wiesmueller@post.rwth-aachen.de http://www.hygiene.ukaachen.de
[2]Dept. of Ecotoxicology and Toxicology, University Trier, Am Wissenschaftspark 25-27, 54296 Trier, Germany
[3]Dermatological Clinic, RWTH Aachen University, Pauwelsstraße 30, 52057 Aachen, Germany
[4]Dept. of Otorhinolaryngology Plastic Surgery, RWTH Aachen University, Pauwelsstraße 30, 52057 Aachen, Germany

Summary: *The dependence of home conditions, which were elicited by a questionnaire, in relation to self-reported Multiple Chemical Sensitivity (sMCS), fragrance allergies (FA) and nasal polyps (PN) was statistically analyzed. Differently distributed home conditions (e.g. usage of toilet cleaners (p=0.000), odor (p=0.000) and disinfectant sprays (p=0.006), universal cleaners (p=0.000) and insecticides (p=0.004)) observed between sMCS-, FA- and PN-affected patients are mainly factors which are associated with odorous effect components. Avoidance of odorous exposure increased from PN-, FA- to sMCS-affected patients. In conclusion, further research on the pathophysiology of these diseases should focus on the role of the respiratory and olfactory system.*

Keywords: *fragrance allergy, multiple chemical sensitivity, nasal polyps, living conditions, indoor air*
Category: *Allergy and other sensitivity reactions*

1 Introduction

Different indoor factors are possible causes and triggers of Multiple Chemical Sensitivity (MCS), fragrance allergies (FA) and nasal polyps (PN). The respiratory and olfactory systems play an important role in these diseases. In contrary to FA the etiology of MCS remains unclear. Severe somatic symptoms, which may be triggered by very low concentrations of chemical substances, are original theory. This theory could not be proved by scientific methods. Another hypothesis is that MCS is a mixture of psychosomatic disorders without any histological or immunological background [12]. A psychosomatic or psychiatric co-morbidity was demonstrated by several studies and is widely accepted [5]. Newer studies give rise to the suspicion that a kind of hypersensitivity of the nasal mucosa might be a correlate for symptoms located in the respiratory system [13]. The actual definition based on the *MCS-Consensus* criteria shows this difficulty to integrate a variety of symptoms: (1) the symptoms are reproducible with (repeated chemical) exposure; (2) the condition is chronic; (3) low levels of exposure (lower than previously or commonly tolerated) result in manifestations of the syndrome; (4) the symptoms improve or resolve when the incitants are removed; (5) responses occur to multiple chemically unrelated substances; and (6) symptoms involve multiple organ systems [1]. Without any doubt, patients suffer severely from their symptoms, clinical research in this field remains necessary.

The immunological causes of FA are well documented by many studies [11]. Contact allergy to one or a mixture of hundreds of possible allergens has been elicited [14]. These conditions, mainly seen in female patients, show an allergic reaction type IV (Coombs and Gell) with a T-Cell triggered mechanism. Two studies, presented by Elberling et al. [8, 9], suggest a high prevalence of airway related symptoms in patients suffering from FA. Whether this sensitivity might also be an immunologic or a conditioned reaction has not been investigated.

The pathomorphology of PN has been well known for decades. Initially, a higher migration and decreased apoptotic rate of eosinophilic granulocytes occurs in the nasal mucosa [2]. On the other hand, the biochemical pathways of chronic inflammatory reaction leading to chronic sinusitis as a precursor and the pathogenesis of polyps seem to be different [15]. Co-morbidity with bronchial asthma and analgetics intolerance suggest cyclooxygenase 1 to trigger these symptoms. Environmental factors are poorly investigated, a relation to woodstoves as a principle resource of heating has been found [10].

The aim of our study was to investigate, whether different disease-related home conditions of patients with self-reported MCS (sMCS), FA and PN can be determined. For the diseases FA and PN this might be the first classification and comparison of these home related conditions.

2 Patients and Methods

Patients were selected in the Dermatological Clinic, the Dept. of Otorhinolaryngology, Plastic Surgery and the outpatients' Unit of Environmental Medicine of the Institute of Hygiene and Environmental Medicine of the RWTH Aachen University. sMCS-patients were enlisted from members of MCS self-help groups in Germany. FA-patients were selected in the outpatients' Unit of Allergology of the Dermatological Clinic as well as by contacting patients from the previous two years, who were diagnosed and treated in this clinic. Patients with PN were selected from a group who were admitted to the Dept. of Otorhinolaryngology for endonasal sinus surgery.

A standardized questionnaire used for the investigation was developed by seven departments of the University Hospital Aachen for studies on the relevance of genetic predispositions and environmental factors for different human diseases. The questionnaire includes 75 questions, 25 of which focus on the home related living conditions. The following questions were included: type of residential building, living space, age of the building, year moved in, year and type of renovation, residential building lived in before. Furthermore the patients had to disclose information about the financial burden, window type, usage of humidifying towers, air cleaners and air conditioning, heating of the flat, heating fuel, existence of open fire, gas or electric cooking, water heater, humid or moldy walls, former existence of mould. Furthermore, existence of chipboards, carpets, usage of wood preservatives, new wooden furniture and seating furniture, maximum 1 year old mattress, pets and plants in the flat and usage of domestic products as universal cleaners, odor and disinfectant sprays are examples of asked questions. This part of the questionnaire was ended with questions concerning changes and time spent in the flat, disturbances inside the flat and general feelings about the rooms.

Home living conditions of the three groups were described by percentages. Stata® 8.2 was used for the statistical analysis. The dependence of questionnaire-obtained home conditions and the occurrence of missing data on sMCS, FA and PN were analyzed using Pearson's χ^2 and Fisher's exact test. Differences in the distribution of financial costs between the study groups were analyzed by Kruskal-Wallis und Mann-Whitney-U test. If significance in general between all groups was found, the groups were tested against each other under consideration of Bonferroni adjustment.

3 Results

The sMCS group consisted of 14 men and 45 women, the FA group of 19 men and 25 women and the PN group of 42 men and 27 women. Not every question was answered by every patient. However, lack of information was not related to the study groups The data obtained reached significance levels on questions about building age (p=0.03). Bonferroni adjustment between the groups showed significance in the category > 20 years and 6-20 years. FA and sMCS patients more often lived in older buildings than the PN-patients. These patients personally renovated more often their flat (p=0.017). On a scale of 1 to 10 the sMCS-patients felt more burdened by the financial costs of their flats (p=0.001). Significance was evaluated through the question about the existence of humidifiers and air cleaners. Data are shown in Figure 1.

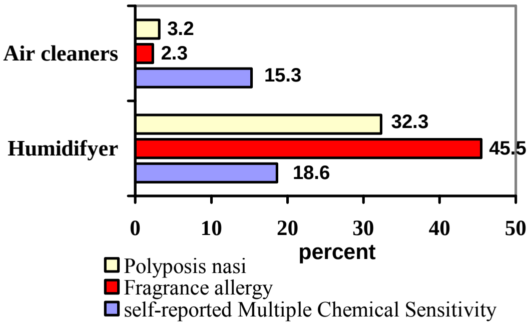

Figure 1: Existence of humidifiers and air cleaners in patients' homes.

In all groups patients answered the question about former existence of mould with 'yes' in similar high percentages (sMCS-patients: 35.85%, FA-patients: 20%, PN-patients: 27.42, p=0.239). Question about existing moldy walls showed significant difference ($p_{sMCS-FA}=0.035$, $p_{sMCS-PN}=0.008$), which was reported to have been more often present in sMCS-patients' homes. Concerning the interior furnishing percentages showed a significant higher usage of new furniture ($p_{PN-FA}=0.006$, $p_{PN-sMCS}=0.000$) and mattress ($p_{PN-FA}=0.016$, $p_{PN-sMCS}=0.009$) by PN-patients in contrary to the FA- and sMCS-group. PN- and FA-patient groups used more often wooden preservatives ($p_{sMCS-FA}=0.006$, $p_{sMCS-PN}=0.020$).

More than 90% of FA- and PN-patients had plants in their rooms, only 76.3% of sMCS-patients owned plants ($p_{sMCS-FA}=0.043$, $p_{sMCS-PN}=0.005$). Usage of domestic products showed significant differences between sMCS-patients and FA-/PN-patients ($p_{sMCS-FA/PN}=0.000$). Four examples of over all nine significant answers are shown in Figure 2.

Changes inside the flat initiated by the disease were carried out by 63.8% of sMCS patients, while only 19.7% of the PN- and 18.2% of the FA-patients changed their interior decoration ($p_{sMCS-FA}=0.000$, $p_{sMCS-PN}=0.000$). The daily time spent in the flat showed significance between the PN- and sMCS-patient groups (p=0.002) and is demonstrated in Figure 3.

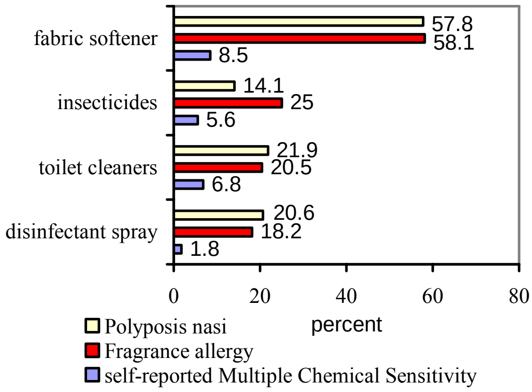

Figure 2: Percentages of domestic products use.

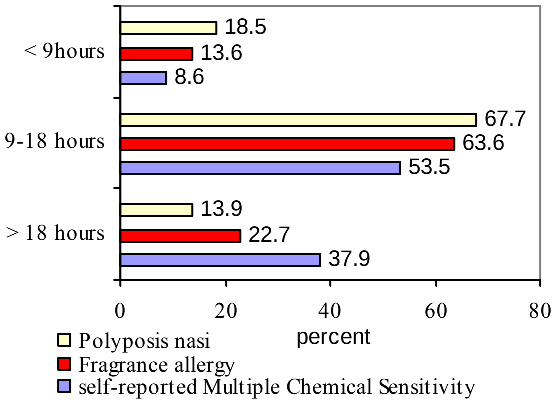

Figure 3: Percentages of time spent inside the flat.

sMCS patients reported a significantly higher level of disturbances inside the flat compared to PN and FA-patients (p=0.000). The results are shown in Figure 4.

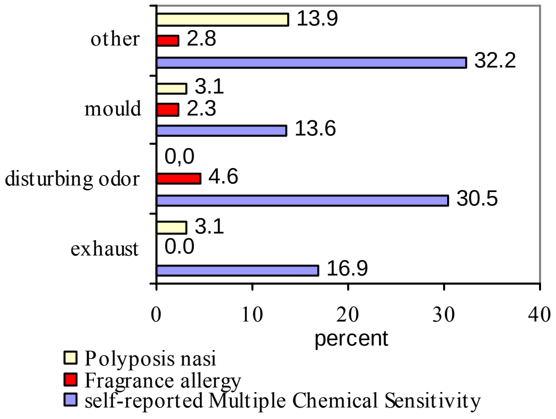

Figure 4: Percentages concerning kind of disturbances inside the flat.

With significant difference sMCS-patients did not feel well inside the flat (11.9%). Only 2.3% of the patients suffering from FA and no PN-patient answered this question in the same way as the sMCS-patients. 61.5% of the PN- and 59.1% of the FA-patients were very content with their living conditions, compared to only 25.4% of the sMCS patients being satisfied ($p_{sMCS\text{-}FA}=0.000$, $p_{sMCS\text{-}PN}=0.000$).

4 Discussion

The data show the sensitivity of sMCS-patients according to odors and typically accused environmental toxic substances. This described sensitivity against airway-related components is particularly found in FA-patients.

The fact that sMCS-patients live in homes, which are older than 20 years, might be interpreted in correlation to US-studies [6] reporting the patients' opinion that new buildings are more polluted than older buildings. No data exist on this hypothesis in relation to FA-patients, although an influence cannot be excluded. The lower percentages concerning renovation during the last years could also be due to fear of using materials like gloss paint, painting colors or dust. Sensitivities to these materials are published [7, 9]. The special interest of sMCS-patients in a clean and non-toxic home may be the reason for higher costs and the usage of air cleaners [6]. On the other hand, the sMCS-patients could fear contamination of humidifying towers containing microorganisms and a following aggravation of their symptoms, while PN-patients might be in the hope of improving symptoms, which they relate to dry and swollen mucosa.

There is an interesting discrepancy in the question of former vs. actual moldy or damp walls. All groups similarly report this factor in high percentages in the past. The fact, that this level is reported just 10% lower in the homes of sMCS-patients in contrary to the other groups is surprising. Mold is one of the most accused origins of symptoms by MCS-patients [4, 6, 7]. The elimination of possible triggers should be the logical consequence. It is uncertain, whether or not this will happen because of a lack of technology and know-how. However, it may also be that the existence of mold is a necessary component of a self-defined understanding according to MCS. The lower ratings of plants in the flats of sMCS-patients can be interpreted in the same, mold avoiding manner.

New furniture and mattress are accused as trigger factors in the etiology of MCS [6]. Other components are wooden preservatives and leather impregnation that can trigger dermatological allergic symptoms [11]. It does not surprise that these groups restrain themselves from buying new furniture.

Interestingly, FA-patients use domestic products as often as PN-patients do; and this significantly more often than sMCS-patients. As expected, sMCS-patients tend to avoid products, such as disinfectant sprays. The data illustrate the massively raised sensitivity against chemical and airway-related products. Based on the data of Elberling et al. [9] a rare use of domestic products would have been logical. Data does not show a decrease in use by FA-patients versus PN-patients, which might in this context be set as a 'control group'. The question is, whether or not the airway symptoms found by Elberling et a1. [9] are conditioned reactions and can therefore be applied to non cosmetic products.

As a result from the wished 'clean' indoor climate sMCS-patients try to change their interior surroundings as a part of their 'therapy' [4, 6, 7]. In this respect, it is a logic consequence that approximately 40% of this group stays inside of their homes for more than 18 hours. Nevertheless this group is disturbed by multiple factors. There is no area which is subjectively free from health hazards. Following this theory, it may be expected that in comparison to the other groups sMCS-patients feel more uncomfortable inside their homes. Similar data can be found [7] showing a social retreat into a self-defined area, which consists of a healthy environment. Although it may be a healthy environment, these patients are still incapable of being completely released from their suffering. The other groups do not seem to be affected by the indoor environment in the described generalized manner.

5 Conclusions

The different home conditions observed between sMCS, FA and PN are mainly factors which are associated with odorous effect components. The avoidance of odorous exposures increased from PN-, FA- to sMCS-affected patients. It remains uncertain, to which extent the reactions of FA-patients, according to furniture etc., should be interpreted as by chance, because reactions to other domestic products are not significantly different from PN-patients. The possibility of Pavlov's conditioning should be investigated.

sMCS-patients showed a reserve of all possible products which could influence patients' health. Products of daily use in housekeeping with an airway component are mainly avoided. The psychosocial component of sMCS can be construed from these data as a situation of retreat into the 'clean' indoor climate. Home conditions that could promote a feeling of wellbeing exist only in a reduced manner. A hypothetical airway dependent pathogenetic cause should be further investigated.

PN-patients showed no reaction and no noticeable hypersensitivities while aggravation of symptoms cannot be established.

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Association between Child Care Center Characteristics with Respiratory Health and Allergies among Young Children in the Tropics

MS. Zuraimi[1], KW. Tham[1], FT. Chew[2], PL Ooi[1,3], C-G. Bornehag [4,5,6], J. Sundell [4]

[1]Department of Building, National University of Singapore, 4 Architecture Drive, Singapore (117566)
email: bdgzms@nus.edu.sg http://www.bdg.nus.edu.sg
[2]Department of Biological Sciences, National University of Singapore.
[3]Disease Control Division, Ministry of Health, Singapore.
[4]International Centre for Indoor Environment and Energy, Technical University of Denmark; Denmark.
[5]Swedish National and Testing Research Institute, Boras, Sweden.
[6]Public Health Sciences, Karlstad University, Karlstad, Sweden.

Summary: *This study explored the associations of child care center characteristics with asthma, allergies and respiratory symptoms of attending children in Singapore. Parents of children with current wheeze, rhinitis and respiratory symptoms are more likely to avoid CCCs that are air-conditioned and near traffic. Associations between asthma, allergic and respiratory symptoms with traffic densities, geographic location and outdoor pollution are no consistent and significant. Similarly, there were no significant associations between symptoms and CCC dampness/mold exposure, although, there are evidence of a dose-response relationship with exposure severity with symptoms. Although not significant, dose-response relationship with CCC floor area to children density quartiles and rhinitis symptoms was observed. The associations of fourth quartile density were significantly higher for phlegm and cough attack symptoms with the remaining respiratory symptoms approaching significance. Children attending CCCs with more than 10 rooms were significantly associated with higher prevalence of phlegm symptoms. Wooden panel and particle boards were associated with higher risk of severe phlegm and LRI respectively while recent painting was significantly associated with higher risk of severe cough. We were not able to find any consistent association between health symptoms children with the frequencies of cleaning of various CCC variables.*

Keywords: *Young children; Respiratory health; Child care center; Indoor air, symptoms, disease, building and operation characteristics*
Category: *Allergy and other sensitivity reactions*

1 Introduction

Indoor air quality (IAQ) in child care centers (CCC) can be an important factor associated with the prevalence and severity of asthma and allergies, as well as with airway infections among young children. Children attending child care centers may be more susceptible to infectious disease compared to those cared for at home, as they may be exposed to conditions that can increase the risk to allergies and even asthma. These conditions are dependent on building and operation characteristics such as (ventilation, proximity to traffic contamination, etc). Also, the child care center environments are similar to home and/or school conditions in the sense that they include a kitchen and mattresses, but may also have classrooms and are air-conditioned during operating hours using mechanically ventilated system with either a dedicated or shared air handling unit (AHU). Additionally, those served by dedicated AHU may function in total recirculation mood with no intentional introduction of outdoor air. It is not surprising that different indoor environments can arise due to these differences [1]. In Karlstad Sweden, it was hypothesized that differences in indoor environmental factors have led to significant differences in the prevalence of allergic symptoms and respiratory infections within 34 child care centers [2]. However, little is known or published about pediatric asthma and associated respiratory allergy and their association with the indoor environment of child care centers, especially in the tropics. The aim of the study was to determine if there are associations between child care center characteristics and several airway, nose and skin symptoms among young children in Singapore.

2 Method

The parents of the children attending these CCCs were the respondents for the questionnaire survey. All the children that were on full-time enrollment (45 hr/ week) were included in this study. The questionnaires were distributed to the children based on the CCC's registers and collected by the respective class teachers with up to 3 reminders. For asthma and allergic symptoms, the international study of asthma and allergies in children (ISAAC) written questionnaire was used. We concentrate on current wheezing episodes, a doctor's diagnosis of asthma, current allergic rhinitis and rhinoconjunctivitis and current eczema symptom. For respiratory symptoms, the American Thoracic Society and the Division of Lung Diseases (ATS-

DLD), of the National Heart, Lung, and Blood Institute, USA, respiratory symptom questionnaire was used. The questionnaire also included questions on potential confounders which include the child's age, gender, ethnicity, housing characteristics (moldy), food allergy, maternal and paternal smoking (current ETS exposure), maternal and paternal atopy, preterm births, breastfeeding, number of siblings, current pet exposure and current symptoms of respiratory infections. Socio-economic status (SES) of the children was assessed by including questions on household income [3]. The parents were asked to state whether they had chosen to avoid air-conditioned CCCs or those near traffic because of allergic diseases in the family ('an avoidance behaviour'), that is, whether they had avoided air-conditioned/near-traffic CCCs because of allergy in the family (yes/no), or had changed CCC for the same reason (yes/no).

The questionnaire data were initially analyzed by cross-tabulation and evaluated where appropriate, using the $\chi2$ test. Multiple regression analysis was used to control for potentially confounding factors. The prevalence ratios (PR) and 95% confidence Interval (CI) were determined by Cox proportional hazard regression model with assumption of a constant risk period as recommended for cross-sectional studies [3, 4]. For asthma and allergies, the covariates used were age, sex, race, socio-economic status, housing type, ETS exposure, maternal and paternal atopy, food allergy, home dampness exposures and respiratory infections. For respiratory symptoms on the other hand, age, sex, race, socio-economic status, housing type, ETS exposure, maternal and paternal atopy, preterm birth, breastfeeding and home dampness exposures were the covariates. Univariate analysis of current pet exposures was not statistically associated with the symptoms and thus not included in the model. The effect of CCC ventilation characteristics of CCCs on asthma, allergies and respiratory symptoms have been discussed elsewhere and will not be repeated here [1].

3 Results and Discussions

There were 4759 responses from the 97 CCCs, a response rate of approximately 70%. Of these, 4629 children attend full day program and were included in the analysis. Table 1 provides the demographic and home characteristics of the attending children the CCCs. The fraction of boys slightly exceeded the girls while the 5 year olds make up the majority of the age groups. The Chinese forms the majority of the ethnic group while children with 1 brother/sister was the highest among the number of siblings. Children with family earning $2-4K form the bulk of the cohort. Prevalence was high for breastfeeding with moderate prevalence for paternal/maternal atopy. 6% of the bedrooms where the children sleeps were classified as 'damp' while 14 of the children were exposed to ETS at home.

Table 1 Demographic and home characteristics

n = 4629		No	%
Gender	male	2424	54
Age	2 yr	553	13
	3 yrs	934	21
	4yrs	1101	25
	5 yrs	1175	27
	6 yrs	618	14
Race	chinese	3701	82
	malay	393	9
	indian	227	5
	others	189	4
Type of housing	Subsidized flat	3803	84
	Private flat	532	12
	landed property	194	4
Total monthly income	<$2K	804	18
	$2-4K	1457	33
	$4-6K	960	22
	>$6K	1148	26
No of siblings	0	1297	28
	1	2391	52
	2	733	16
	>3	165	4
Breastfeeding	yes	3155	71
Preterm birth	yes	409	9
Food allergy	yes	252	6
Refrained from AC CCCs	yes	1286	28
Refrained from near traffic CCCs	yes	1435	31
Home ETS	yes	625	14
Maternal atopy	yes	603	14
Paternal atopy	yes	534	12
Home dampness	yes	268	6

Among asthma and allergy symptoms, the most frequently reported symptoms were current wheezing, nocturnal cough, rhinitis, eczema and flexural rash (Table 2). The prevalence of 'doctor diagnosed asthma' is 7.5%. Among the respiratory symptoms, current cough with cold/flu was the highest followed by full of phlegm with cough with cold/flu. The prevalence of current lower respiratory illness (positive answers to bronchiolitis, bronchitis, pneumonia and croup questions in the past 12 months) is 21.3%.

Table 2 Current asthma, allergy and respiratory symptoms for full time attending children.

n = 4629	No	%
Asthma and Allergies		
Wheeze in past 12 months	716	15.5
Doctor diagnosed asthma	332	7.5

Wheezy after exercise in past 12 months	154	3.5
Nocturnal cough in past 12 months	1253	28.2
Rhinitis in past 12 months	1180	25.5
Rhinoconjuctivitis in past 12 months	357	7.7
Eczema in past 12 months	583	12.6
Flexural rash in past 12 months	502	10.8
Respiratory Symptoms		
Cough with cold/flu in past 12 months	3124	68.9
Cough with cold/flu at most days in past 12 months	869	25.2
Full of phlegm w cold/flu in past 12 months	1809	40.3
Full of phlegm w cold/flu at most days in past 12 months	588	22.0
Gets attack of cough > 1 week in past 12 months	1148	26.0
Lower Respiratory Illness in past 12 months	802	21.3

28.2% of the parents reported some kind of avoidance behavior with regards to placing their children in air-conditioned (AC) environments while 31.5% avoided CCCs that are close to traffic. The influence of parent's avoidance on the risk of symptoms is described in Table 3. Current wheeze, dry cough, rhinitis, phlegm symptoms, attacks of cough and LRI were significantly associated with avoidance behavior for AC. For parent's of children with current symptoms of wheeze and rhinoconjunctivitis, a significant number avoid CCCs that are close to traffic. Subsequently, we incorporate these avoidance behaviors to control their influence on other risk factors.

Table 3. Associations of symptoms with avoidance behavior for air-conditioned and near- traffic CCCs

Current Symptoms	Prevalence Ratio (95% CI)	
	Avoid AC	Avoid Traffic
Wheeze	**1.38 (1.15-1.66)**	**1.21 (1.01-1.45)**
Doctor-diagnosed asthma	1.17 (0.87-1.59)	1.19 (0.89-1.60)
Wheezy after exercise	1.18 (0.79-1.76)	1.31 (0.89-1.94)
Had a dry cough	**1.23 (1.07-1.41)**	1.13 (0.98-1.30)
Rhinitis	**1.25 (1.08-1.44)**	1.09 (0.95-1.26)
Rhinoconjuctivitis	1.15 (0.88-1.50)	**1.38 (1.07-1.78)**
Eczema	0.95 (0.77-1.18)	1.14 (0.93-1.40)
Flexural rash	0.92 (0.73-1.16)	1.09 (0.88-1.36)
Cough with cold/flu	1.07 (0.98-1.18)	1.04 (0.95-1.13)
Cough with cold/flu at most days	1.07 (0.90-1.28)	1.07 (0.90-1.27)
Full of phlegm w cold/flu	**1.25 (1.11-1.41)**	1.11 (0.98-1.25)
Full of phlegm w cold/flu at most days	**1.25 (1.01-1.54)**	1.19 (0.97-1.47)
Gets attack of cough lasting > 1 week	**1.21 (1.05-1.41)**	1.15 (0.99-1.33)
Lower Respiratory Illness (LRI)	**1.38 (1.16-1.65)**	1.05 (0.88-1.25)

We next evaluate the risk of symptoms associated with outdoor environments of the child care centers (Table 4). It is observed that the prevalence ratios of most the symptoms were not significant. It is also observed that higher traffic densities and bigger roads are protective of one of the phlegm symptoms. Other CCCs outdoor environment variable did not show consistent association with the health of children.

The prevalence of CCC dampness and mold exposure were 72.8 and 42.8% respectively. Of all the current symptoms studied, only associations of wheeze, cough attacks and LRI with mold exposure in CCC approached significance (Table 5). If we assume that mold growth indicates the source strength of exposure with reference to dampness alone, we found a dose-response relationship (not significant) with asthma (exluding doctor-diagnosed asthma), allergies and respiratory symptoms. We then evaluate the intensity of current symptoms experienced with exposure to severe dampness and mold (both prevalence - 19.1%). Despite the non-significant results, we found that severe dampness increases the risk of respiratory symptoms when compared to just dampness alone. The non-significant relationship between dampness/mold exposure and health symptoms findings mirrors those reported by Nafstad et al [5]. However, dose response relationships recorded here suggest that causal agents of these indicators do not have a significant influence on health symptoms in child care settings which may be due to limited exposure time, larger environment and good ventilation.

There was no consistent association for the age of CCC building with symptoms (Table 6). Similarly, building types did not influence the asthma and allergic symptoms among children. However, there are indications that building types may influence respiratory symptoms; the associations with CCC in office buildings approach significance for all symptoms, less so CCC in single houses (SH) while buildings specially designed (CCC) for CCCs are associated with LRI among children. The latter could be the influence of parents whose children had contracted LRI and had wanted a 'healthier' environment. We also compared the density of the CCC by dividing the floor area with the number of children in each CCC. The density were then divided into quartiles and subsequently evaluated for associations with symptoms. Although not significant, there is a dose-response relationship with density quartiles and rhinitis symptoms. The associations of fourth quartile density were significant for phlegm and cough attack symptoms while the associations of remaining respiratory symptoms approach significance. Phlegm symptom

Table 4. Associations of symptoms with CCCs outdoor environment variables (Prevalence Ratio (95% CI))

Variable	Description	Wheeze	Doctor-diagnosed asthma	Rhinitis	Rhinoconjun-ctivits	Eczema
Traffic types	Small local street	1	1	1	1	1
	Local street	1.1 (0.9–1.4)	1.0 (0.7-1.4)	0.9 (0.8–1.1)	0.9 (0.7–1.3)	1.0 (0.8-1.2)
	Expressway	0.9 (0.7-1.3)	1.4 (0.9-2.2)	0.9 (0.7–1.1)	0.7 (0.4-1.1)	1.0 (0.7-1.5)
Traffic densities	Light	1	1	1	1	1
	Medium	0.9 (0.8–1.2)	0.9 (0.7-1.3)	0.9 (0.8–1.1)	0.8 (0.6–1.1)	0.9 (0.7–1.2)
	Heavy	1.0 (0.8–1.3)	1.1 (0.8-1.6)	1.0 (0.8–1.1)	1.1 (0.8–1.5)	1.1 (0.8–1.2)
Type of place	Sub-urban	1	1	1	1	1
	Urban estate	1.0 (0.7-1.3)	1.4 (0.9-2.3)	0.8 (0.7-1.0)	**0.7 (0.5–1.0)**	0.5 (0.2-1.2)
	Outer part of city	1.2 (0.9–1.6)	1.0 (0.6-1.8)	0.9 (0.7-1.2)	0.7 (0.5–1.1)	1.0 (0.8-1.5)
	Central city	1.0 (0.4-2.2)	NS	1.0 (0.5-1.7)	0.9 (0.3-2.4)	0.9 (0.5-1.7)
Other pollution	None	1	1	1	1	1
	Factory	1.2 (0.7–1.9)	0.5 (0.2–1.7)	0.8 (0.5–1.2)	0.4 (0.1–1.2)	**0.4 (0.2–0.9)**
	Waste dump	0.7 (0.5–1.1)	1.1 (0.6–2.1)	1.1 (0.8–1.4)	1.1 (0.6–1.9)	0.8 (0.5–1.2)
	Carparks	0.9 (0.7–1.1)	1.0 (0.7-1.5)	1.0 (0.8–1.2)	1.0 (0.7–1.3)	0.9 (0.7–1.2)
	Construction works	1.0 (0.7–1.3)	1.0 (0.6-1.7)	1.1 (0.8–1.4)	1.2 (0.8–1.8)	0.9 (0.7–1.3)
		Cough with cold/flu at most days	Full of phlegm w cold/flu	Full of phlegm w cold/flu at most days	Gets attack of cough lasting > 1 week	Lower Respiratory Illness (LRI)
Traffic types	Small local street	1	1	1	1	1
	Local street	0.9 (0.8–1.1)	1.0 (0.9-1.1)	**0.8 (0.6–1.0)**	0.9 (0.8–1.1)	1.0 (0.9–1.3)
	Expressway	0.8 (0.6–1.0)	0.9 (0.7-1.0)	**0.5 (0.3–0.6)**	0.9 (0.7–1.1)	1.1 (0.9–1.5)
Traffic densities	Light	1	1	1	1	1
	Medium	0.9 (0.7–1.1)	1.0 (0.9–1.1)	**0.7 (0.6–0.9)**	0.9 (0.7–1.0)	1.0 (0.8–1.2)
	Heavy	0.9 (0.8–1.1)	1.0 (0.9–1.1)	**0.8 (0.6–1.0)**	0.9 (0.8–1.1)	1.1 (0.9–1.3)
Type of place	Sub-urban	1	1	1	1	1
	Urban estate	1.0 (0.7–1.3)	1.0 (0.8-1.2)	0.8 (0.6–1.2)	1.0 (0.8–1.3)	1.0 (0.8–1.3)
	Outer part of city	1.1 (0.8–1.6)	1.1 (0.9-1.3)	0.9 (0.6–1.3)	1.2 (0.9–1.5)	1.3 (1.0–1.7)
	Central city	0.9 (0.4–2.2)	1.1 (0.6-1.9)	1.1 (0.4-3.2)	1.7 (0.9–3.0)	1.0 (0.5–2.2)
Other pollution	None	1	1	1	1	1
	Factory	1.2 (0.7–2.0)	0.9 (0.6–1.3)	0.8 (0.4–1.6)	1.0 (0.6–1.5)	0.8 (0.4–1.4)
	Waste dump	1.2 (0.8–1.9)	0.9 (0.7–1.2)	1.0 (0.6–1.6)	1.1 (0.8–1.6)	1.1 (0.7–1.6)
	Carparks	1.1 (0.9–1.4)	0.9 (0.7–1.0)	1.0 (0.8–1.4)	1.0 (0.8–1.2)	0.9 (0.7–1.1)
	Construction works	1.2 (0.8–1.7)	0.8 (0.6–1.0)	1.0 (0.6–1.5)	1.0 (0.8–1.4)	0.9 (0.6–1.2)

Table 5. Associations of symptoms with CCCs dampness and mold variables (Prevalence Ratio (95% CI))

Variable	Description	Wheeze	Doctor-diagnosed asthma	Rhinitis	Rhinoconjun-ctivits	Eczema
Damp	Yes	1.0 (0.8–1.2)	1.2 (0.7–1.3)	0.9 (0.8–1.0)	1.0 (0.8–1.3)	1.0 (0.8–1.1)
	Severe damage	1.1 (0.9-1.4)	**0.6 (0.4-0.9)**	0.9 (0.8–1.1)	1.1 (0.8-1.5)	1.1 (0.9-1.4)
Mold	Yes	1.1 (1.0–1.4)	1.0 (0.7–1.3)	1.0 (0.8–1.1)	1.0 (0.8–1.3)	1.0 (0.9–1.3)
	Severe damage	1.1 (0.9-1.4)	**0.6 (0.4-0.9)**	0.9 (0.8–1.1)	1.1 (0.8-1.5)	1.1 (0.9-1.4)
		Cough with cold/flu at most days	Full of phlegm w cold/flu	Full of phlegm w cold/flu at most days	Gets attack of cough lasting > 1 week	Lower Respiratory Illness (LRI)
Damp	Yes	1.0 (0.8–1.2)	0.8 (0.8–1.0)	1.0 (0.8–1.2)	0.9 (0.8–1.1)	1.0 (0.8–1.2)
	Severe damage	1.1 (0.9–1.4)	1.0 (0.9–1.2)	1.1 (0.8–1.4)	1.0 (0.9–1.2)	1.0 (0.8–1.2)
Mold	Yes	1.1 (0.9–1.3)	1.0 (0.9–1.1)	1.0 (0.8–1.2)	1.1 (1.0–1.3)	1.2 (1.0–1.4)
	Severe damage	1.1 (0.9–1.4)	1.0 (0.9–1.2)	1.1 (0.8–1.4)	1.0 (0.9–1.2)	1.0 (0.8–1.2)

Table 6. Associations of symptoms with CCCs building characteristics (Prevalence Ratio (95% CI))

Variable	Description	Wheeze	Doctor-diagnosed asthma	Rhinitis	Rhinoconjun-ctivits	Eczema
CCC Age	1-2 yrs	1	1	1	1	1
	3-4 yrs	1.0 (0.7–1.4)	1.0 (0.6–1.9)	1.0 (0.8–1.3)	1.1 (0.7–1.8)	1.1 (0.8–1.6)
	>4 yrs	1.0 (0.8-1.4)	1.4 (0.9-2.2)	0.9 (0.7–1.0)	0.9 (0.6-1.3)	1.1 (0.8-1.5)
Building	Office vs void deck	0.7 (0.4-1.2)	0.6 (0.3-1.6)	1.1 (0.8–1.6)	1.0 (0.5-2.0)	1.2 (0.8-2.0)

type	SH vs void deck	1.0 (0.8-1.4)	0.6 (0.4-1.0)	1.1 (0.9–1.3)	1.2 (0.8-1.7)	1.2 (0.8-1.5)
	CCC vs void deck	1.1 (0.9-1.5)	0.8 (0.5-1.3)	1.1 (0.9–1.4)	1.3 (0.9–1.9)	1.0 (0.8-1.4)
	Others vs void deck	1.0 (0.6-1.4)	0.8 (0.4-1.5)	1.2 (0.9–1.6)	1.6 (1.0-2.7)	0.7 (0.5-1.3)
Density	Q1	1	1	1	1	1
	Q2	1.3 (0.7-2.4)	**2.2 (1.1-4.4)**	0.8 (0.4–1.8)	0.8 (0.2–3.4)	1.1 (0.5–2.5)
	Q3	1.0 (0.8-1.2)	0.9 (0.6-1.3)	1.0 (0.8-1.1)	1.0 (0.8-1.4)	1.0 (0.8-1.3)
	Q4	1.1 (0.9-1.3)	1.0 (0.7-1.4)	1.1 (0.9-1.3)	1.2 (0.9-1.6)	1.2 (1.0-1.5)
Room No	'> 10' vs '1-3'	1.1 (0.7-1.7)	1.0 (0.5-1.9)	1.2 (0.9-1.7)	1.3 (0.7-2.4)	1.0 (0.6-1.7)
		Cough with cold/flu at most days	Full of phlegm w cold/flu	Full of phlegm w cold/flu at most days	Gets attack of cough lasting > 1 week	Lower Respiratory Illness (LRI)
CCC Age	1-2 yrs	1	1	1	1	1
	3-4 yrs	1.0 (0.7–1.4)	0.9 (0.8–1.1)	**1.6 (1.1–2.3)**	1.0 (0.8–1.4)	0.9 (0.7–1.3)
	>4 yrs	1.1 (0.9-1.4)	0.9 (0.8-1.1)	1.3 (1.0–1.7)	1.1 (0.9-1.3)	0.9 (0.7–1.1)
Building type	Office vs void deck	1.3 (0.8-1.9)	1.0 (0.8-1.2)	1.6 (1.0–2.5)	1.3 (1.0-1.9)	1.2 (0.8-1.8)
	SH vs void deck	1.0 (0.8-1.3)	1.0 (0.8-1.2)	1.3 (1.0–1.7)	1.1 (0.9-1.4)	1.2 (1.0-1.5)
	CCC vs void deck	1.0 (0.8-1.3)	1.0 (0.8-1.2)	1.0 (0.7–1.3)	1.0 (0.8-1.2)	**1.3 (1.0-1.6)**
	Others vs void deck	0.9 (0.6-1.3)	1.0 (0.8-1.2)	1.0 (0.6–1.8)	1.0 (0.8-1.4)	1.0 (0.7-1.4)
Density	Q1	1	1	1	1	1
	Q2	1.3 (0.6-2.6)	1.2 (0.7-1.9)	1.2 (0.5-2.9)	1.2 (0.6-2.3)	1.4 (0.7-2.8)
	Q3	1.0 (0.8-1.2)	1.0 (0.9-1.1)	0.9 (0.7-1.1)	1.0 (0.8-1.2)	1.1 (0.9-1.3)
	Q4	1.2 (1.0-1.4)	1.2 (1.0-1.3)	**1.3 (1.0-1.6)**	**1.3 (1.1-1.5)**	1.2 (1.0-1.4)
Room No	'> 10' vs '1-3'	1.4 (0.9-2.2)	1.0 (0.8-1.4)	**1.1 (1.0-2.9)**	1.1 (0.8-1.6)	0.8 (0.6-1.3)

Table 7. Associations of symptoms with CCCs building material variables (Prevalence Ratio (95% CI))

Variable	Description	Wheeze	Doctor-diagnosed asthma	Rhinitis	Rhinoconjun-ctivits	Eczema
Wall type	Painted concrete	1	1	1	1	1
	Painted gypsum	1.0 (0.7–1.5)	1.3 (0.7–2.2)	1.1 (0.9–1.5)	0.8 (0.5–1.5)	1.1 (0.7–1.6)
	Wooden panels	1.4 (0.7–3.1)	1.4 (0.3–5.8)	0.8 (0.4–1.8)	0.3 (0.0–2.4)	1.7 (0.7–3.9)
	Painted drawings	1.0 (0.8–1.2)	1.0 (0.7–1.4)	1.0 (0.8–1.2)	0.8 (0.6–1.1)	0.9 (0.7–1.1)
Floor type	Concrete/Tiles	1	1	1	1	1
	PVC/linoleum	1.0 (0.8-1.2)	1.2 (0.9-1.6)	0.9 (0.8–1.0)	1.1 (0.8-1.4)	1.0 (0.8-1.3)
	Wood	1.1 (0.8-1.5)	0.7 (0.4-1.3)	1.0 (0.7-1.2)	1.0 (0.8-1.2)	1.2 (0.8-1.6)
Shelf type	Wood	1	1	1	1	1
	PVC/plastic	2.2 (0.8-6.0)	1.7 (0.4-6.9)	2.3 (0.7-7.2)	0.5 (0.1-3.7)	1.2 (0.2-9.0)
Curtain type	None	1	1	1	1	1
	Plastic blinds	1.0 (0.7–1.6)	0.6 (0.3–1.3)	0.9 (0.6–1.2)	1.3 (0.7–2.3)	**0.6 (0.3–1.0)**
	Wooden blinds	0.2 (0.0–1.7)	0.5 (0.1–3.5)	1.0 (0.5–2.1)	0.9 (0.2–3.8)	0.5 (0.1–1.9)
	Textile	1.0 (0.8–1.3)	**0.6 (0.4–0.9)**	0.9 (0.7–1.1)	1.0 (0.7–1.5)	0.8 (0.6–1.1)
Ceiling type	Concrete	1	1	1	1	1
	Particle board	1.0 (0.8–1.2)	0.9 (0.6–1.2)	1.1 (0.9–1.3)	1.2 (0.9–1.6)	1.0 (0.8–1.3)
	Wooden panel	1.1 (0.8–1.4)	0.8 (0.4–1.3)	1.2 (0.9–1.5)	1.3 (0.8–1.9)	1.2 (0.8–1.6)
Renovate	Past 12 months	1.0 (0.8-1.2)	1.0 (0.8-1.4)	1.0 (0.9-1.2)	0.9 (0.7-1.2)	1.1 (0.9-1.4)
Painting	Past 12 months	1.0 (0.8-1.2)	0.8 (0.6-1.1)	1.0 (0.9-1.2)	1.1 (0.8-1.4)	1.0 (0.8-1.2)
		Cough with cold/flu at most days	Full of phlegm w cold/flu	Full of phlegm w cold/flu at most days	Gets attack of cough lasting > 1 week	Lower Respiratory Illness (LRI)
Wall type	Painted concrete	1	1	1	1	1
	Painted gypsum	1.1 (0.8–1.6)	0.9 (0.7–1.2)	1.5 (1.0–2.2)	0.9 (0.7–1.2)	1.1 (0.8–1.6)
	Wooden panels	1.8 (0.8–4.1)	1.2 (0.7–2.3)	**2.4 (1.1–5.6)**	1.0 (0.5–2.2)	0.7 (0.2–1.8)
	Painted drawings	1.1 (0.9–1.3)	0.9 (0.8–1.0)	1.2 (0.9–1.5)	0.9 (0.8–1.1)	0.9 (0.7–1.1)
Floor type	Concrete/Tiles	1	1	1	1	1
	PVC/linoleum	**0.7 (0.6-0.9)**	1.0 (0.9-1.2)	**0.7 (0.6–0.9)**	1.0 (0.8-1.1)	**1.2 (1.0-1.5)**
	Wood	1.0 (0.7–1.3)	1.2 (0.9–1.4)	1.1 (0.8–1.5)	1.0 (0.8–1.3)	1.1 (0.8–1.5)
Shelf type	Wood	1	1	1	1	1
	PVC/plastic	1.0 (0.3-4.1)	0.8 (0.3-2.1)	NS	NS	1.6 (0.6-4.4)
Curtain type	None	1	1	1	1	1
	Plastic blinds	1.2 (0.8–1.9)	**0.7 (0.5–0.9)**	1.0 (0.5–1.7)	0.8 (0.6–1.2)	1.0 (0.7–1.4)
	Wooden blinds	0.8 (0.2–2.5)	0.7 (0.4–1.5)	1.5 (0.5–5.0)	1.2 (0.6–2.3)	0.7 (0.3–1.7)
	Textile	1.0 (0.7–1.3)	0.9 (0.8–1.1)	0.9 (0.7–1.3)	0.9 (0.7–1.1)	0.9 (0.7–1.1)

Ceiling type	Concrete	1	1	1	1	1
	Particle board	1.1 (0.9–1.4)	1.0 (0.9–1.2)	1.2 (0.9–1.5)	1.0 (0.8–1.2)	**1.3 (1.0–1.5)**
	Wooden panel	1.2 (0.9-1.6)	1.1 (0.9-1.3)	**1.5 (1.0–2.0)**	1.1 (0.9-1.4)	1.1 (0.9-1.5)
Renovate	Past 12 months	1.0 (1.0-1.3)	1.0 (0.9-1.1)	1.0 (0.8-1.3)	1.0 (0.9-1.2)	**0.8 (0.7-1.0)**
Painting	Past 12 months	**1.2 (1.0-1.4)**	1.0 (0.9-1.2)	1.0 (0.8-1.3)	1.1 (1.0-1.3)	1.0 (0.9-1.2)

Table 8. Associations of symptoms with cleaning frequency variables (Prevalence Ratio (95% CI))

Current Symptoms	Prevalence Ratio (95% CI)					
	Floor; '2x day vs >1 day'	Shelf; 'daily vs weekly'	Curtain; 'weekly vs monthly'	Toilet; '2x daily vs weekly'	Toy; 'daily vs ≥ weekly'	Mattress; 'daily vs ≥ weekly'
Wheeze	0.9 (0.5-1.7)	1.0 (0.8-1.3)	1.0 (0.7-1.3)	1.3 (0.6-2.9)	1.2 (0.9-1.6)	1.0 (0.8-1.2)
Doctor-diagnosed asthma	1.3 (0.6-2.9)	0.9 (0.6-1.3)	1.1 (0.6-1.7)	0.8 (0.2-3.3)	1.0 (0.7-1.7)	0.8 (0.6-1.0)
Rhinitis	0.8 (0.5-1.3)	1.0 (0.9-1.2)	1.1 (0.9-1.4)	1.2 (0.7-2.1)	1.2 (0.9-1.5)	1.0 (0.8-1.1)
Rhinoconjuctivitis	0.6 (0.2-1.7)	1.0 (0.7-1.3)	1.0 (0.6-1.4)	1.9 (0.8-4.3)	1.1 (0.7-1.7)	0.8 (0.6-1.1)
Eczema	0.9 (0.5-1.8)	1.0 (0.8-1.3)	1.2 (0.8-1.7)	1.2 (0.5-2.6)	1.3 (0.9-1.8)	1.1 (0.9-1.3)
Cough with cold/flu most days	1.0 (0.9-1.3)	1.0 (0.8-1.2)	0.8 (0.6-1.1)	1.2 (0.5-2.7)	1.0 (0.7-1.3)	1.1 (0.8-1.2)
Full of phlegm w cold/flu	0.7 (0.5-1.1)	1.0 (0.8-1.1)	1.1 (0.9-1.3)	1.1 (0.7-1.9)	1.1 (0.9-1.3)	1.0 (0.9-1.1)
Full of phlegm w cold/flu most days	1.6 (0.8-3.2)	1.1 (0.8-1.4)	0.9 (0.7-1.3)	1.1 (0.4-3.5)	1.1 (0.8-1.5)	**0.8 (0.6-1.0)**
Gets attack cough lasting > 1 week	0.7 (0.4-1.1)	0.9 (0.7-1.0)	1.2 (0.9-1.5)	0.5 (0.2-1.2)	1.1 (0.9-1.4)	0.9 (0.8-1.1)
Lower Respiratory Illness (LRI)	1.2 (0.7-1.9)	0.9 (0.7-1.1)	1.2 (0.9-1.6)	1.7 (0.8-3.2)	1.1 (0.8-1.5)	1.0 (0.8-1.2)

among children attending CCCs with more than 10 rooms was significantly associated.

Table 7 shows the association of symptoms with CCC building material variables. Wall type was not significantly associated with any symptoms studied. However, PVC/linoleum was protective of severe cough and phlegm symptoms and is a risk for LRI. No associations between floor and ceiling types with asthma and allergies, and shelf type and any symptoms were found. Wooden panel and particle boards were associated with higher risk of severe phlegm and LRI respectively. However, plastic blinds appear to be protective of current eczema and phlegm symptoms. Recent renovation in CCCs was found to be protective of LRI while recent painting was significantly associated with higher risk of severe cough.

Finally, we explored the association of symptoms with CCC cleaning frequency variables (Table 8). We were not able to find any consistent association between health symptoms children with the frequencies of cleaning of various CCC items.

4 Conclusion

This study shows that only few CCC characteristics are associated with respiratory health and allergies among young children in tropical Singapore.

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Indoor Fungi and Fungal Allergens – Possibilities and Limitations of Allergy Diagnosis and Exposure Assessment

G. Fischer, N. Hollbach, M. Raptis, and W. Dott,

Institute of Hygiene and Environmental Medicine, Mycology Section, RWTH Aachen University, University Hospital, Pauwelsstr. 30, 52074 Aachen, Germany, email: Guido.Fischer@post.rwth-aachen.de

Summary: *The possibilities and limitations of routine diagnosis of fungal allergies in connection with differentiated exposure assessment in indoor environments are summarized and critically evaluated. The number of test extracts commercially available is inadequate and the production of additional test extracts is needed and must consider a) differences in protein spectra between spores and mycelium as well as b) differences in protein spectra depending on the type of substratum.*

Keywords: *allergy, diagnosis, fungi, indoor*
Category: *Allergy and other sensitivity reactions*

1 Introduction

The spectrum of indoor fungi occurring in connection with microbial contamination due to dampness in indoor environments is wide. Only for a few relevant species allergen extracts are commercially available. Moreover, the allergenic relevance of typical indoor fungi connected with dampness is widely unknown. Communication between microbiologists generating species lists from indoors and allergologists doing routine diagnosis of patients exposed is often sparse and needs to be improved.

2 Material and Methods

The present study compares data on species-differentiated exposure assessment in indoor air with the possibilities and limitations in routine allergy diagnosis. The abundance and the hygienic relevance of the different species will be analyzed. Those species with possible allergenic impact will be summarized, an in addition, their pathogenic potential to produce toxic or irritating secondary metabolites or to cause infections will be considered for risk assessment. The diagnostic tools in routine allergology will be discussed with regard to species spectra in indoor air.

3 Results

There is a great discrepancy between the diversity of fungi in contaminated indoor environments (more than 120 species) and the spectrum of diagnostic tools available in routine allergy diagnostics (15-20 test extracts, Table 1). The results of microbial investigations on the one hand and clinical allergy testing on the other hand are often not cross checked by the investigators.

3.1 Drawbacks of quality control standards for commercial test extracts

Most manufacturers offer a set of 10 to 20 fungal allergen extracts (Table 1), that can routinely be used by allergologists for prick, intracutane, or/and nasal provocation testing. Often, fungal mixes are used as initial step (mix of allergens from *C. herbarum*, *A. alternata*, *A. fumigatus* and *P. chrysogenum*). The majority of commercially available extracts represents species that are characteristic for the outdoor microspora (except *P. chrysogenum*). Such kind of diagnosis is of extremely limited significance for people with indoor fungal contamination due to moisture damages. The prevalent species multiplying on building materials in case of moisture problems are very diverse (Table 1), but are not equally represented among the test extracts. Thus, sensitization to typical indoor species can not be diagnosed with the extracts available. In German indoor environments, species such as *Acremoium strictum, Aspergillus penicillioides, A. restrictus, A. versicolor, Chaetomium globosum, Phialophora fastigiata, Scopulariopsis brevicaulis, S. fusca, Stachybotrys chartarum, Stemphylium botryosum*, *Trichoderma harzianum, T. viride,* and *Tritirachium album* are known as moisture indicators on building materials (Table 1). Among these, allergen extracts are available only for *Chaetomium globosum* and *Stemphylium botryosum*.

Epidemiological data on the prevalence of fungal sensitization/allergy were assessed using the commercially available extracts. Consequently, valid data on sensitizations to typical indoor contaminants are still lacking.

3.2 Comparability of test extracts from different manufacturers

It is commonly known that the response achieved with test extracts (for a certain species) of different manufacturers can differ significantly. Allergen spectra and protein content of respective species may vary for extracts of different manufacturers [7, 3], which is commonly known among experienced clinical allergologists. Although the manufacturers aim to reach high quality standards in the production of test extracts, some conventions and practises are ambiguous and may negatively influence the quality and/or applicability of extracts:

a) For allergen production the microfungi are cultured in liquid culture, where they do not produce conidia (vegetative spores) due to submers growth. The extracts thus only contain mycelial allergens. Pulmonary exposure indoors is basically due to airborne spores (conidia) that may differ from the allergens of the spores.
b) Fungal strains are achieved from reference culture collections to reach a constantly high quality and to be sure of taxonomic identity. The drawback of such practise is that the strains used since many years (decades) will certainly be degenerated and may differ from wild strains *in situ* with respect to their protein/metabolite content. It is probable, that patients will show different reactions to standardised extracts and wild strain allergens.
c) The method of dialysis used for purification of allergen extracts may discriminate proteins with allergenic potential of low molecular weight [1].

Heterogeneity of allergen extracts is under debate since many years and is mainly due to cultivation time, culture conditions, and the extraction method [2, 9].

Moreover, there are several cases of inconsistency in nomenclature, where the invalid names of fungi (left column) are still in use for the commercial test extracts (valid names in the right column):

Penicillium notatum	– *Penicillium chrysogenum*
Alternaria tenuis	– *Alternaria alternata*
Epicoccum purpurascens	– *Epicoccum nigrum*
Helminthosporium halodes	– *Exserohilum rostratum*
Rhizopus nigricans	– *Rhizopus stolonifer*
Penicillium frequentans	– *Penicillium glabrum*

Thus, it is difficult for clinical allergologists to select the test extracts relevant for indoor air on the one hand, and to synchronize the panel of test extracts with the spectrum of species detected on interior finishes on the other hand.

3.3 Cross reactivity and homology of indoor fungal allergens

Meanwhile, for some species cross reactivities were described (Table 3). For indoor hygiene, possible cross reactivities between outdoor and indoor fungal allergens are of primary concern. In Europe, one of the most frequently encountered *Penicillium* species indoors is *P. chrysogenum* (invalid name *P. notatum*). Cross reactivity with outdoor allergens has not been described until now. But, for *Pen chr 13* (34 kD, alcalic serine protease) a cross reactivity to *Pen c 1* (33 kD, alcalic serine protease) from *P. citrinum* was described. *P. citrinum* can also occur in indoor environments, but is generally known as contaminant on cereals and spices. In was found to be the most prevalent *Penicillium* species in the Taipei area.

Table 1: Frequently occurring microfungi in indoor environments, humidity indicators, and test extracts commercially available for routine diagnosis

Species	**Humidity indicator**	**Allergen extract available***		
		Bencard	ALK	HAL
Acremonium strictum	#			
Alternaria alternata		+	+	+
Aspergillus flavus				
A. fumigatus		+	+	+
A. niger		+		+
A. ochraceus				
A. parasiticus				
A. penicillioides				
A. restrictus				
A. sydowii				
A. tamarii	#			
A. terreus	#			
A. ustus				
A. versicolor	#			
A. wentii				
Aureobasidium pullulans			+	+
Botrytis cinerea			+	+
Chaetomium globosum	#			+
C. cladosporioides		+		+
C. herbarum			+	
C. sphaerospermum				
Curvularia lunata				+
Emericella nidulans				
Epicoccum nigrum		+		
Eurotium herbariorum				
Fusarium culmorum				+
Fusarium solani				
Geomyces pannorum				
P. aurantiogriseum				
P. brevicompactum				+
P. chrysogenum		+	+	+
P. citrinum				
P. digitatum				
P. commune				+
P. crustosum				
P. expansum			+	
P. glabrum				
P. griseofulvum				
P. purpurogenum				
P. olsoni				
P. roqueforti				
Phialophora fastigiata	#			
Phoma glomerata				
Rhizopus stolonifer				
Rhodotorula minuta		+		(+)
Scopulariopsis brevicaulis	#			
Scopulariopsis fusca	#			
Stachybotrys chartarum	#			
Stemphylium botryosum	#			+
Trichoderma harzianum	#			
Trichoderma viride	#			
Tritirachium album	#			
Ulocladium chartarum				
Verticillium spp.				
Wallemia sebi				
Sum:	**13**	**7**	**7**	**14**

* Legend: Data on the availability of test extracts were compiled from the homepage of the manufacturers

Another frequently occurring species in indoor environments is *P. brevicompactum*, of which only one allergen is described until now (*Pen b 13*, alkalic serine protease). *P. brevicompactum* is also a regularly occurring contaminant on food and is very frequent as biodeteriogen on decaying plant material. From the allergological point of view, possible contaminations of food have to be considered in case of fungal allergies. For *P. oxalicum* only *Pen o 18* is described, which shows cross reactivity with *Pen c 1*. The species is common in soil, on decaying vegetation, and freshly harvested corn, but is not a typical food contaminant.

The cross reactivities and homologies between the above *Penicillium*-species make it likely, that sensitization diagnosed by use of commercial "*P. notatum*" extracts may be due to an exposure to either *P. chrysogenum*, *P. citrinum*, or *P. brevicompactum*. On the other hand, clinical allergologists need to consider that in case of exposure to *Penicillium* species indoors, the application of a "*P. notatum*" extract can be useful, even if *P. chrysogenum* was not detected.

It is thus of major importance to pay more attention to a differentiated exposure assessment on the basis of a more refined routine diagnostic. In a large epidemiological study where a set of 7 microfungal allergen extracts from different manufacturers were tested in a cohort of 4962 subjects, the allergens were addressed on the genus level (e.g. *Alternaria*, *Aspergillus*, *Cladosporium* etc.), which is not sufficient from the hygienic and allergology point of view.

3.4 Differences in species spectra

A great number of species occur in indoor environments and differences in species spectra have been described either depending on a) the type of substratum (different building materials), b) the origin of the dampness (water availability), and/or c) the type of building construction.

Basically, the availability of water is the principle factor for the development of different fungal communities. On dry substrata, where moisture is available due to intermitting condensation of water from air, only extremely xerophilic species (**minimal a_W for growth < 0,75**), such as *A. penicillioides* (0.73-0.75), *A. restrictus* (0.71-0.75), *Eurotium* spp. (0.71-0.74), and *Wallemia sebi* (0.69-0.75) can grow and multiply. The growth of such primary colonizers on carpets and walls does not always get visible at first sight, as some species produce only slightly pigmented spores.

In case of increased moisture (continuous condensation), another set of species (**minimal a_W for growth 0.75 – 0.80**) will occur, consisting mainly of *Penicillium* and *Aspergillus* spp. as secondary colonizers, i.e. *Aspergillus candidus (0.75), A. ustus, A. versicolor (0.78), A. sydowii (0.78), P. chrysogenum (0.78), P. citrinum (0.80), P. commune (0.83),* and *P. brevicompactum (0.78).*

A third group of fungi (tertiary colonizers) only grows at water activities between **0.80 and 0.90**, e.g. *Cladosporium cladosporioides* (0.86-0.88), *C. herbarum* (0.85-0.88), *Alternaria alternata* (0.85-0.88). As these species are the most prevalent ones in outdoor air, they will grow and multiply with a high probability after sedimentation on humid building materials. Especially *C. cladosporioides* and *C. sphaerospermum* can be found on moist building materials, whereas *C. herbarum* shows a clear preference for outdoor substrata.

On very wet substrata (**a_w > 0.90**) and especially those rich in cellulose, some of the most toxic species such as *Chaetomium globosum*, *Memnoniella echinata*, *Stachybotrys chartarum* (0.94), and *Trichoderma* spp. develop more abundantly (quaternary colonizers). Especially *Trichoderma* spp. are often found in cellars with a higher percentage of wooden building materials. Species found in mouldy buildings are *T. atroviride, T. citrinoviride, T. harzianum, and T. longibrachiatum*.

A distinction between primary, secondary, and tertiary colonizers was already proposed by Grant *et al.* [5], but this scheme did not adequately include the extremely xerotolerant species mentioned above in group 1. This group is highly relevant for indoor hygiene, as the species can grow at extremely low a_w-values and occur with high percentages in house dust. Moreover, they are easily overlooked during inspections, because their conidia are brightly coloured.

In situ on the building materials the ecological conditions may be more complex, so that species with different demands for water activity can occur close to each other at the same sites. Therefore, species spectra may consist of species from group 1-4 (Table 2), although the fungal community is mostly dominated by species adapted to discrete water activities.

As both the origin of the moisture in building materials and the type of the building construction influence the water availability basically, these factors influence the microbial community indoors as well. Consequently, exposure to fungi can change with the quality and type of defects in construction.

Specific exposure situations of patients need to be addressed in allergy diagnosis. Allergy diagnosis should concentrate on indoor fungal allergens and additional extracts of frequently occurring indoor species should be commercially available in future. It is of little significance when patients with indoor microbial contaminations are tested for sensitizations to classical outdoor allergens such as *Alternaria* *alternata* and *Cladosporium herbarum*. There are hints in literature that *Alternaria* in indoor environments rather belongs to *A. infectoria* than to *Alternaria alternata* (pers. comm. B. Andersen, Denmark, DTU-IBT). If so, it should be investigated, if *A. infectoria* differs from *A. alternata* with regard to protein spectrum and allergen content.

Table 2: Species spectra of indoor fungi and health impact of species

Health impact:	**a_w**	**Allerg.**	**Tox.**	**Opp.**
Primary colonizers (G1):				
A. penicillioides	0.73-0.75	*		
A. restrictus	0.71-0.75	*		#
Eurotium spp.	0.71-0.74	*		
Wallemia sebi	0.69-0.75	*		
Secondary colonizers (G2):				
A. candidus	0.75	*		
A. ustus		*		
A. versicolor	0.78	*	+	#
A. sydowii,	0.78	*		
P. chrysogenum	0.78	+	+	
P. citrinum	0.80	+	+	
P. commune	0.83	*		
P. brevicompactum	0.78	+	+	
Tertiary colonizers (G3):				
C. cladosporioides,	0.86-0.88	*		
C. herbarum	0.85-0.88	++		
Alternaria alternata	0.85-0.88	++	+	#
Quaternary colonizers (G4):				
Chaetomium globosum		*	+	
Memnonielle echinata		*	+	
St. chartarum	0.94	*	+	
Trichoderma spp.		*	+	

Legend: allerg. = allergenic impact (compare Table 3), + = allergens described or mycotoxin-producer, * = species can be regarded as potentially allergenic; tox. = species known to produce mycotoxins; opp. = opportunistic species (discussed as causative agent of otomycosis, onychomycosis), # = species described as opportunistic

3.5 Substratum-dependent production of allergens

Different strains of one species may differ in their protein content [3, 8] and, moreover, variation can be expected even for one specific strain when growing on synthetic and natural substrata. In preliminary experiments with cultures on building materials (unpublished) the species tested showed different spectra of proteins on natural substrata. *C. cladosporioides* and *P. chrysogenum* produced a greater diversity of proteins on wallpaper (substituted either with distilled water or with 5% sucrose) compared to the liquid-culture in Sabouraud-broth, while the number of proteins decreased again when grown on painted wallpaper (water-based paint). Interestingly, in *P. chrysogenum* proteins with molecular weights between 32 and 35 kDa (the alcalic serine protease *Pen chr 13* has 34 kDa) were not expressed on wallpaper. In *A. alternata* and *Aspergillus versicolor* proteins with molecular weights between 28 and 45 kDa were not expressed on wallpaper inoculated with a spore suspension (distilled water), but were found both on wallpaper inoculated with a 5% sucrose solution and in Sabouraud broth. Interestingly, the latter two species did not grow on painted wallpaper as the paint obviously inhibited growth.

If the proteins found in our experiments can be assigned to known allergens of *Alternaria alternata* on the basis of their molecular weight only, one can conclude that the spectrum of major allergens can be significantly reduced on natural substrata. Only one of four known allergenic proteins was expressed on wallpaper wetted with distilled water (22 kDa, putatively *Alt a 7*) and on wallpaper inoculated with 5% sucrose (45kDa, putatively *Alt a 5/11*) (Table 3). It is interesting to note that *Alt a 7* is homologous to *Cla h 5* (yeast cell cycle protein 4) and *Alt a 5* and *11* are homologous to *Cla h 6* (Enolase), which makes cross reactivity likely. As the latter species is primarily an "outdoor species", their relevance for indoor hygiene is rather limited.

In contrast, *A. versicolor* it should is common in indoor environments especially in house dust. The species is thus worth of more detailed investigations on its allergenic potential. It must be kept in mind that also *A. sydowii* is frequently found indoors and that the protein spectrum may differ from *A. versicolor*. Moreover, *both species* are able to synthesize sterigmatocystin, a precursor in the aflatoxin biosynthetic pathway. As this mycotoxin was found in house dust, its toxicological and immune-modulatory potential must be kept in mind, especially because of the fact that the substance could be activated by reactive oxygen species secreted by alveolar macrophages. The physiological properties of the species should therefore be kept in mind from the allergology point of view.

It is thus necessary, to verify the present results and to test more relevant indoor species on natural building materials for their protein spectrum and expression of allergens.

4 Discussion

Taking the above difficulties in account, routine allergy diagnostics with respect to fungal exposure indoors is not reliable at the moment. There is a strong need to much better standardize the production of test extracts of microfungi and to improve the availability and widen the spectrum of test extracts of relevant indoor species. It was recently stated that the limiting quality of fungal extracts requires future studies using an allergenic molecule based approach [7].

It must be considered that protein spectra of mycelium and spores may differ. Therefore, the impact of allergy testing with commercial extracts that have been produced mainly from liquid cultures (mycelial balls) must be critically evaluated. Conidia are the major propagules in indoor air and are thus inhaled by the residents [4].

The incidence of mould allergies in persons with airway symptoms ranges between 1% and 10%, in atopic persons percentages of up to 30% occur. Recently, a great epidemiological study in Italy showed that 19 percent of the allergic population are sensitized to at least one fungus [7]. As the incidence of allergies seems to increase and in parallel microbial contaminations in indoor environments have become more and more frequent, there is a need to better differentiate the exposure to microfungi on the species level and to enlarge the number of commercially available test extracts, especially for typical indoor fungi.

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Table 3: Fungal allergens, protein function, and cross reactivity (after: Horner et al. 1995, Breitenbach et al. 2002, Bisht et al. 2003, Kurup 2003)

Species	**Allergen, MW (kD)**	**Biological function**	**Mycelium /Spores**	**Cross reactivity (cr), homologies, pathogenesis**
Alternaria tenuis (**valid:** *A. alternata*)	Alt a 1 (28)	*Glycoprotein*, heat-resistent	M, S	c.r.: *Stemphylium* spp., *Ulocladium* spp. (higher content!)
	Alt a 2d (28)		-	
	Alt a 3	Heat-Shock-Protein 70	-	
	Alt a 4 (57)	Proteindisulfide-Isomerase	-	
	Alt a 5 (45)	**Enolase**	-	Cla h 6
	Alt a 6 (11)	**Acid Ribosomal Protein P2**	-	Cla h 4
	Alt a 7 (22)	**YCP4** Yeast cell cycle protein	-	Cla h 5
	Alt a 11 (45)	**Enolase**	-	
	Alt a 10 (53)	**Aldehyddehydrogenase**	-	Cla h 3
	Alt a 12 (11)	**Acid Ribosomales Protein P1**	-	
Aspergillus fumigatus	Asp f 1 (17)	Mitogillin-Ribotoxin, Heat-Shock-Protein 90	-	Homology: Mitogillin in *A. restrictus*
	Asp f 2 (37)	Fibrinogen-binding Protein	-	
	Asp f 3 (19)	Peroxysomal Protein	-	Pen c 3
	Asp f 4 (30)	*Glykoprotein*	-	
	Asp f 5 (42)	Metalloprotease	-	
	Asp f 6 (23)	Mn-Superoxiddismutase	-	
	Asp f 8 (11)	**Acid Ribosomal Protein P2**	-	(c.r. in general:
	Asp f 9 (31)	*Glykoprotein*	-	with *Botrytis cinerea*)
	Asp f 10 (34)	Aspartate-protease	-	
	Asp f 11 (19)	Cyclophylin	-	
	Asp f 12 (65)	Heat-Shock-Protein 70	-	
	Asp f 13 (34)	Alcalic Serinprotease	-	
	Asp f 15 (20)	Serinprotease	-	
	Asp f 18 (34)	Vakuolar Serinprotease	-	
	Asp f 22	**Enolase**	-	Pen c 22; function in ABPA
Cladosporium herbarum	Cla h 1 (13)	-	-	(c.r. in general:
	Cla h 2 (20-22)	Glycoprotein (80% Polysaccharide)	-	with *C. cladosporioides*)
	Cla h 3 (53)	**Aldehyddehydrogenase**	-	*Alt a 10*
	Cla h 4 (11)	**Acid Ribosomal Protein P2**	-	*Alt a 6*
	Cla h 5 (22)	**YCP4** Yeast cell cycle protein	-	*Alt a 7*
	Cla h 6 (48)	**Enolase**	-	*Alt a 11*
	Cla h 12 (11)	Acid Ribosomal Protein P1	-	
Curvularia lunata	(26), (31), (38), (45), (50)			c.r.: *A. alternata, E. nigrum*
	(26), (45), (50)			c.r.: *A. fumigatus*
Epicoccum nigrum	(17), (26), (43)	13 Allergens, 9 allergens (S), 6 allergens (M)	M, S	Atopic patients: prevalence 20-30%
				c.r.: *A. alternata*
	(37), (80)			c.r.: *C. lunata*
	(36), (63)			c.r.: *C. herbarum*
	(34)			c.r.: *P. citrinum*
Fusarium spp.		14 common epitopes known	-	
F. culmorum	Fus c 1 (11)	**Acid Ribosomal Protein P2**	-	
	Fus c 2 (13)	Thioredoxin-like protein	-	Cop c 2
	Fus c 3		-	
F. solani	Fus s 1 (65)	In total 21 Allergene, Atopic persons: prevalence of 24%	M, S	c.r.: *Epicoccum nigrum, Wallemia sebi, P. notatum, Aspergillus glaucus*
F. equiseti		12 Allergens	M, S	
F. moniliforme		9 Allergens	M, S	
'Helminthosporium halodes'	—	17 Allergens (14 – 94 kD); valid name: ***Exserohilum rostratum***	M, S	c.r.: *A. alternata* und *B. cinerea*
P. brevicompactum	Pen b 13		-	
P. notatum (**valid:** *P. chrysogenum)*	Pen chr 13 (34)	**Alcalic serinprotease**; in total 11 allergens (20 – 90 kD)	-	Homology: Pen c 1, Asp f 11, 13
	Pen chr 18 (32)	**Vacuolare Serinprotease**	-	Pen c 1
	Pen chr 20 (68)	N-acetyl-glucosaminidase	-	
P. citrinum	Pen c 1 (33)	Alcalic Serinprotease	-	c.r.: *P.* chrysogenum and *P.* brevicompactum
	Pen c 2 (39)	Vacuolar Serinprotease	-	Homology: *A. niger*
	Pen c 3 (18)	Peroxisomal Membraneprotein	-	Asp f 3
	Pen c 13	**Alcalic Serinprotease**	-	
	Pen c 18 (34)	**Vacuolar Serinprotease**	-	*Asp. oryzae, A. flavus, A. fumigatus*
	Pen c 19 (70)	Heat-Shock-Protein	-	
	Pen c 22 (46)	**Enolase**	-	Asp f 22
	Pen c 24 (25)	Elongation factor 1-β (EF 1-β)		EF 1-β of *S. cerevisiae*
P. oxalicum	Pen o 18 (34)	**Vacuolar Serinprotease**	-	Pen c 1
'Rhizopus nigricans' (**valid**: *R. stolonifer*)	Rhiz 3b (12)	Glycoprotein	-	
	Rhiz 4b (14)	Glycoprotein	-	

Legend: Biological function: **bold** = homologous to other species, - = no information available

Predicting Infiltration Factors in Urban Residences for a Cohort Study

L.K. Baxter[1], H.H. Suh[1], C.J. Paciorek[2], J.E. Clougherty[1] and J.I. Levy[1]

[1] Harvard School of Public Health; Dept. of Environmental Health; Exposure, Epidemiology and Risk Program,
Landmark Center – 401 Park Drive 4th floor West, Boston, MA, 02215 Email: lbaxter@hsph.harvard.edu
[2] Harvard School of Public Health; Dept. of Biostatistics, Boston, MA

Summary: *Although ventilation can influence indoor exposure patterns, most epidemiological studies have relied only on outdoor concentrations to estimate exposures. In large cohort studies, it is implausible to measure air exchange rates for all participants, so reasonable proxies are needed. As part of a cohort study assessing asthma etiology in lower socioeconomic position communities, indoor and outdoor measurements of* $PM_{2.5}$ *were collected and infiltration factors were estimated using the indoor-outdoor sulfur ratio. Predictors of infiltration factors included housing and activity patterns collected via questionnaires and public databases. The open windows was the most significant predictor, with home characteristics providing less predictive power, indicating the importance of occupant- specific behaviors.*

Keywords: *indoor air, traffic, particulate matter, sulfur, infiltration factor*
Category: Indoor/outdoor relationships for exposures

1 Introduction

With people spending the majority of their time indoors and ambient $PM_{2.5}$ penetrating readily indoors [1,2] a substantial portion of an individual's exposure to ambient generated $PM_{2.5}$ will occur while indoors. Ventilation characteristics vary across homes so relying solely on outdoor air pollution levels can lead to substantial exposure misclassification. This may be particularly important for understanding risks in urban lower socioeconomic position (SEP) communities, which reside mostly in apartments resulting in unique ventilation patterns (given adjoining units and lack of central air conditioning). In large cohort studies, it is implausible to measure air exchange rates for all participants so reasonable proxies are needed. Mass balance principles indicate that the indoor/outdoor ratio of pollutants without indoor sources will equal the infiltration factor (F_{INF}), and previous studies have estimated F_{INF} using sulfur concentrations [2]. Thus, indoor and outdoor sulfur concentrations can provide a reasonable estimate of infiltration and overall ventilation characteristics.

Past studies have shown that a number of factors related to home characteristics and occupant behaviors can influence ventilation patterns or infiltration factors. These include age of construction [1,3], housing type (multi- vs. single-family home) [4,5], floor levels [5], opening windows [1,6] and air conditioning use [7,8]. Studies have also observed seasonal differences in F_{INF} with residences monitored during the non-heating season (warmer outdoor temperatures) having a higher mean F_{INF} compared with those monitored during the heating season [1,9]. Therefore, property assessment data available on individual building characteristics, along with questionnaire data on occupant behaviors, can theoretically be used to produce an air pollution infiltration model [10].

This study seeks to identify predictors of particulate matter infiltration by utilizing public databases and questionnaire data in the context of a prospective birth cohort study assessing the contributions of environmental, social, and genetic factors to asthma etiology. This will allow for reduced exposure misclassification and could ultimately allow for evaluation of the differential health effects of pollution generated outdoors to that generated indoors, and quantification of the contribution of indoor sources to indoor concentrations.

2 Methods

2.1 Data Collection

The data analyzed were taken as part of the Asthma Coalition for Community, Environment, and Social Stress (ACCESS), a cohort study assessing asthma etiology focused on lower SEP households. Participants were drawn in part from the ACCESS cohort, with additional non-cohort participants enrolled for geographic representativeness (i.e., to reflect neighborhoods not yet represented in the cohort but where future recruitment was planned). Residential indoor and outdoor concentrations of particulate matter ($PM_{2.5}$) were measured for 3 – 4 days during the heating (December – March) and non-heating (May – October) seasons using a Harvard Personal Environmental Monitor (PEM). Sampling, preparation, and analysis procedures have been described previously [11]. Sulfur concentrations were determined by X-ray fluorescence spectroscopy (XRF), conducted according to standard operating procedures at the Desert Research Institute (DRI; Reno, NV, USA) including their quality control and assurance

[12,13]. When possible, two consecutive measurements were collected at each home, providing one-week average concentrations and minimizing weekday/weekend effects.

A standardized questionnaire, administered at the end of each sampling period, collected home characteristics/ occupant behavior data. Additional information on home characteristics were collected through the City of Boston, Brookline, Cambridge, and Somerville property tax records. Information from the city data was preferentially used to ensure public availability, but for homes missing from the city databases (mainly tax-exempted housing), we used data from the questionnaire as a substitute. This data includes floor level, housing type, and age of home. Occupant-specific behaviors potentially influencing infiltration include time windows open per day and the use of an air conditioner. Standard quality control measures were taken throughout the study, including the use of field and laboratory blanks, replicate samples for all air pollution measures, and the development of a detailed field and laboratory protocol.

2.2 Data Analysis

The infiltration factor was estimated at each home by utilizing the principles of the of the mass-balance model. A single compartment mass balance model under steady-state conditions is seen in Equation (1):

$$Cin_{ij} = F_{INFij} Cout_{ij} + \frac{Q_{ij} / V_i}{a_i + k_j} \qquad (1)$$

where i is the participant and j is the pollutant; Cin_{ij} and $Cout_{ij}$ are the indoor and outdoor pollutant concentrations (µg/m^3); (F_{INFij}) is the infiltration factor, Q_{ij} is indoor source strength (µg/h), a_i is the air exchange rate (h^{-1}), V_i is the house volume (m^3), and k_j is the decay rate (h^{-1}). When a pollutant lacks indoor sources, F_{INF} can be estimated as the indoor/outdoor concentration ratio as in Equation (2) using sulfur (S) concentrations [Sarnat 2002].

$$Cin_{iS} = F_{INFS} Cout_{iS} + \frac{Q_{iS} / V_i}{a_i + k_S}, \quad Q_{iS} = 0$$
$$\Rightarrow F_{INFiS} = \frac{Cin_{iS}}{Cout_{iS}} \qquad (2)$$

For our analysis, the assumption of no indoor sources of sulfur was tested empirically by regressing the indoor sulfur concentrations against outdoor sulfur concentrations and examining if the intercept was significantly different from zero or if any hypothetical sources of sulfur significantly predicted indoor concentrations.

To predict F_{INF}, a sequential model-building approach was taken. We first used information from the property assessment database and other publicly available data, to determine the degree to which F_{INF} could be predicted without participant contact. We then added terms related to occupant activities during the sampling week. Only variables with a logical causal connection to F_{INF} were considered, including season, floor level, multi-unit/single-family dwellings, age of home, home air conditioning use, and opening of windows. We performed linear regression treating F_{INF} as a continuous variable, but also chose to dichotomize instead of using the actual values because of the possibility that small measurement errors could significantly influence the indoor-outdoor ratio and related air exchange rates in some contexts. Using logistic regression, the same process as for the linear regression was followed, including first terms generated from publicly available data followed by terms from questionnaire data. This framework allows us to determine if publicly available information is adequate to describe the ventilation characteristics of a home. We will be able to determine whether occupant specific activities (not normally available from publicly assessable databases) influence ventilation characteristics and if this additional information improves the predictive power of the models.

3 Results

3.1 Home Characteristics/Occupant Behaviors

A total of 66 sampling sessions were conducted, with 23 of the homes monitored in both seasons, 15 in only the non-heating, and 5 in only the heating. The 43 sites were distributed among 39 households with 4 of the participants moving and allowing us to sample in their new home. The locations of all of the sampling sites are distributed throughout urban Boston. The prevalence of season of sampling, home characteristics, and occupant behaviors is summarized in Table 1.

Table 1. Distributions of season of sampling, home characteristics and occupant behaviors

Variable	Percent
Season (n = 65)	
Non-heating	57 %
Heating	43 %
Floor (n = 64)	
1st level	31 %
> 1st level	69 %
Housing Type (n = 64)	
Detached Building: multi – family	56 %
Detached Building: single – family	3 %
Apartment Building	41 %
Year Home Built (n =64)	
before 1950	77 %
1950 or later	23 %
Open Windows (n = 61)	
No	38 %
Yes	62 %
Air Conditioner(AC) Use (n = 57)	
No	41 %
Yes	16 %

3.2 Summary Statistics

In 99% of the samples, sulfur concentrations were above the LOD and indicated good method precision (mean relative difference = 5%). Summary statistics for the measured residential indoor and outdoor concentrations, and indoor-outdoor (I/O) ratios are presented in Table 1 and Figure 3, respectively. The median I/O sulfur ratio (0.76) was used to dichotomize F_{INF}.

Table 2. Indoor and Outdoor Sulfur Concentrations (units = µg/m^3) and Indoor/Outdoor Ratios

	N	Mean (SD)	Median	Range
Indoor	62	1.1 (0.70)	0.93	0.31 – 3.9
Outdoor	58	1.5 (1.5)	1.3	0.41 – 11
I/O	56	0.81 (0.26)	0.76	0.13 – 1.7

3.3 Regression Models

Outliers (studentized residual > 4) were removed that unduly influenced regression results. Multivariate regression analyses were performed using these candidate predictors and the outputs are summarized in Tables 2 and 3. Of note is the combination of the detached building categories, given the few single-family homes. When F_{INF} was treated as a continuous variable (Table 2), season was the only publicly available data that significantly predicted infiltration factors, which were lower in the heating season than in the non-heating season. The addition of occupant-specific behaviors increased the predictive power of the models, and opening of windows was statistically significant (being positively associated with infiltration factors).

When F_{INF} was treated as a dichotomized variable (Table 3), season and the year the home was built were significantly ($p < 0.1$) associated with high./low infiltration rates when only publicly available variables considered, with floor level being marginally significant ($p < 0.2$). The odds of a home being categorized in the 'high' infiltration factor group are significantly less than 1 if sampling was conducted in the heating season and if the home was built after 1950, and significantly greater than one for homes located above the 1st floor. When publicly available data and questionnaire data are combined, open windows was significantly associated with the dichotomized variable for F_{INF}, with all other considered variables being marginally significant. The odds of a home being categorized in the 'high' infiltration factor group are less than 1 if sampling was conducted in the heating season, the home is in an apartment building, was built after 1950, and if an air conditioner was used. The odds ratio is greater than one for homes located above the 1st floor and if the occupants kept the windows open at least 5 hours a day.

Table 3. Predictors of continuous F_{INF} variable gathered from publicly available and questionnaire data using linear regression (* $p < 0.1$; $^{\#}$ $p < 0.2$)

	Publicly Available Data	Publicly Available Data + Occupant Behaviors
R^2	0.21	0.38
Predictors	*β (SE)*	*β (SE)*
Season (Ref: Non-heating)	-0.13 (0.04)*	-0.05 (0.07)
Floor (Ref: 1st level)	0.04 (0.06)	0.01 (0.06)
Housing Type (Ref: Detached)	0.01 (0.07)	0.00 (0.06)
Year Home Built (Ref: before 1950)	-0.05 (0.06)	-0.03 (0.06)
Open Windows (Ref: No)	N/A	0.17 (0.06)*
AC Use (Ref: No)	N/A	-0.07 (0.06)

Table 4. Predictors of dichotomized F_{INF} variable gathered from publicly available and questionnaire data using logistic regression (* $p < 0.1$; $^{\#}$ $p < 0.2$)

	Publicly Available Data	Publicly Available Data + Occupant Behaviors
AUC	0.82	0.86
Predictors	*OR (95% CI)*	*OR (95%CI)*
Season (Ref: Non-heating)	0.11 (0.03 – 0.43)*	0.17 (0.02– 1.7)$^{\#}$
Floor (Ref: 1st level)	4.0 (0.72 – 22)$^{\#}$	5.0 (0.71 – 35)$^{\#}$
Housing Type (Ref: Detached)	0.52 (0.08 – 3.6)	0.22 (0.02 – 2.1)$^{\#}$
Year Home Built (Ref: before 1950)	0.12 (0.02 – 0.86)*	0.15 (0.02 – 1.4)$^{\#}$
Open Windows (Ref: No)	N/A	7.2 (0.98 – 54)*
AC Use (Ref: No)	N/A	0.19 (0.02 – 1.5)$^{\#}$

4 Discussion

We found no evidence of significant indoor sources of sulfur, but found a strong relationship between indoor and outdoor concentrations ($R^2 = 0.78$) with an insignificant intercept (results not shown). Thus, sulfur I/O may adequately estimate F_{INF} as described in Equation (2). As the F_{INF} may ultimately be treated as dichotomous variables in epidemiological applications, and given some instability in the air exchange rate-infiltration factor relationship, the F_{INF}s were also dichotomized. We were interested in examining if the significance of the predictors differed between the two outcome variables, as they may be useful for different applications, and it is possible that cruder proxies (such as publicly available information) may be more useful for categorization than in estimating exact F_{INF}s.

The significant contributors and the measured concentrations and ratios are comparable to those seen in other studies [1,4,6]. However, we observed at most a marginally significant effect of housing type, floor level, and air conditioning use. The housing type categories may be too similar to observe an effect. Only 2 of the detached buildings were single-family homes; the rest were multi-unit dwellings similar to apartment buildings in many respects. Lack of power may have also affected the relationships between F_{INF}s and air conditioning use, with its use in only 16 homes during the sampling period and an obvious correlation with season. In addition, none of the homes had central air conditioning, but rather had windows units. The air conditioning may be run less and only affect certain rooms as opposed to the whole apartment. Central air conditioning would decrease the time windows were open and may also indicate a tighter (less leakage) home. Although not statistically significant, the effects estimates for these factors are in the hypothesized direction with higher F_{INF}s in detached homes, homes on higher floors, and in homes with no air conditioner use.

There are a few limitations in our analysis. As in any monitoring study, this study was potentially limited by errors in exposure measurements and methods of data collection. While sulfur has been shown to be a good proxy for F_{INF} in Boston homes this relationship may not be generalizable to other geographical areas with lower outdoor sulfate concentrations or more prevalenct indoor sources. Categorization into high/low F_{INF} was based on the median, so our logistic regression findings would not directly apply to other datasets. Additionally, public databases maintained for tax assessment purposes resulted in missing data, especially for buildings with tax exemptions. Information on occupant activities depended on questionnaire data, and although a standardized questionnaire was used, there may still be a lack of accuracy and reliability in the data. Finally, the sample size limited our ability to explore a larger range of potential terms. The lack of heterogeneity in basic home characteristics (age, type, etc…) may have made it difficult to observe the effects of factors gathered from in publicly available databases.

5 Conclusions

In multivariate models publicly-available predictors added little discriminatory power once activity patterns were incorporated. However, they may be effective predictors of F_{INF} when the aim is to place homes into broad categories. The addition of occupant behaviors, specifically open windows, improved the predictive power of the models and was the most significant contributor to $F_{INF.}$ Our models indicate that $PM_{2.5}$ infiltration in apartments can be reasonably estimated using questionnaire data on activity patterns, but that home characteristics do not strongly predict F_{INF} among urban apartment dwellers.

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How Healthy Is The Bedroom?

E. Hasselaar[1] and J.T. van Ginkel[1]

[1]OTB Research Institute for Housing, Urban and Mobility Studies, Delft University of Technology,
P.O. Box 5030, 2600 GA Delft, The Netherlands
email: e.hasselaar@tudelft.nl

***Summary**: We spend 30-40% of our life time in the bedroom, well secured from the outdoor environment, but is the indoor environment secure and healthy? The bedroom is probably the most important place in our home. While asleep, we do not act in control of the environment. It affects us, but in the morning we walk away from it. The paper focuses on the indoor climate of the bedroom. The bedroom is often poorly ventilated, full of house dust mite allergen, and with daily peak levels of other pollutants.*

Keywords: indoor environment, bedroom, health risk exposure
Category:healthy housing

1 Introduction

The study deals with the bedroom as a separate microclimate. We are exposed to the environment of the bedroom for more than one third of our lives. During the night, our bodies take a rest from the physical and psychic stresses of the day, we digest and emit metabolic waste and go through many other processes that are essential for long-term health. Undisturbed relaxation is the basis for quality of life [1]. A bedroom supports healthy sleep when it allows us to rest free from environmental stresses: noise, biological and chemical agents, overheating. TVOC sources are likely to be found in the bedroom, creating for instance a higher risk of asthma in infants [2]. People get up from their beds in the dark and walking in semi sleep creates risk of falling over obstacles. During the day, the senses stimulate active regulatory mechanisms to control the temperature and air quality. During sleep we smell and feel, but control of the environment is poor, while in the morning we tend to walk away from environmental stresses. The high levels of CO2 that are measured point at low ventilation rates. This paper describes the microclimate in the bedroom. The focus is on the moisture balance, air flow patterns and change rate and house dust mite allergen. The study results in indicators that mark the relation between housing, occupant behaviour and exposure to health risk in the bedroom.

In the major part of Dutch houses the volume of master bedrooms ranges between 30-40 m^3. Moisture is produced by occupants and building related sources. Moisture is absorbed in the mattress, pillows, walls, etc., condensates on surfaces and is removed by evaporation in combination with ventilation. High moisture levels create a good environment for house dust mite. Exposure to house dust mite allergen is a major problem, as in 15-20% of the houses someone has allergic reactions to house dust. Growth conditions of mites depend mainly on relative humidity and temperature. One study found that for D. Pteronyssinus the optimal conditions were 25 ^{o}C and 80% RH, but these mites multiplied between 17 ^{o}C and 32 ^{o}C [3]. Above 85% mould toxins will contaminate food supplies. Below the critical equilibrium level of 60-70% relative humidity (different per specie), and in general below 55%, mite will dehydrate and eventually die. Mite can survive in conditions that are considered hostile, provided there are pockets or regular periods with more favourable conditions, for instance in the bed. Mite can be dry-frosted [4]. The World Health Organisation suggests a safety threshold of 2 microgram of allergen protein per gram of house dust. Above this (pragmatic and not exact) level the conditions may trigger asthma attacks.

2 Method

Home inspection visits and interviews resulted in a database with 333 cases. The relations between occupancy, use of ventilation openings, moisture production and mould problems are analysed on the basis of these data, resulting in variables with strong correlations.

Air flow patterns

Particle distribution was monitored with particle counters in the size range of PM2,5 [5] and with smoke tests to illustrate air flow patterns with different inlet and exhaust systems and ventilation scenarios.

Moisture balance

The moisture balance for a dwelling is used to identify the activities and conditions that contribute to moisture related problems. The scenario presented in this paper is based on a household with two adults and three children in a single family dwelling. Two bedrooms are shared by two persons, one child has a private bedroom. The average air change rate of the house is set at 0.5 ACH and was differentiated per room. The exhaust volume for the central exhaust ventilation represents a practical situation: 1 of 24 hrs at high set point and the rest of the day at low set point. The kitchen exhaust is 21 dm^3/s, bathroom 14 dm^3/s, toilet 5 dm^3/s at high set point, with 40% of these values at low set point. The (uncontrolled) emission of air from the crawl space is 2,5 dm^3/s, RH 90% and T=13 ^0C. Outdoor air has 6 kg/dm^3*10^{-6} moisture on average of day and night.

House dust mite
163 dust samples were collected from mattresses and carpets of bedrooms and carpets and sofas of living rooms [4], [6] and [7]. The measured concentrations and variables were compared. Der p1 concentration of 2 µg/g dust was adopted as a threshold value to distinguish between high and low risk on HDM allergy. Correlations with housing characteristics were examined statistically on the basis of a part of the available data and resulted in models. The rest of the data were used to validate these models. These steps result in indicators that mark the relation between environmental conditions and exposure to health risk. Table 1 shows the structure of the model.

Table 1. Structure of the model

Agent concentration and exposure			
Growth conditions			
Source indicators	Emission indicators	Transport indicators	Concentration
Exposure			
Resulting exposure of occupant to concentration of agent			

The resulting exposure is used to rank the health risk. Personal health effects are not measured.

3 Results

Air change rate
Night time ventilation is often quite low (air change rate of 0,2 – 0,5 ACH) due to (nearly) closed inlet openings. Ventilation behaviour is influenced by fear of draught and cold, sleep disturbance by noise from outside or from mechanical ventilation systems inside the house. According to the dataset, 44% sleep with closed grates or windows in the winter time and for the bedrooms of children this is even higher. In 43% of the houses the door of the bedroom or the connection to other windows does not permit a good flow to exhaust points. When occupants heat the bedroom the inlet openings stay closed for longer periods, while this effect is more obvious with only larger openings (sash windows) available. Given the small floor area and volume in social housing and also the higher occupancy rate, the available fresh air volume of 3-5 dm^3/s is low compared to a standard volume of 7 dm^3/s per person, a volume that is required to keep the human metabolic waste (=CO2) concentration at a constant level (C)2<1000 ppm).

Moisture balance
In a house with five persons the occupants produce in the used scenario 9 dm^3 of moisture per 24 hours. The building adds to the moisture level as well, in this scenario with 2,5 dm^3 per 24 hours.

Table 2. Moisture production by occupancy

Moisture production	**in ml/24 hrs [dm^3*10^{-3}]**
Sleeping 8 hours (2, 1, 1, 1 person)	1240
Shower 2x morning	570
Washing at washbasin 1x	60
Tea making, use of water cooker	15
Cleaning floor and using kitchen sink	240
Watering plants (2x/week 1500 cm^3)	500
One person present 8.00-16.00 hrs	600
Laundry 4 kg	30
Drying in attic	2000
Handwash 0,3 kg	50
Drying 0,3 kg on door rack	100
Three persons 16.00-18.00 hrs	450
Cooking between 17.30 and 18.00	500
Five persons 18.00-20.00 (22.00)	1200
Dishwashing 19.00, coffee 20.00 hrs	220
Two wet coats in hall	300
One shower around 21.00 hrs	400
One bath at 22.00 hrs	300
All wet towels in bathroom	200
Production by occupancy	**8995**

Building related moisture production	**in ml/24 hrs [dm^3*10^{-3}]**
Moisture from crawl space	2200
Moisture from cavity in wall	300
Production by the building	**2500**

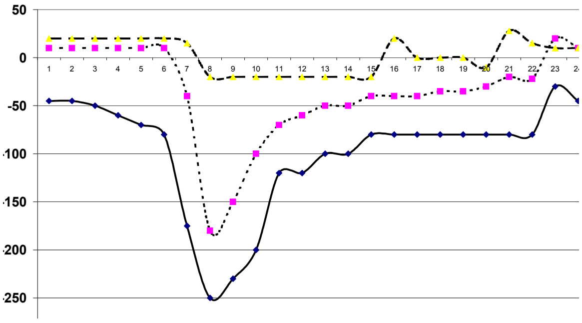
Table 2 presents the total for all rooms. The moisture level indoors varies per room and per period of time. The removal of moisture depends on the volume of air and the difference in vapour pressure. In the scenario for this study the total removal capacity is 14,7 dm^3 per 24 hours. See table 3.

Table 3. Removal of moisture by ventilation

Removal of moisture by ventilation	**in ml/24 hrs [dm^3*10^{-3}]**
Total removal capacity	**14676**

The conditions are not stable, both production and removal are dynamic processes. During a large part of the day more moisture is removed than produced, except in the late afternoon and evening. The balance of separate room differs much from the balance of the dwelling. Figure 1 shows the balance between production and removal in three bedrooms. The balance is the sum of theoretical production and removal volumes; the values below the 0-axis show more removal than production. In practical conditions the moisture peaks will lead to 100% RH including condensation in a certain space, until the production reduces and the space starts to dry. Figure 1 shows the production minus removal capacity without the complex processes that occur in a certain space.

Figure 1. Moisture balance over 24 hours in three bedrooms

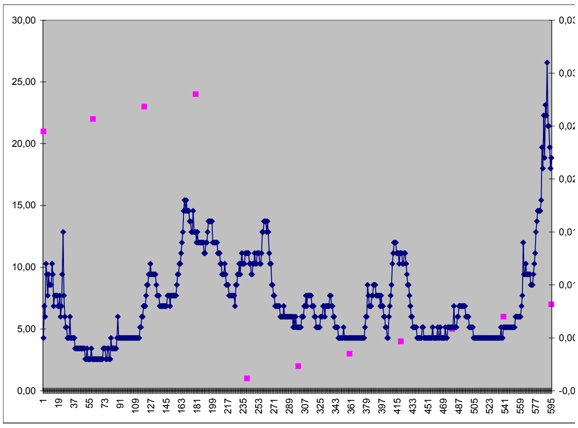


The master bedroom (lowest line of Figure 1) is well ventilated with dry air from outside. Ventilation removes more moisture than is produced. The bedroom for the two children (topmost line) is ventilated with warm and moist indoor air and the moisture balance is effected by vapour transport from the bathroom and the living room.

Sleeping in aerosols

A monitor (PM2,5) was placed next to a bed of an adult sleeping person and recorded the aerosol mass concentration. Figure 2 shows how the aerosol concentration is related to sleep patterns and movements during sleep over a period of 9 hours. The inlet openings of the bedroom were closed. Temperature differences create air flow patterns. Cool inlet air drops from an inlet opening to the floor and is uplifted by the heat flux of persons in bed. This air flow secures the circulation of fresh air near the nose. Moving around in bed blows mattress dust including house dust mite allergen to the breathing area. The covers act as a blow pipe towards the nose. The figure shows body movements at short and longer intervals of approximately 1,5 hours and periods of quiet sleep [5].

Figure 2: PM2,5 concentration near the bed during sleep



House dust mite allergen concentration

The dataset average concentrations of Der p1 are: sofa: 1,3 µg/g (σ=1,6) (n=24), carpet: 3,78 µg/g (σ=9,3) (n=37), mattress: 6,48 µg/g (σ=9,8) (n=64). The average concentration of dust from the mattresses is high. Der p1 concentrations in mattresses are higher in multi–family (73% > 2 µg/g) than in single-family houses (45% > 2 µg/g), with 9,2 and 4,2 µg/g respectively. The number of persons in a house (occupancy load), thermal bridges and visible mould show the strongest correlation with house dust mite allergen concentration of >2 µg/g dust. Occupancy load is defined as the number of occupants divided by the number of rooms in the house. A separate group of data was used to test a model that uses occupant load as the predicting variable for high allergen concentration. In 76% of the cases the model prediction was good; 10% was predicted lower than measured and 23% was predicted higher than measured.

Table 4. Comparison of modelled and measured concentration of house dust mite allergen

	model > 2 µg/g	model ≤ 2 µg/g
measured > 2 µg/g	45%	10%
measured ≤ 2 µg/g	22%	23%

The odds ratio of 5,45 (95% confidence interval and limit values of 1,75 and 69) result in a significant correlation between the occupant load and the allergen concentration. In only 10% of the houses in the second data set the occupant load predicted low Der p1 levels whereas the measured concentrations were larger than 2 µg/g. Occupancy load is a strong (proxy) indicator of exposure to house dust mite allergen. If the occupancy of a single-family house is larger than 1, an elevated risk on HDM allergy is likely to occur. For multi-family houses the occupancy only needs to be higher than 0,5 for an elevated risk level of HDM allergy to occur with great probability. Multi family houses are in general more air tight and smaller than single-family houses, which leads to higher moisture concentration.

4 Discussion

The experiments to study air flows and air change rates point at the importance of large inlet openings and overflow openings or exhaust openings in the bedroom to provide enough fresh air for a two person bedroom. The mechanical exhaust system has low impact on the flow through a bedroom, except when a stairwell creates a large stack effect and the door to the bedroom has a large opening (range of >200 cm2). The moisture balance shows that moisture removal with cool fresh air is important. High peaks in the house effect the moisture level in other rooms, especially in bedrooms that are cooler and poorly ventilated. The indirect effect of high moisture levels is (faster) growth of the population of house dust mite. Mould and moisture loving pest animals (sow-bugs, fish-moths) could add to the allergen level. Reliable data on the age of mattresses was not available and modelling of the age parameter was not possible. However, the age of the mattress is probably an indicator of allergen concentration as well. A new mattress does not contain house dust mite allergen. Because mites will grow in any mattress that is slept on during the warm and humid summer period, allergen material will accumulate in the course of a few years. All mattresses over five years of age (or 8 years with anti-mite cover) are very likely to contain allergen material above a concentration of 2 µg/g, with the potential to cause an asthma attack or even sensitization.

The health importance of the bedroom
In The Netherlands 2-5% of health loss is supposedly related to the physical environment [8]. Looking at the estimates for lung cancer, inflammation of the lungs, respiratory problems and accidents, an estimated 0,3 – 0,8 % of the total burden of disease is related to the bedroom. Better bedroom conditions can avoid 20-35% of this burden of disease [5].

5 Conclusion

The bedroom is not a healthy place, especially for persons with respiratory problems and sensitivity to house dust mite allergen. Health risk in bedrooms is indirectly caused by moisture production. Low air change rates are quite common. With poor ventilation all kinds of pollutants will build up and the exposure to allergen will increase. The moisture balance study shows that ventilation with cool fresh air is important and that high peaks somewhere in the house will effect the moisture level in bedrooms that are likely to be cooler and poorly ventilated with fresh air.
Growth conditions for house dust mite allergen are not strongly influenced by low air humidity or temperature. Despite few data available for validation, the age of the mattress supposedly is an important indicator of the allergen concentration. The resulting priority indicators of allergen concentration are:
-the number of persons sleeping in bedrooms or the occupancy load of the house;
-the age of the mattress.
Secondary indicators that support the analysis of growth conditions and concentration of allergic dust are ventilation of mattress and covers and high ventilation levels leading to low winter temperatures (lower than 15 ^{0}C. The type of mattress (spring, foam, water bed) is indicator of the amount of dust. The use of mite protective covers and dust removal by cleaning have a minor effect. Good ventilation during sleep reduces the allergen concentration in the bedroom air, but does not prevent exposure to dust blown from under the covers to the breathing area.

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Relevance of Microfungi and their Secondary Metabolites (Mycotoxins) for Indoor Hygiene

G. Fischer, R. Thißen, C. Schmitz, W. Dott

RWTH Aachen University, Institute of Hygiene & Environmental Medicine,
Mycology Section, University Hospital, Pauwelsstraße 30,
D-52057 Aachen, Germany
E-mail: Guido.Fischer@post.rwth-aachen.de

Summary: *Toxic secondary metabolites of fungi are present in airborne fungal spores, and may thus occur in airborne dust and bioaerosols. A limited number of mycotoxins has already been quantified in native bioaerosols or house dust. Concentrations are mostly in the range of 0.1 to 50 ng per 10^6 conidia (spores) depending on the compound and the species. A number of mycotoxins has been shown to exhibit cytotoxic, genotoxic and immune-modulating effects. If tested for cytotoxicity as single compounds IC_{50} values are in the range of 1 – 50 µg per ml, in some cases (gliotoxin, satratoxin) 2 to 3 orders of magnitude lower (ng per ml). There are indications that different mycotoxins can have synergistic effects, that may also occur for mycotoxins in combination with structural compounds, i.e. glucans, pigments, and proteins. The most important aims for further research on mycotoxins will be to analyse extracts of native aerosol samples for microbial metabolites, to study the effect of pulmonary exposure to relevant mycotoxins and structural compounds of fungal conidia, and to study the various kinds of toxic effects on mammalian cell systems in vivo and in vitro..*

Keywords: *mycotoxins, fungi, indoor air, public health*
Category: *Indoor air exposure*

1 Introduction

The possible respiratory uptake of mycotoxins from the air has so far not been sufficiently taken into account. Toxic secondary metabolites are present in airborne spores, and may thus occur in airborne dust and bioaerosols. Potential health risks can not be estimated reliably, unless exposure to mycotoxins is determined qualitatively and quantitatively and effects on relevant cell systems in the lung are known. If airborne fungal spores are inhaled down to the bronchia and alveoli, they will be lysed and the human body is exposed to primary and secondary metabolites. In some cases, mycotoxins are clearly involved in pathogenesis. Long-term exposure to living or dead particles containing fungal toxins e.g. aflatoxins, gliotoxin, ochratoxin, patulin and trichothecenes seems to be able to eventually suppress or modulate the immune response in healthy people. Since most investigations on immune-modulation by mycotoxins have focused on oral application [5], further research is necessary to elucidate the role of exposure by pulmonary uptake. The importance of airborne mycotoxins in environmental hygiene has recently been summarized [17]. In air hygiene the inhalation of mycotoxins must be considered. The production of mycotoxins basically depends on the type of substrate available. Mycotoxins are excreted into the substrate or can be present in fungal cells. Consequently, two routes for mycotoxins becoming airborne are possible: a) the dust may be contaminated by mycotoxins excreted by the fungi; b) the conidia (and spore fragments) contain toxic metabolites which become air-borne by propagation. It seems that the amount of mycotoxins basically depends on the number of conidia present in airborne dust [11, 13]. The pulmonary uptake of mycotoxins and its effects in animal and in *in vitro* experiments have not been investigated sufficiently. In addition, epidemiological studies are needed to enlarge knowledge on possible symptoms and health impacts in connection with exposure levels.

2 Occurrence of mycotoxins in fungal conidia

A number of mycotoxins has been found to occur in conidia of different species [11, 12, 13, 40] (Fig. 1, Table 1). The production and content of mycotoxins depend basically on the nutrient supply in the substratum (sugar and nitrogen content), and the temperature for growth. For gliotoxin the following circumstances lead to maximum concentrations of the compound: 30% glucose (in Czapek-Dox Broth), 37 °C, highest amount after 29 h incubation [4]. A trend in substrate-dependent mycotoxin production in indoor air can be deduced from the data by Tuomi et al. [47]. The total ratio of mycotoxin-containing and mycotoxin-free samples was highest for cellulose (20/24), gypsum (8/10), and synthetic materials (3/4), but was rather low for mineral wool (1/5), or plaster/sand/soil (1/10).

In case of gliotoxin the concentrations found in conidia [40] matched our findings very well (Table 1). The concentrations of the aflatoxins in conidia range a factor of 5 (for G_1) to 10 (for B_1) times higher compared to our findings (Table 1). Although the results by Senkpiel et al. [40] were partly achieved by spiking samples with standard compounds (pers. comm. Senkpiel), both findings matched quite good with regard to the order of magnitude of the mycotoxin content in conidia.

Table 1: Data on the occurrence of mycotoxins in conidial extracts (CE) on synthetic medium (SM) and natural substrata (NS). Data on the range of concentrations given for conidia from synthetic medium [ng per 10^7 conidia] originated from different replications of experiments and different strains analysed by HPLC-DVD/FLD.

Mycotoxin / compound	CE-SM	CE-NS	Conc. in conidia SM [ng per 10^7 conidia]	Comparison to: Senkpiel et al., 2000
A. flavus, A. parasiticus:				
Aflatoxin B1	+	n.a.	5 – 59 (35 – 144)	1300
Aflatoxin G1	+	n.a.	7 – 14 (71 – 125)	440
A. fumigatus:				
Verruculogen	+	n.a.	1 – 5	
Gliotoxin	+	n.a.	8 – 24	11, (22‡)
Tryptoquivaline	+	+	n.q.	
Trypacidine	+	+	n.q.	
A. ochraceus:				
Ochratoxin	-	-	n.d.	0.4*
A. versicolor, E. nidulans				
Sterigmatocystine	+	+	10 – 375 (5 – 3404)	-
P. brevicompactum:				
Mycophenolic acid	+	n.a.	1 – 32	-
P. crustosum:				
Roquefortine C	+	+	25 – 63	-
Penitrem A	+	n.a.	3 – 135	-
P. expansum:				
Patulin	-	n.a.	-	48**
Roquefortin C	+	+	35 - 555	
P. roqueforti:				
Roquefortin C	+	+	19 - 750	
Mycophenolic acid	+	n.a.	3 - 7	

Legend: + = mycotoxin found; - = mycotoxin not found; n.a. = no data available; n.q.= no quantification possible due to lack of standards; n.d. = not detected; * = analysed by ELISA; ** = concentration calculated on the basis of 10^9 conidia extracted; ‡ = ex. Schulz et al., 2004.

3 Occurrence and activity of mycotoxins in bioaerosols

Exposure to airborne mycotoxins on workplaces in agriculture has intensely been studied during the 1980s and its relevance for both environmental health and occupational medicine has clearly been defined in the beginning 1990s [20, 26]. Until now, the only toxins detected in airborne dusts and bioaerosols have been trichothecenes of *Stachybotrys chartarum*, aflatoxins of *Aspergillus flavus*, and metabolites of *A. fumigatus* (Table 2). However, investigations on the potential of distinct species to produce mycotoxins on semi-natural substrates indicated, that additional compounds to those already found in native bioaerosols may occur [13]. The majority of the mycotoxin-positive samples of building materials from water-damaged houses (82%) contained cellulosic matter, such as paper, board, wood, or paper-covered gypsum board [47]. Investigation on the occurrence of air- or dust-borne mycotoxins in indoor and occupational environments have been summarized in Table 2.

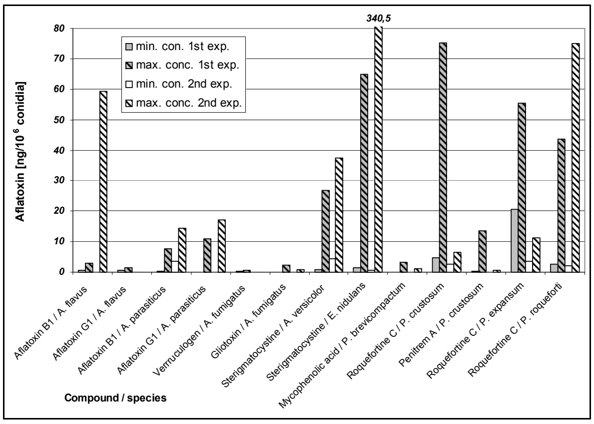

Fig. 1. Concentration of mycotoxins in conidia of different species. The experiments were repeated half a year later (1st and 2nd experiment) with identical strains to get an impression of the reproducibility of the mycotoxin content in conidia.

3.1 Exposure in occupational environments

On workplaces in agriculture and waste-handling mainly two species are of concern due to very high numbers of conidia in bioaeosols, i.e. *Aspergillus flavus, A. parasiticus* (Aflatoxins) and *A. fumigatus* (fumitremorgens, tryptoquivalines). Own investigations showed that aflatoxins can be found in native bioaerosols and that concentrations in the bioaerosols corresponded to the concentrations to be found in conidia from pure cultures. However, a correlation between fungal counts in air and the concentrations of air-borne mycotoxins could not be described until now. This seems to be due to a combination of factors influencing the synthesis of mycotoxins under natural circumstances, e.g. nutrient-dependent production, accumulation and/or biodegradation, fluctuations in fungal population, and allelopathy. The occurrence of tryptoquivaline (tremorgen) and trypacidin (5-50 µg per 10^9 conidia) from *A. fumigatus* in native dusts and bioaerosols sampled in a composting facility has been demonstrated [11]. The detection of these compounds coincided with an extraordinary high density of conidia in air (10^7 CFU m^{-3}). Gliotoxin and verruculogen have been found in very low amounts in conidia (Fig. 1, Table 1).

3.2 Exposure in indoor air

Stachybotrys chartarum – trichothecenes:
Stachybotrys chartarum produces trichothecenes, e.g. satratoxines H and G, verrucarins B and J,

trichoverrins, and atranones A and H, some of which proved to be of toxicological relevance in case of exposure to 10^3 - 10^4 CFU m^{-3} air, which can be reached in agricultural environments [43]. But, also building materials of high cellulose and low nitrogen content that become moist and are subjected to temperature fluctuations can provide ideal growth conditions for *S. chartarum* toxin production [7]. Few clinical reports on human cases of toxicosis due to *Stachybotrys chartarum* are available in literature. Symptoms observed in connection with contamination by *Stachybotrys* spp. comprise coughing, rhinitis, sore throat, nose bleeding, moderate fever, diarrhea, headaches, dermatitis, fatigue and general malaise [36], a not yet validated case of acute pulmonary haemorrhage in infants [10], and central nervous system (CNS) symptoms [7]. A clear cause-effect relation between the occurrence of the fungus and the symptoms observed in patients is difficult to establish, which can partly be attributed to the fact that isolation of the fungus from substrates with extremely high amounts of airborne fungal spores is difficult. A detection of conidia by direct microscopy is necessary. In addition, a number of symptoms described by the patients exposed to *Stachybotrys* spp. could as well be caused by other factors, e.g. chemical noxae, infections or neurological effects. Moreover, it has recently been shown that three chemotypes can be distinguished in Stachybotrys chartarum, all differing with respect to their toxic and inflammatory potential as characterized by cytotoxicity assays [1]. However, there is no doubt that the mycotoxins produced by *Stachybotrys chartarum* are the most toxic ones known.

A. ochraceus / P. verrucosum – Ochratoxin:
A first report of ochratoxin in house dust has been published [35]. Samples of dust collected from the heating ducts yielded up to 1,500 ppb of ochratoxin A. In air samples taken previous to this sampling *Aspergillus ochraceus* and *Penicillium* spp. had been found. The production of the mycotoxin could not solely be ascribed to *Aspergillus ochraceus* as the penicillia present in the dust have not been identified to the species level. It has often been falsely assumed that ochratoxin is produced by several *Aspergillus* and *Penicillium* species [35, 36], which is not true for the penicillia.

Aspergillus versicolor - Sterigmatocystine
Sterigmatocystine was found to be the prevalent compound (12 – 31 µg/g) in crude building materials from water damaged buildings in Finland [47]. The compound was also found in samples of house dust in amounts of 2-4 ng/g, that contained 104 cfu/g of A. versicolor [8]. These results matched quite good with our findings that, *A. versicolor* and *Emericella nidulans* may contain up to 375 ng, respectively 3,404 ng per 10^7 conidia (Table 1). Adjusted to an amount of 10^4 conidia the amount would be approximately 0.4 and 3.4 ng, which is in the range of the concentrations found by Engelhart et al. *in situ*. One must consider that the concentrations of microorganisms were assessed as colony-forming units (cfu) by these authors. It is likely that a significant amount of conidia in house dust is non-viable, but may contain sterigmatocystine. If also on natural substrata E. nidulans spores contain higher amounts of sterigmatocystine than *A. versicolor* (Table 1), its presence in house dust could considerably influence the contamination with this mycotoxin.

P. chrysogenum, *P.citrinum* - Citrinine:
Citrinine was found in three samples of wood-based building materials in concentrations of 20 – 35 µg/g [47]. In our studies we found Oxaline (not quantified) and roquefortine C in conidia (17 – 23 ng per 10^7 conidia) on synthetic substrates, whereas after growth on natural substrates (compost) the compound were not detected.

Other mycotoxins detected:
In a finish study, the presence of fungi in wood-based building materials was not correlated with the presence of the expected mycotoxins [47]. For instance, *Fusarium* spp. were isolated from 15% of the samples, but the majority of samples (10 of 12) containing non-macrocyclic trichothecenes characteristic of *Fusarium* spp. yielded no *Fusarium* isolates.

Table 2: Occurrence of air- and dust-borne mycotoxins.

Mycotoxins / Species	**Substrate / Type of sample**	**Concentration**	**Reference**
Aflatoxins *A. flavus, A. parasiticus*	Grain dust (maize)	**206** ppb ⇒ **107** ng m^{-3}	Burg & Shotwell 1984
Aflatoxin B_1 *A. flavus, A. parasiticus*	Respirable peanut dust	22.7 - 612.4 ppb ⇒ **0.4 - 7.6** ng m^{-3}	Sorenson *et al.* 1984
Satratoxins G, H *Stachybotrys atra*[1]	Artificially generated aerosols/ dusts	**9.5** ng mg^{-1} dust	Sorenson *et al.* 1987
Aflatoxin B_1 *A. flavus*	Airborne grain dust	**0.04** – **4,849** ng m^{-3}	Selim *et al.* 1998
Trypacidin, Tryptoquivaline *A. fumigatus*	Total dust composting facility	semi-quantitative analysis: **5-50** µg per 10^9 conidia	Fischer *et al.* 1999b
Ochratoxin *A. ochraceus, Penicillium* spp.	Dust from heating ducts	up to **58 - 1,500** ppb	Richard *et al.* 1999

Sterigmato-cystine *A. versicolor*	Building material (water damaged)	**12 – 31** µg/g	Tuomi et al., 2000
	House dust contaminated with 3.1 x 10^4 cfu of *A. versicolor*	**2 - 4** ng/g	Engelhart et al., 2002

[1] Stachybotrys atra Corda 1837 = Stachybotrys chartarum (Ehrenb. Ex Link) Hughes 1958. S. atra is a facultative synonym of S. chartarum, thus based on different type material [17].

4 Cytotoxicity of mycotoxins and other structural components

Effects of mycotoxins

The cytotoxic properties of mycotoxins on different cell systems have been documented in a number of studies, e.g. for tracheal epithel cells [6, 51], embryonal fibroplasts of the lung [2], ciliar respiratory tract epithelium of chicken in vitro [9, 28-33], and feline-fetus-lung cells [3]. Moreover, inhibition of cytokine secretion and proliferation of blood cells was described [50]. Fungal spores have been shown to trigger the production of inflammatory mediators in macrophages by in vitro testing [27, 37]. An immunosuppressive effect of gliotoxin was already described by Sutton et al. [44, 45].

Preliminary experiments have shown a positive cumulative toxic effect in mixed lymphocyte populations, when they were treated sequentially with subinhibitory doses of gliotoxin and Aspf1 (18-kDa RNase) [24]. Wichmann et al. [50] showed that, the mycotoxin gliotoxin among others may contribute to a reduction in type 1 helper cells and its cytokines in human blood. There is only few information on the effect of different mycotoxins on lung cells in literature [22, 25, 42, 48, 49].

The cytotoxic effect of conidial extracts on the human lung epithelial carcinoma cell line A549 was assumed to be due to unknown secondary metabolites in fractions of these extracts (Schulz et al., 2004). Unfortunately, the conidial extracts tested by these authors were derived from strains that did not synthesize the characteristic mycotoxins (with exception of one isolate of *A. fumigatus*) and, therefore, the cytotoxicity measured could not be compared to that of standard mycotoxins tested, e.g. patulin, satratoxin H, aflatoxin B1 and G1, ochratoxin A, sterigmatocystine, penitrem A, roquefortine C. Therefore, the cytotoxic and /or immune-modulatory effects of all these mycotoxins should be investigated in different cell systems, so that combinations of different mycotoxins and combinations of mycotoxins with structural compounds, e.g. glucans and pigments, are considered.

Effects of other structural components of fungal spores

Besides the endotoxins of gram-negative bacteria, components of the fungal cell wall such as glucans and structurally related compounds seem to cause inflammations of the airways [46], which is of major importance in occupational environments due to high amounts of ß-glucans and possible interactions with endotoxins on workplaces [22]. However, interactions between glucans and spore-associated mycotoxins [13] need to be studied further with respect to the inflammation of airways. As cytokines play an essential role in the mediation of inflammation processes and certain mycotoxins are known to influence cytokine excretion, glucans and mycotoxins may have synergistic effects. It has been reported that pigments (i.e. dihydroxynaphthalene-melanin) can inhibit the phagocytosis of conidia [22]. Melanins can reduce the excretion of reactive oxygen species in alveolar macrophages, a process that may affect the phagocytosis of microorganisms in the lung. Thus, melanins may inhibit the immune-response on a cellular level, while mycotoxins and glucans seem to influence the immune system on the physiological level (influence on mediators for inflammation). It is likely that in certain cases, when people are exposed to a combination of these different compounds, combinatory effects can lead to health effects that can not be ascribed to one factor alone.

5 General conclusions and perspectives

The number of species that have been studied in experiments concerning exposure to mycotoxins in air is still limited. If data from the last two decades are critically evaluated, taxonomic, toxicological and chemical expertise must be considered to estimate possible health effects reliably. It can be concluded that the reliable identification of fungi to the species level [15] is the basis for the estimation of potential health hazards with respect to sensitization and development of allergies. In addition, the enumeration of fungal species present in air and building materials is important to verify the severity of mould damage and to eventually clarify the cause of damage. Finally, the chemical analysis of mycotoxins in mouldy materials is necessary for an estimation of potential health hazards due to dispersal of such bioaerosols from the microbial contamination.

Literature on health effects of mycotoxins in indoor air of the recent years did not provide compelling evidence that exposure at levels expected in most mould-contaminated indoor environments is likely to result in measurable health effects [see 36]. Some theoretical calculations derived from the data summarized above, may visualize the relevance of air- and dust-borne mycotoxins indoors: If a maximum concentration of 10^2 (-10^3) conidia per m^3 air of a toxigenic fungus is to be found in case of microbial contamination indoors, a person would inhale 10^6 conidia in approximately 830, respectively 83 days, assuming a vital capacity of 0,5 m^3 per h. This amount of spores could contain 2 - 100 ng of mycotoxins to which the body is internally exposed throughout that period. In case of a fungal contamination in house dust a concentration of 10^5 conidia per g can be assumed for toxigenic species (e.g. *A. versicolor*). If again an amount of 2 - 100 ng of mycotoxins (in 10^6 conidia) is supposed to be toxicologically relevant, 10 g house dust must be inhaled to reach that concentration. These calculations may visualize the risk for toxic effects due to pulmonary inhalation indoors. Table 3 summarizes mycotoxin concentrations indoors and their respective health impact in humans (cytotoxic and immune-modulatory effects).

However, it would be important to investigate if trace amounts of mycotoxins – in combination with other structural components (glucans, pigments, proteins) of fungi and bacteria – can eventually alter the immune system and cause allergic reactions in humans. The most important aims for further research on mycotoxins will be to analyse extracts of native aerosol samples for microbial metabolites, to study the effect of pulmonary exposure to relevant mycotoxins and structural compounds of fungal conidia, and to study their cytotoxic, genotoxic and immune-modulating effects on mammalian cell systems in vivo and in vitro.

Table 3: Cytotoxic, immune-modulatory and internal concentrations of mycotoxins with hygienic relevance

Mykotoxin / species	**Cyto-toxicity (ng ml^{-1})**	**Immune-modulation (ng ml^{-1})**	**Indoor exposure**	**Internal exposure**
Sterigmato-cystin / *A. versicolor*	-	-	**2 - 4** ng g^{-1} dust	?
Ochratoxin / A. ochra-ceus	**30 – 8.000**	**34 / 83**	**58 – 1.500** ng g $^{-1}$ dust	**0,17 – 0,88** ng ml^{-1}
Gliotoxin / *A. fumigatus*	**150 – 200**	-	**8 - 24** ng / 10^7 conidia **40** ng cm^{-2} building mat.	?
Chaeto-globosine A/C / *Chaetomium globosum*	-	-	**50 / 7** µg cm^2 building mat.	?
Satratoxine G/H / *Stachybotrys chartarum*	**10**	**2,5**	**9.5** ng mg^{-1} dust	?

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Indoor Environmental Quality (IEQ) In Food Processing Industry

M.Z.M Yusof*. A.M. Leman[1], A. Husain[1], S. Hasan[1], L.P. Jun[1], N.A M. Ahyan[1]

[1]Faculty of Mechanical & Manufacturing Engineering, Kolej Universiti Teknologi Tun Hussein Onn
(KUiTTHO), Locked BeglOl,
86400 Parit Raja, Batu Pahat, Johor Email: mdzainal@kuittho.edu.mv http://www.kuittho.edu.my

***Summary**: This study was carried out in a food processing industry located at Pt. Raja, Johor, which produced foods such as kebab, pita bread and satay. Thermal environmental parameters such as air temperature and velocity and VOCs were measured at processing areas. The Portable VOC Monitor, Air Velocity Meter, IAQ Meter, Dust Trak Aerosol Monitor and Ultrafine Particle Counter were used to measure the indoor environmental quality at five processing areas, namely the Bread Processing, Bread Packaging, Filling and Packaging, Cooking and Satay Processing. VOCs (Isobutylene gas) were found in the area without air conditioning system (Bread Processing, Cooking and Bread Packaging Area) which ranged from 0 - 4832 ppm while for the area served with air conditioning system was almost free from VOCs (Filling and Packaging and Satay Processing Area). Bread processing area has the lowest value of air velocity compared to the others. Particle count ranged from 2710- 50000 pt/cc. Aerosol measurement were 0 - 0.042 mg/m3 . The highest temperature was 33.8"C at the Cooking Area, and the building was suitable for the food processing.*

***Keywords**: IAQ, VOC, Food Processing, Ventilated Building, Mechanical Ventilation.*
***Category**: Indoor Air Exposure*

1 Introduction

1.1 Research Background

Indoor air quality (IAQ) is a complex issue, much more so than any single environmental issue. There are hundreds of pollutants that affect IAQ and thousands of sources. Research indicates that more than 900 different contaminants are present in indoor environments, depending on the particular operations and activities which occur within the specific environments. The indoor environment in any building involves the interactions of a complex set of factors that are constantly changing [1].

A healthy indoor environment is one which promotes the comfort, health, and well-being of the building users. Temperature and humidity are controlled within a comfort zone. Normal concentrations of respiratory gases, such as carbon dioxide, are maintained. The air is free of significant levels of contaminants and odors. Also contributing to a sense of well being are comfortable levels of lighting and sound, appropriate ergonomic conditions, and job satisfaction. These factors are not air quality issues in the strict sense but, nevertheless, affect occupant's perceptions of IAQ and, therefore, are important in a healthy indoor environment [1]. The average person spends approximately 90% of their time indoors. Recent studies have indicated that indoor air is often dirtier and/or contains higher levels of contaminants than outdoor air. Because of this and increased awareness regarding poor indoor air quality (IAQ), it is not surprising that the number of reported employee complaints of discomfort and illness in non industrial workplaces is increasing [1]. Hence, this project was under taken based on the need of finding the quality of the indoor air in the food processing industry. Therefore, this study will evaluate the VOC (isobutylene gas) and air velocity of the air inside the production area.

2 Literature Review

2.1 Indoor Air Quality

Generally, indoor pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems in homes. Inadequate ventilation can increase indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor air pollutants out of the home. High temperature and humidity levels can also increase concentrations of some pollutants [2].

According to Regulation 26, of the Malaysian Factories and Machinery (Safety, Health and Welfare) Regulations 1970, air cleanliness was defined as; (1) in every factory where any process carried on therein there is given off any fume or dust which is, or is likely to be, injurious or offensive to any person, or where any substantial quantity of dust or fume is being accumulated, measures shall be taken to protect such persons against inhalation of the fume or dust and to prevent it accumulating in the factory [3].

Indoor air quality can affect people's health and can have economic and legal implication called air pollution. Air pollution may be defined as the presence of substances in air at concentrations, durations and frequencies that adversely affect human health, human welfare or the environment. Air pollution is not a recent phenomenon. The remains of early humans demonstrate that they suffered the detrimental effects of smoke in their dwellings [5]. For example, pollutants can cause or contribute to short- and long-term health problems, including asthma, respiratory tract infections, allergic reactions, headaches, congestion, eye and skin irritations, coughing, sneezing, fatigue, dizziness and nausea. They can also cause discomfort, and reduce attendance and productivity. Recent data suggest that poor IAQ can reduce a person's ability to perform specific mental tasks requiring concentration, calculation, or memory [6].

2.3 Possible sources of poor indoor air quality

There is a wide range of pollutants present in indoor and outdoor air. They include many types of particulates, sulphur oxides, carbon monoxide and other photochemical oxidants, nitrogen oxides toxic compounds and a variety of volatile organic compounds (VOC). The major sources of indoor air pollution are from the industrial processes, heating and cooking [7].

Beside the major sources, there still some minor sources which if ignored, it will become bigger and bigger sources. For example, by smoking indoors, smoke drifting in from outdoors, or smoke being carried indoors on clothing. Other things that burn, like oil, gas, kerosene, charcoal briquettes, wood or candles are also sources of indoor air pollutions. Other sources are including, improper circulation of fresh, outside air central heating, cooling or humidifying systems, new or recently installed building materials and furnishings, including carpets and certain wood pressed products and household cleaning and maintenance products [8].

2.4 Volatile Organics Compound (VOC)

During the years from 1984 to 1996 several controlled experiments were performed in laboratories around the world in which human responses to VOCs known to be indoor air pollutants were investigated [10]. The term 'organic compound' was used by early chemists to describe chemical substances that were believed to be created only by the metabolic processes of living organisms. This concept was embodied in the philosophy of 'vitalism', a belief that persisited until 1828 when the chemist Friedrich Wohler demonstrated that organic compounds could be created synthetically in the laboratory from inorganic substances [11]. At room temperature, VOC are emitted as gases from solids or liquids. Concentrations of many VOCs are consistently higher indoors than outdoors [12].

2.4.1 Isobutylene Gas

Exposure to isobutylene may occur at workplaces where it is manufactured. Based on physical properties, the primary workplace exposure would be by inhalation.[13]. Isobutylene is only used as a chemical intermediate. It is mainly used as a monomer or copolymer for the production of synthetic rubber and various plastics. Approximately 72% of available isobutylene is used for the production of butyl rubber. Approximately 17% is used for the production of antioxidants for food, food packaging, supplements and for plastics. Approximately 9% is used for the production of (polymer) fuel oil or lube oil additives. Approximately 2% is used for various other intermediate applications.Isobutylene has a low order of acute toxicity, and being gas at normal temperature and pressure, ingestion or dermal absorption of this material is unlikely. The 2-hour LC50 of isobutylene in mice was 180,000 ppm (415 mg/L) and the 4-hour LC50 in rats was 270,000 ppm (620 mg/L). Inhalation of isobutylene can produce central nervous system depression, anesthesia and/or asphyxiation. However, these effects are only seen at very high concentrations, i.e., approximately 20% or higher. Isobutylene is predicted to produce narcosis in humans at concentrations exceeding the lower explosive limit (LEL) of 18,000 ppm [13].

2.5 Air Velocity/Ventilation

In air conditioning, heating and ventilating work, it is helpful to understand the techniques used to determine air velocity. In this field, air velocity (distance traveled per unit of time) is usually expressed in feet per minute (f.p.m.). By multiplying air velocity by the cross section area of a duct, you can determine the air volume flowing past a point in the duct per unit of time. Volume flow is usually measured in cubic feet per minute (c.fm.).

Ventilation is actually a combination of processes which results in the supply and removal of air from inside a building. These processes typically include bringing in outdoor air, conditioning and mixing the outdoor air with some portion of indoor air, distributing this mixed air throughout the building, and exhausting some portion of the indoor air outside. The quality of indoor air may deteriorate when one or more of these processes are inadequate.

Ventilation is also a determinant of thermal comfort and, more generally, of satisfaction with the indoor environment. The main purpose of ventilation is to provide fresh air and to remove accumulated noxious gases and contaminants. Ventilation helps remove heat generated in a working area by convection and cools the body. It is not always possible to lay down acceptable limits from the point of view of thermal comfort. However, air speeds less than approximately O.lms" ^{1} will usually cause a sensation of staleness and stuffiness-even at relatively low temperature. Air speeds greater than 0.2ms"^{1} may be perceived as drafty. In hotter conditions (with a corrected effective temperature of more that 24°C) air speed of 0.2 to 0.5ms"^{1} will aid body cooling, particularly when the relative humidity is high. It is apparent that whether or not air movement is perceived as an irritating draft or a cool breeze depends on the ambient temperature and the relative humidity [14].

After achieving industry consensus in 1989, the ASHRAE Standard 62-1989: Ventilation for Acceptable Indoor Air Quality was accepted as voluntary standard for "minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to avoid adverse health effects." This standard applies to all types of facilities, including dry cleaners, laundries, hotels, dormitories, retail stores, sports and amusement facilities, and teaching, convalescent and correctional facilities. The specified rates at which outdoor air must be supplied to each room within the facility range from 15 to 60 dm/person, depending on the activities that normally occur in that room.

The processes involved in ventilation provide for the dilution of pollutants. In general, increasing the rate at which outdoor air is supplied to the building decreases indoor air problems. The other processes involved in ventilation however, are equally important. Buildings with high ventilation rates may suffer indoor air problems due to an uneven distribution of air, or insufficient exhaust ventilation. Even in a well-ventilated building there may be strong pollutant sources which impair indoor air quality. The closer such a source is to an exhaust however, the more effective the ventilation; local exhaust ventilation, e.g., a chemical fume hood, is most effective. It is good practice to provide separate exhaust systems in areas where copy machines or solvents are used. Providing localized exhaust for these specific sources can result in a reduction of the amount of overall building exhaust ventilation necessary.

2.6 Indoor Air Temperature

The temperature in a building may affect the tenants' comfort level. A survey done by the International Facility Management Association (IFMA) found that the most frequent complaint from office tenants was thermal comfort (too hot/cold). Recent research conducted within the International Centre for Indoor Environment and Energy showed that temperature influence not only man's thermal sensation, but also the perception of indoor air quality. By exposing human subjects to different levels of indoor air temperature, it was observed that the air was perceived as less acceptable with increasing air temperature, although the subjects were kept thermally neutral [15].

The air quality was not significantly improved by decreasing the pollution load on the air when the air was warm. This indicates that warm air always will be perceived as unacceptable and that ventilation therefore may not be sufficient for improving the perceived the air quality. Furthermore, the studies indicated that increasing indoor air temperature may cause increased pollutant emission from the building materials, which will result in a deteriorated air quality. These results underline the significance of indoor air temperature on the required ventilation rate. To obtain a good indoor air quality and optimizing energy consumption for ventilation, maintaining a moderate level of indoor air temperature and acceptable for thermal comfort should be considered [16].

3 Methodology

3.1 Company Profile

The company was founded in 1997, located at Small and Medium Industrial Area, Parit Raja, Batu Pahat, Johor. The main products of this company are kebab, pita bread, and satay. They have twenty to thirty main customers and their products mostly are supplied to Johor Bahru, Batu Pahat and Kuala Lumpur, but occasionally, they also supply satay to MAS Airline. The company was categorized as small and medium size food processing industry, which employed forty employees.

3.2 Project Scope

The main objective of the project is to evaluate the indoor air quality in a food processing industry focusing on Volatile Organics Compounds (VOCs) inside the production area. The scopes of works are follows:

a) Measuring the environmental parameters such as air temperature and air velocity.

b) Monitoring the concentrations levels of VOC.

c) Comparing the result with recommended standards.

3.3 Walk Through Inspection and Interview

A walk through inspection on all the processing and production areas such as pita bread and kebab, cooking, filling and packaging section. The measurement of VOCs, air temperature and air velocity at selected points were conducted. The employees were interview on matters pertaining to their perceptions on the indoor environmental parameters of their work stations.

3.4 Measurement Device

Two IAQ devices had been used, which were MiniRAE 2000 Portable Voc Monitor PGM-7600 and TSFs VelociCalc Air Velocity Meters. Below are the detail descriptions about the devices:

Just mention the ranges of measurement possible and the accuracy. Mention a bit on the measurement methods; equipment location and interval of measurement; mention any relevant standard.

3.5 Data Collection

Data is obtained from measurement of physical parameters and VOCs. Concentration levels of selected VOCs using an appropriate instruments as ststed in 3.3 above.

4 Result and Discussions

4.1 Physical Parameters

4.1.1 Description of Selected Processing Area

The basic data for the selected processing area is as shown in Table 1.

Table 1: Basic Data for Processing Section

Section	Measurement Location	Floor Size	Floor-Ceiling Height (Ft)
Bread Processing	P1, P2, P3	54' x 22'	12'
Filling and Packaging	P4, P5	24' x 22'	12'
Cooking	P6	12'x 22'	12'
Skewing Satay	P7, P8	12' x 22'	12'
Bread Packaging	P9	24' x 22'	12'

4.2 Findings and Analysis of Velocity of Air

Results of air velocity measurement are shown in Table 2 below.

Table 2: Results of Air Velocity Measurement

Reading	P1	P2	P3	P4	P5	P6	P7	P8	P9
1	0.06	0.03	0.05	0.15	0.24	0.28	0.29	0.06	0.41
2	0.16	0.03	0.05	0.11	0.26	0.28	0.28	0.1	0.21
3	0.12	0.03	0.02	0.07	0.21	0.37	0.31	0.14	0.19
4	0.09	0.04	0.01	0.08	0.13	0.25	0.3	0.17	0.21
5	0.08	0.01	0.01	0.13	0.09	0.41	0.26	0.12	0.21
6	0.06	0.13	0	0.07	0.09	0.54	0.28	0.05	0.24
7	0.05	0.07	0.04	0.11	0.07	0.3	0.22	0.15	0.25
8	0.04	0.09	0.03	0.06	0.07	0.46	0.29	0.15	0.25
9	0.07	0.05	0.05	0.12	0.13	0.26	0.3	0.1	0.21
10	0.08	0.07	0.03	0.09	0.16	0.24	0.31	0.1	0.29
11	0.09	0.11	0.03	0.04	0.04	0.52	0.35	0.08	0.2
12	0.1	0.06	0.02	0.02	0.1	0.31	0.3	0.09	0.27
13	0.11	0.04	0.05	0.06	0.08	0.17	0.28	0.18	0.25
14	0.31	0.05	0.03	0.12	0.12	0.18	0.24	0.13	0.36
15	0.16	0.04	0.05	0.08	0.23	0.17	0.23	0.12	0.27
average	**0.105**	**0.057**	**0.031**	**0.088**	**0.135**	**0.316**	**0.283**	**0.116**	**0.255**
min	0.04	0.01	0	0.02	0.04	0.17	0.22	0.05	0.19
max	0.31	0.13	0.05	0.15	0.26	0.54	0.35	0.18	0.41

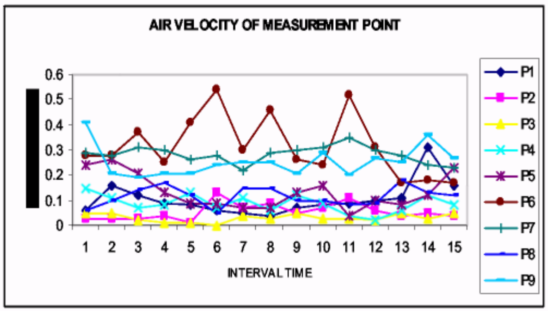

Figure 1: Graph of Air Velocity

4.3 Findings and Analysis of Temperature~

Table 3: Result of Temperature Measurement

Section	Point	Temperature
Bread Processing	P1	31.4°C
	P2	31.5°C
	P3	31.7°C
Filling and Packaging	P4	22.2°C
	P5	16.7°C
Cooking	P6	33.8°C
Skewing Satay	P7	26.8°C
	P8	24.5°C
Bread Packaging	P9	34.1°C

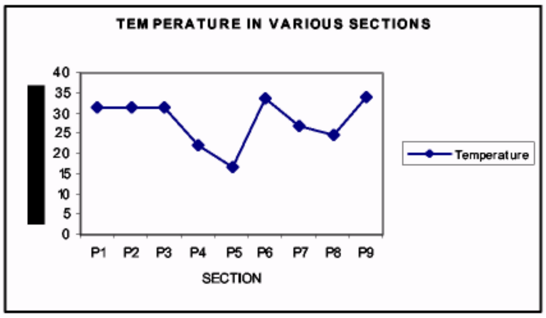

Figure 2: Graph of Air Temperature

The temperature in i.e. Bread Packaging section was 34.1°C. This section was not equipped with air conditioning system to maintain the freshness and quality of the bread. The temperature in air conditioner will caused the existing of fungus early.

4.2 Findings and Analysis of VOCs

Table 4: Data of VOCs

Section	Min	Max	Avg
P1 (Bread Processing)	2.18	2.78	2.42
P2 (Bread Processing)	0.66	1.18	0.85
P3 (Bread Processing)	0	0.14	0.021
P4 (Filling and Packaging)	0.58	2.01	1.3
P5 (Filling and Packaging)	0.65	2.25	1.58
P6 (Cooking)	1.54	2.56	2.06
P7 (Sticking Satay)	0	0.025	0.005
P8 (Sticking Satay)	0	0.022	0.004
P9 (Bread Packaging)	1.5	2.07	1.75

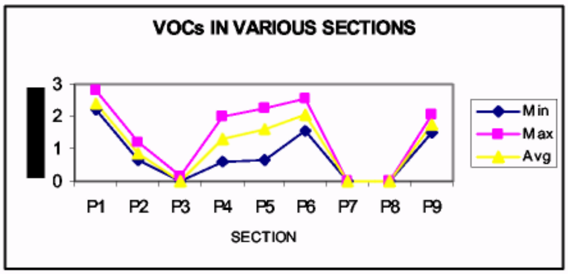

Figure3: Graph of VOCs

5. Discussion and Conclusion

5.1 Discussion on Air Velocity

From the finding data, the air velocity in the bread processing area (PI and P2) is less than O.lm. This results that some of the employee's complaint about the processing area for bread is too hot and uncomfortable for them. According to [14], air speeds less than approximately O.lm per second will usually cause a sensation of staleness and stuffiness-even at relatively low temperature. From the finding data also, P6 show the highest air velocity, which is 0.316m/s. This is because they use a standing fan inside the production area to faster their processing satay. P7 and P9 show the air velocity more than 0.2m/s. According to [14], air speeds greater than 0.2m per second may be perceived as drafty. In hotter conditions (with a corrected effective temperature of more that 24°C) air speed of 0.2 to 0.5m per second will aid body cooling, particularly when the relative humidity is high. It is apparent that whether or not air movement is perceived as an irritating draft or a cool breeze depends on the ambient temperature and the relative humidity.

5.2 Discussion on Temperature

From the finding data, P6 shows the highest temperature compared to the others, which is 33.8°C. This is because P6 is near to the cooking area. P5 shows the lowest temperature, which is!6.7°C because P5 is near to the freezer. The temperature for the bread processing area (PI, P2 and P3) is quite high, around 31°C. According to the QC Officer, Mr.Zulhilmi, if the temperature is too low during the processing bread, it will affect the quality of the bread and will caused the existing of fungus earlier. According to the Figure 2.2, if the temperature in the range of 30°C to 40°C, it will cause uncomfortable situation to the employees. If the temperature in the range of 16°C to 20°C, it also will cause slightly uncomfortable situation to the employees.

5.3 Discussion on VOCs

From the data findings, it shows that the processing area without air conditioning system has more influences of VOCs which are at Bread Processing Area (PI, P2 and P3), Processing Area 3-Cooking (P6) and Bread Packaging Area (P9). While at air conditioning processing area, it was almost free from the isobutylene gas, means that it also free from VOCs. P6 shows the highest contain of isobutylene gas because it is the area for cooking including roasting satay, frying kebab and melting cheese. The smoke and heat resulted from the process caused the gas to exist. Anthropogenic sources of isobutylene can result from combustion of fossil fuels and losses from gas plants and refineries. For PI, P2 and P9, the contain of VOCs was quite high during the production because this gas had existed from the antioxidants from bread packaging process. According to [12], approximately 17% is used for the production of antioxidants for food, food packaging, supplements and for plastics. P3 had shown the influence of chemical detergent can exposed the area with VOCs.

Processing area for satay and kebab packaging and sticking satay was totally free from isobutylene gas except for the end of measurement processes at P8 because air conditioning system will absorb indoor air, compress it and produce cool air. While air absorbing process take place, it absorb the contain of all air inside the room including VOCs. So the rooms are expected to be very clean and suit to production process as needed.

5.4 Conclusion

As a conclusion, after the study of indoor air quality for VOCs, velocity of the air and the temperature in production area of Food Industries, the result shown that the content of VOCs in the production area will not affect the safety and health of the employees because the content of the parameter of VOCs.

In term of air velocity, only the bread processing area shows the low ventilation rate and causes a sensation of staleness and stuffiness. The temperature of the cooking area, filling and packaging also cause a slightly uncomfortable situation to the employee.

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Evaluation of the Indoor Air Quality in Swimming Pools

A. Matos [1], S. Alves[1], M. Elisa Duarte [2], P. Pacheco [3] and A. F. Pires [1]

[1]CRSPLVT, Av. dos EUA, 53, 1700 LISBOA, Portugal
Email: antoniomatos@arslvt.min-saude.pt
[2]SRS Setúbal, Av. dos Combatentes da Grande Guerra, 91, 3º Dto. 2900 SETÚBAL, Portugal
[3]SRS Lisboa, Av. dos EUA, 75, 1700 LISBOA, Portugal

Summary: *The study "Evaluation of the Indoor Air Quality in Swimming Pools" has been developed in 7 swimming pools of the Região de Lisboa e Vale do Tejo. The aim of this study is to relate the concentrations of trihalomethanes and chloramines in the air with the disinfectant used in the water treatment and other environmental variables. The project includes two components: environmental and human. The first component considers the characterization of the pool and the evaluation of some environmental parameters. The human component includes the pool's appreciation by workers and users in what concerns the environmental conditions and its effects on health.*

Keywords: *swimming pool, indoor air quality, disinfectant, trihalomethanes, chloramines, health risk.*
Category: *Indoor Air Quality (IAQ) / Indoor Climate*

1 Introduction

The increasing number of indoor pools and the consequent increase of the exposed population - users and workers - urges the necessity to evaluate the indoor environment and its effect on health.

To minimize the impacts it is of great importance the evaluation of the agents that may represent risks on health. For some years, the evaluation of water quality has been made, nevertheless the indoor air quality and the knowledge about surfaces hygiene is still very incomplete.

Although the existing health and well being benefits, pools are also a source of health risks for users and workers. Users are those who mainly contribute to those risks. Once their elimination is not possible, technical measures must be carried out in order to minimize health effects. These measures include treating the water, renewing the atmosphere and cleaning the surfaces. In fact, users introduce in pools not only bacteria and others microorganisms they carry, but also chemicals, such as nitrogenous compounds. This water contamination is caused through user's skin, secrecies and body fluid from several human origins. In order to minimize microbiological risks, disinfection of water is extremely necessary.

Chlorine and bromine are usually used as disinfectants because of their efficiency and easy operation and control. Nevertheless, these disinfectants originate substances potentially dangerous for health such as trihalomethanes (THM) chloramines and bromamines, disinfection byproducts.

Because their volatility those chemicals formed in water are transferred to atmosphere. The evaporation from liquid to air depends on the disinfectant vapor pressure, its concentration and solubility on water, water temperature and water turmoil caused by users. The exposition to these disinfection byproducts depends mainly from the ventilation system efficiency.

Byproducts formation should be minimized by the control of the precursors substances in water through the adoption of good practices of individual hygiene and daily water renewal.

The mechanisms of THM formation as byproducts of water disinfection are long known through studies concerning drinking water.

The reaction of chlorine against several nitrogenous precursors organic molecules, possibly originated by urine and sweat, results on their fragmentation and bonding between chlorine and carbon in different positions. In that way, formation of several different molecules such as chloroform, bromoform, bromodichloro-methane dibromochloromethane and many others takes place, being chloroform ($CHCl_3$), the one that forms in greater quantity, although bromoform is more relevant in seawater pools. While bromamines quickly degrades into inert products and are not aggressive to skin and mucosa, chloramines have irritant effect on eyes, nose, pharynges and lungs and a characteristic and unpleasant smell.

Man absorption of those substances and products takes place by done three exposure routes: ingestion, inhalation and dermal contact. Independently of user's activities and permanence time, disinfection products accumulation in atmosphere is a reason for frequent complaints, in some pools. These products should be removed from atmosphere through adequate ventilation. However, climate conditions and air treatment – heating, cooling and dehumidification – can contribute to its accumulation in closed spaces, resulting on complaints and health problems.

Irritation of respiratory track mucosa, ears and eyes are known on short-term exposition; studies about long-term exposition (prolonged and repeated exposition) to those products are yet subject of discussion, such as hepatotoxy and kidney effects.

Chronic effects related to the presence of chlorine byproducts on air, such as bronchial hyper-reactivity permanent or transitory are also in study.

On the other hand, annoyance effects resulting from accumulation of these products in atmosphere, like ocular irritation and unpleasant chlorine smell, are well known [1].

The aim of the study consist on the evaluation of air quality in indoor swimming pools, in what concerns volatile organic compounds such as TMH and chloramines. Also there is an intention on the collection of users and workers information about their appreciation of the pool and its influence on their health and welfare and the relation between those two components.

- Environmental – evaluation of trihalomethanes and chloramines concentration in the air.
- Human – workers and users assessment on their health and welfare.

The project has been developed in partnership with Instituto Nacional de Saúde Dr. Ricardo Jorge who made the determination of the referred substances and was financed by Fundação Calouste Gulbenkian.

2 Material and methods

Sampling dimension and pools characterization

From a universe of 306 public pools (municipals, sport clubs, schools, tourism, health clubs), from which 156 are indoor, included on the "Programa de Vigilância Sanitária das Piscinas de Utilização Colectiva de Lisboa e Vale do Tejo" in 2003, six indoor pools were chosen for this study, two in each district: Lisboa, Santarém and Setúbal.

The selection was made concerning different criteria, such as ventilation, water treatment, existence of indoor air quality complaints, geography and THM concentration in water. In table I the characteristics of the chosen pools are presented.

Table 1 Selected pools characterization

Distrito/ Pool		Nr of workers	Dimensions (m)	Disinfectant	Daily users (average)
Lisboa	1	24	25×12.5	Chlorine	300
	2	33	25×20	Chlorine	680
Santarém	3	34	25×12.5	Chlorine	300
	4	20	16.5×10	Chlorine	180
Setúbal	5	8	16×7.5	Chlorine	80
	6	1	5.5×3	Bromine	6
	7	12	r. 7.5	Bromine	20

Pool nr. 7 was added later to the study because nr.6 was closed and lost all users.

Equipment and sampling material

Methodology for sampling and analysis of THM and chloramines followed the recommendations from *National Institute of Occupational Safety and Health* (NIOSH) and from *Institut National de Recherche et de Sécurité* (INRS), respectively.

Environmental analysis consisted on the collection of air samples using low flow pumps. Collectors used depended on the chemical substance in study, having been used:

- Chloramines: quartz fiber filters and silica gel tubes with sulfamic acid;
- THM: Activated coal tubes from SKC, ref^a 226-01.

Sampling pumps were calibrated before used with flow adjusted for 1 l/min for chloramines and 0.2 l/min for THM sampling.

Air temperature and relative humidity were determined with temperature humidity meters.

Concentration of free residual disinfectant in water was also determined with photometers or comparators.

Sampling and analytical methodology

Sampling was taken place monthly between August 2003 and November 2005, in a total of 487 samples for chloramines and 462 for THM. They were done at four distinct points, as near as possible from the pool in study in order to represent all pool's area. Sampling point's high was between 1 and 1.5 meter from floor.

Sampling time was about 60 minutes for chloramines and 90 to 120 minutes for THM.

In each sampling, air temperature and relative humidity were determined. During air sampling, temperature, pH and concentration of free residual disinfectant were determined in pool water.

Analytical methods used for the quantification of chloramines and chlorine compounds were methods 007 and 009 from file *Métropole* from *Institut National de Recherche et Sécurité de France* (INRS). Analytical techniques used were ionic chromatography and potenciometry with residual chlorine electrode for chloramines and chlorine compounds, respectively.

For the determination of THM concentration, the used method was based on *Manual of Analytical Methods* from NIOSH - "*National Institute for Occupational Safety and Health*"– 1003 4th edition, Revision of March 2003. It was used a gas chromatograph (*Agilent Technologies* 6890N) with capillary column, with FID detector.

Evaluation criteria

Although reference values are not yet established for chloramines and THM in pool's atmosphere, World Health Organization (WHO) presents, for projects and ventilation systems operation, the following concentration of THM in air, for concentrations determined at a distance of 150 cm above the water surface: 136µg/m^3 for a worst case scenario, 36µg/m^3 for an moderate exposure scenario and 33µg/m^3 for a low exposure scenario, concerning absorbed doses by inhalation [1].

WHO considers that data that would permit to establish guidelines for trichloramines concentrations in air doesn't exist. In what concerns occupational health, documents published in review of INRS consider as comfort value 0.5mg/m^3 as NCl_3 for longtime exposition (equivalent to VME) and 1.5mg/m^3 as NCl_3 for short time exposition (equivalent to VLE). [2]

Human component

The perception of the occupants on the swimming pool (users and workers) can be a tool to evaluate the environment conditions, through the identification of the main complaints and associated symptoms.

The main goal of this component of the study is to evaluate the indoor air quality of the swimming pools comparing it with the opinion of users and workers and its auto-evaluation of presented symptoms.

It was followed a methodology seats in the application of satisfaction questionnaires. These questionnaires were of auto fulfilling and voluntary participation, having for base the questionnaire "Örebro"[3], with adaptations. The questionnaires were previously tested.

Every questionnaire includes questions related with:

- Individual data;
- Users appreciation about pool, showers, locker rooms and others facilities;
- Workers appreciation about work conditions;
- Water and air quality;
- Health symptoms related with pool's use;
- Other comments.

After the application of the questionnaires a final sample of 88 workers was got (67% of the workers of the 6 swimming pools) and 454 users (30% of the daily average number of users from the 6 swimming pools).

Details of this study are presented in a poster at this conference.

3 Results

Data presented concerns a preliminary evaluation of air analysis and human questionnaires. At the moment, statistical analysis is still being developed; nevertheless it is possible to present the following results.

In figure 1 the values obtained for THM in each pool during study are presented and compared with WHO reference values in similar conditions to this study of 136µg/m^3 and 33 µg/m^3 for worst case and low exposure scenario.

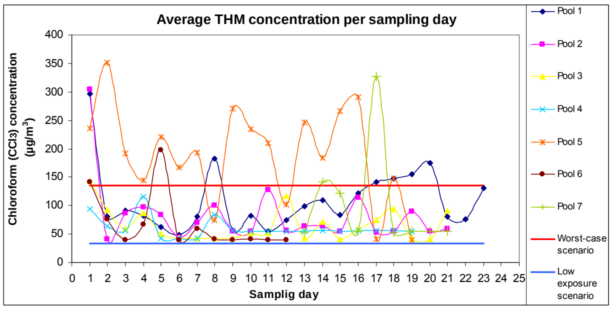

Figure1 - average THM concentration per sampling day

In figure 2 the values obtained for chloramines in each pool during study are presented and compared with INRS reference values in similar conditions to this study of 0.5mg/m^3 as NCl_3 and 1.5mg/m^3 as NCl_3 for high and low exposition respectively.

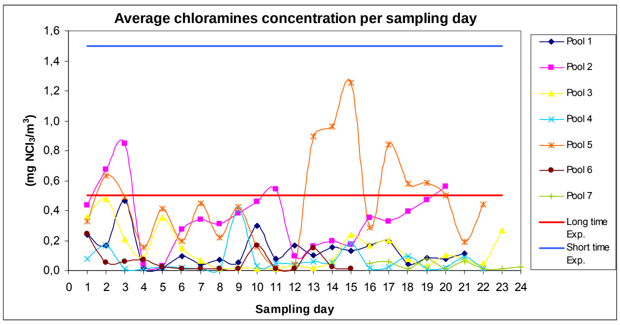

Figure 2 - average chloramines concentration per sampling day

For each pool and for each evaluated parameter (THM and chloramines) it is presented, in tables 2 and 3, the number of determinations, the average (mean), the median, maximum and minimum values and percentiles 25 and 75.

Table 2 THM results (µg/m^3)

Pool	Obs (n)	Mean	Std. Dev.	Median	Min	Max	Percentile	
							25	75
1	91	109.2	63.0	90.0	36	356	58	139
2	84	82.1	61.0	55.0	31	371	54	83
3	84	65.7	31.8	45.5	41	174	42	84
4	76	60.5	19.5	56.0	42	167	55	56
5	57	190.0	92.1	210.0	39	406	115	258
6	34	69.8	73.6	41.0	39	420	40	80
7	36	101.4	95.6	54.5	52	465	53	103

Table 3 Chloramines results (mg/m^3)

Pool	Obs (n)	Mean	Std. Dev.	Median	Min.	Max.	Percentile	
							25	75
1	84	0.132	0.133	0.10	0.01	0.68	0.04	0.17
2	80	0.354	0.224	0.35	0.01	0.98	0.18	0.51
3	92	0.134	0.147	0.08	0.01	0.70	0.03	0.21
4	86	0.061	0.087	0.02	0.01	0.44	0.01	0.08
5	66	0.458	0.335	0.39	0.01	1.52	0.19	0.63
6	43	0.066	0.102	0.01	0.01	0.46	0.01	0.07
7	36	0.034	0.036	0.01	0.01	0.14	0.01	0.05

In tables 4 and 5 it is presented per pool, the percentage of workers and users complaints in what concerns both environmental and symptoms parameters. The environmental parameters valued were:

- Air temperature too high.
- Air temperature too low.
- Humidity in excess.
- Unpleasant smells.

Valued symptoms were:

- Eyes irritation and itching.
- Nose and throat irritation.
- Skin irritation, itching, and dryness.

Table 4 workers complaints

Pool	Workers		
	n (% answers)	environ. parameters % complaints	symptoms parameters % complaints
1	16 (42.4)	53.1	37.5
2	14 (66.7)	85.7	81
3	30 (88.2)	66.7	54.4
4	15 (75)	23.3	46.7
5	8 (100)	90.6	100
6	-	-	-
7	5 (41.7)	30	60

Table 5 users complaints

Pool	Users		
	n (% answers)	environ. parameters % complaints	symptoms parameters % complaints
1	132 (65.5)	37.7	26.5
2	177 (57.5)	37.7	27.9
3	100 (71.4)	47.3	25.3
4	32 (53.3)	11.7	26
5	9 (25.7)	36.1	25.9
6	-	-	-
7	4 (13.3)	18.8	7.7

Figures 3 to 14 present, for each pool, the variation of THM and chloramines compared with air parameters: relative humidity and air temperature.

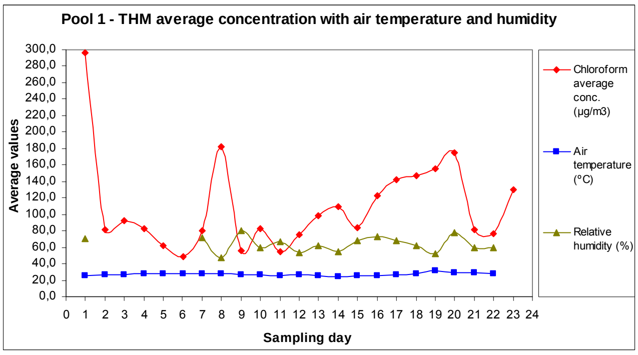

Figure 3 - pool 1 average THM concentration with environmental parameters

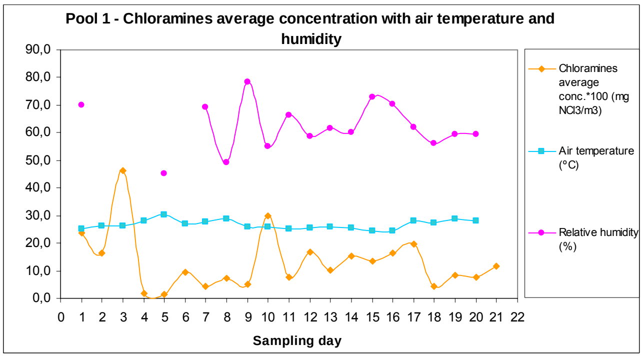

Figure 4 - pool 1 average chloramines concentration with environmental parameters

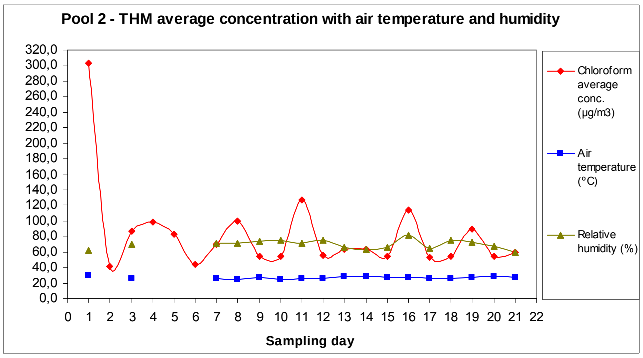

Figure 5 - pool 2 average THM concentration with environmental parameters

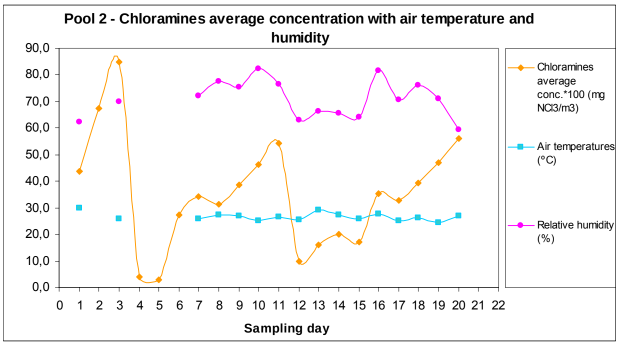

Figure 6 - pool 2 average chloramines concentration with environmental parameters

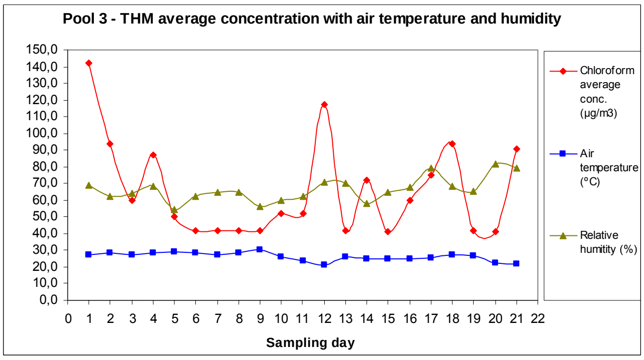

Figure 7 - pool 3 average THM concentration with environmental parameters

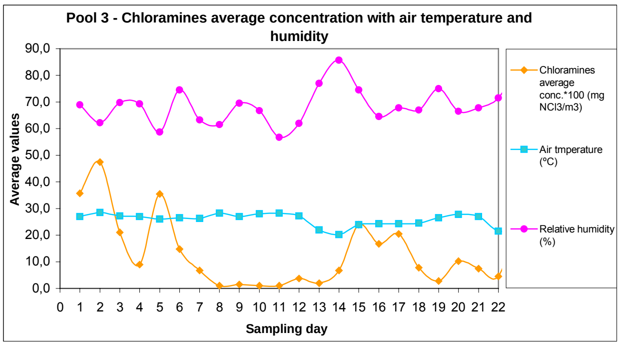

Figure 8 – pool 3 average chloramines concentration with environmental parameters

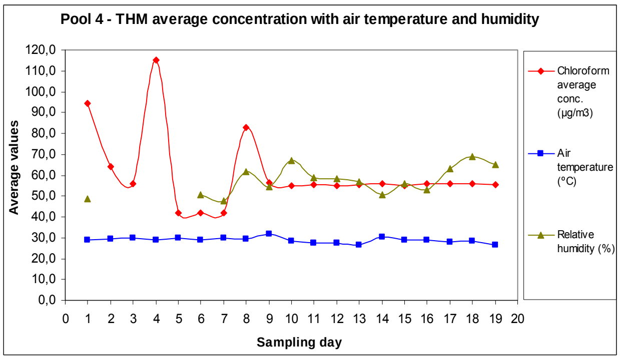

Figure 9 - pool 4 average THM concentration with environmental parameters

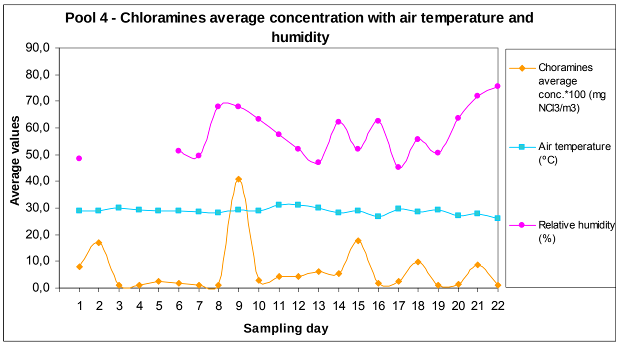

Figure 10 - pool 4 average chloramines concentration with environmental parameters

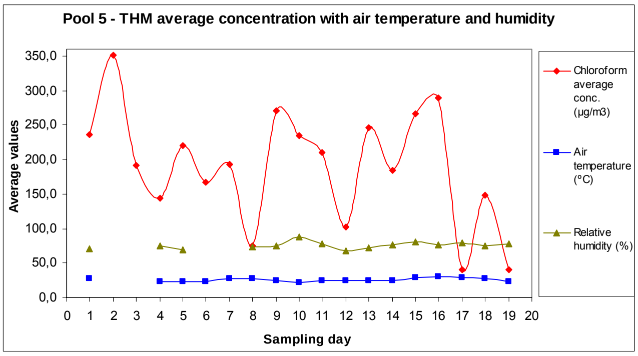

Figure 11 - pool 5 average THM concentration with environmental parameters

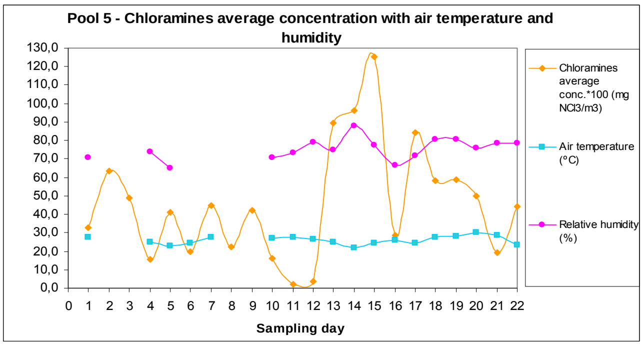

Figure 12 - pool 5 average chloramines concentration with environmental parameters

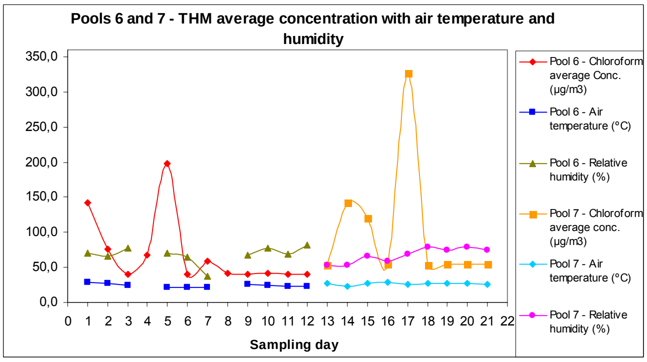

Figure 13 - pools 6 and 7 average THM concentration with environmental parameters

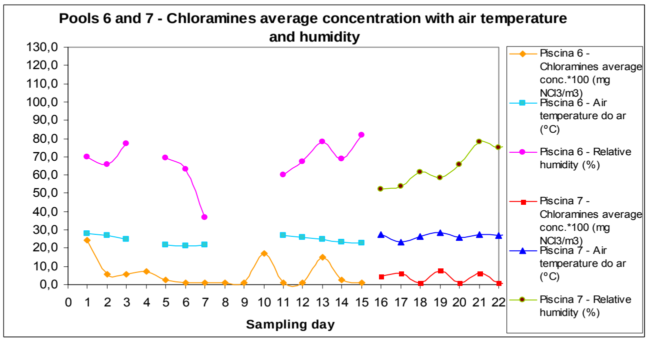

Figure 14 - pool 6 and 7 average chloramines concentration with environmental parameters

4 Conclusions

In all pools the THM average concentration is higher than WHO reference value for low exposure scenario; concerning the worst case scenario, only two of them have never exceeded the reference value. At pool 5, 80% of sampling results were higher than this reference.

In what concerns chloramines average concentrations the results are better as none is higher than the limit value recommended by INRS for short time exposition. Only pools 2 and 5 exceed in 20% and 32% the long time exposition value respectively.

It is possible to observe that in pool 5, average concentrations, median and percentiles of THM and chloramines are higher than all other pools.

Nevertheless the questionnaires application subjectivity, it is possible to conclude that pool 5 presents the higher percentage of workers complaints in what concerns environmental and symptoms parameters. This result agrees with THM and chloramines observed values and with the structure of the building where the pool is located: a basement with high patronage and deficient ventilation.

Concerning users motivations (sporting, social and leisure) and their short permanence time in the pool, when compared with workers, users complaints percentage is less relevant not only in terms of environmental but also as physical complaints.

In what concerns figures 3 to 14, that show for each pool the relation between THM and chloramines average concentration and the environmental parameters (temperature, relative humidity) it is not evident the relation between those variables.

Nevertheless, as told before, the statistical analysis is being developed at moment so it is precipitated to take any conclusions. In fact, those concentrations depend on several factors such as structural conditions of the buildings, ventilation systems, user's number, operation and maintenance of the pool, and so on.

For future work it will be important to establish how the evaluation of the studied parameters is related to deficient operational conditions. The knowledge of the workers and users appreciation of the swimming pool, also allows the manager to verify the effectiveness of the prevention and corrective actions.

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Exposure to Biological Agents and Children Health

Ljiljana Stosic[1], D. Nikic[2], M. Nikolic[2], S. Milutinovic[1], A. Stankovic[2]

'Public Health Institute Nis, 50 Dr Zorana Djindjica Avenue 18000 Nis Serbia and Montenegro [2]University of Nis, School of Medicine, 81 Dr Zorana Djindjica Avenue 18000 Nis Serbia and Montenegro
email: skorpia@bankerinter.net

Summary: *The objective of this investigention was to estimate the effects of the biological agents on the prevalence of respiratory symptoms and diseases as well as the prevalence of nonspecific symptoms on different organs at children. 1074 children aged 7-11 years from three primary schools in Nis (Serbia And Montenegro) were studied. A standard questionnary prepared by WHO was used. It is established that children were exposed to difference sources of pollutants in own homes. The presence of insects and rats in households was the most significant risk factor for all the symptoms and diseases which were estimated.*

Keywords: *biological agents, children health*
Category: *Anamnestic retrospective study*

1. Introduction

Biological air pollutants are found to some degree in every home, school, and workplace. Sources include outdoor air and human occupants who shed viruses and bacteria, animal occupants (infects and other arthropodes) that shed allergens, and indoor surfaces and water reservoirs where fungi and bacteria can grow, such as humidifiers [1]. A number of factors allow biological agents to grow and be released into the air. Especially important is high relative humidity, which encourages house dust mite populations to increase and allows fungal growth on damp carpet [2-4]·

Biological agents in indoor air are know to cause three types of human disease: infections, where pathogens invade human tissues; hypersensitivity diseases, where specific activation of the immune system causes disease; and toxicosis, where biologically produced chemical toxins cause direct toxic effects [5]. In addition, exposure to conditions conducive to biological contamination (e.g., dampness, water demage) has been related to nonspecific upper and lower respiratory symptoms [6].

The objective of this investigention was to estimate the effects of the biological agents on the prevalence of respiratory symptoms and diseases as well as the prevalence of nonspecific symptoms on different organs at children.

2. Method

The study sample consisted of 1074 children aged 7 -11 years from three primary schools in Nis (Serbia And Montenegro). A standard questionnary prepared by WHO was used. Training physicians have filled out qestionnary in directly interview with parents of children. Investigation was done during the six months (since January to June 2004)

The first group of questionnary consisted of the questions about risk factors in child's home (for example: heating in living room, passive smoking, keeping pets). Socio-economic status (parents education, number persons in household) was considered too. We paid attention on the presence biological agents at home. Positive answers which were given on questions: "Have you got any pets at home?", "Have you got problems with insects and rats in househould?", "Do you have too much textile materials (carpets, curtains, covers) at home?", "Have you got old mattress on your bed?" meant that child had been exposed to biological agents.

The second part of the questionnary was about prevalence of respiratory symptoms (nasal congestion, nasal secretion, dyspnea, wheezing, cough), respiratory deseases (sinusitis, bronchitis, asthma, pneumonia) and nonspecific symptoms (watery eyes, dry throut, headache, fatigue) in children in the past 12 months. Respiratory diseases were diagnosed by physician.

All the collected data were taken in and done in software system. All children were divided in a group of exposed to biological agents and a group of nonexposed. In bouth of them, prevalence of symptoms and disease were analysed. Interview data were analysed using programmes Epiinfo 6 and Microsoft excel. Statistical significance between prevalence of symptoms and diseases in children exposed and children nonexposed to biological agents is established by Pearson Chi-Squared test. The odds ratio and 95% confidence intervals were calculated to evaluate the presence of associations between all symptoms and diseases in the children and environmental variabiles.

3. Results

In sample of this investigation, 554 (51.60%) were boys and 520 (48.40%) were girls. Mean age was 9.067 (SD ±1.297) for boys and 9.096 (SD ±1.233) for girls(Table1).

Table 1 Caracteristics of the Study Population

SEX	Number (%)	Mean age
Male	554 (51.60)	9.067 ±1.297
Female	520 (48.40)	9.096 ±1.233

Almost 20 % of children have kept pets in household. Most of the children with pets have kept birds.

23.74 % of children lived in homes which had problems with insects or rats.

Large amounts of textiles materials, which are good sources of dust mite, had more than 48.70 % of children, and 23.37 % had old mattress (more than seven years old).

Table 2 Children exposure to different sources of biological agents

Sources of biological agents	**Presence**
Keeping pets	200 (18.62%)
Insects and rats	255 (23.74%)
Much amounts of textile materials	523 (48.70%)
The old mattres	251 (23.37%)

Efects of biological agents on children health

It isn't established positive relationship between keeping of pets and health (Table 3), except nasal congestion (OR-1.51; 1.00 to 2.29).

Table 3 Exposure to allergens of pets and influence on the children health

Symptoms and diseases	exposed	nonexposed	$\chi2$	OR	CI	
nasal congestion	165	662	4.2*	1.51	1.00 -	2.29
nasal secretion	115	443	3.03	1.32	0.95 -	1.82
dyspnea	29	115	0.25	1.12	0.70 -	1.77
wheezing	62	258	0.17	1.07	0.76 -	1.52
cough	35	171	0.45	0.87	0.57 -	1.33
sinusitis	3	25	1.19	0.52	0.12 -	1.82
bronchitis	74	288	1.19	1.19	0.86 -	1.67
asthma	9	22	2.28	1.82	0.77 -	4.24
pneumonia	25	112	0.01	0.97	0.59 -	1.58
watery eyes	31	126	0.15	1.09	0.69 -	1.7
dry throut	40	167	0.08	1.06	0.71 -	1.58
headache	71	279	0.95	1.17	0.84 -	1.64
fatigue	67	285	0.06	1.04	0.74 -	1.46

* $p<0.05$

The presence of insects (coakroaches) and rats in households was a significant risk factor for all the symptoms and diseases which were estimated besides for asthma and pneumonia (Table 4).

Table 4 Exposure to allergens of insects and rats and the influence on the children health

Symptoms and diseases	exposed	nonexposed	$\chi2$	OR	CI	
nasal congestion	210	617	5.41*	1.53	1.05 -	2.22
nasal secretion	158	400	13.41*	1.71	1.27 -	2.3
dyspnea	52	92	14.05*	2.02	1.37 -	2.99
wheezing	99	221	13.03*	1.72	1.26 -	2.33

cough	69	137	13.39*	1.85	1.31 -	2.61
sinusitis	12	16	5.8*	2.48	1.09 -	5.62
bronchitis	114	248	18.11*	1.86	1.38 -	2.51
asthma	9	22	0.49	1.33	0.56 -	3.07
pneumonia	40	97	2.58	1.38	0.91 -	2.1
watery eyes	57	100	16.03*	2.07	1.42 -	3.02
dry throut	70	137	14.37*	1.88	1.33 -	2.66
headache	105	245	11.23*	1.64	1.21 -	2.22
fatigue	112	240	18.86*	1.89	1.4 -	2.55

* $p<0.05$

The large amounts of textiles indoor act as significant reservoirs of irritants and allergens and have impact on the indoor air quality and health of the exposed. Children with much textile materials in home environment have higher risk for appeareance of nasal congestion (OR-1.57; 1.17 to 2.12), wheezing (OR-1.33; 1.02 to 1.75), and nonspecific symptoms (fatigue OR-1.57; 1.21 to 2.05 and dry throut (1.41; 1.03-1.93). Children with asthma didn't have the large amounts of textiles in home. Data are showed in Table 5.

Table 5 Exposure to allergens from textile materials and influence on the children health

Symptoms and diseases	exposed	nonexposed	χ2	OR	CI	
nasal congestion	424	403	9.53*	1.57	1.17 -	2.12
nasal secretion	279	279	0.79	1.11	0.87 -	1.43
dyspnea	66	78	0.55	0.88	0.61 -	1.26
wheezing	172	148	4.66*	1.33	1.02 -	1.75
cough	102	104	0.07	1.04	0.79 -	1.43
sinusitis	12	16	0.39	0.79	0.35 -	1.77
bronchitis	183	179	0.75	1.12	0.86 -	1.45
asthma	9	22	4.94*	0.42	0.18 -	0.97
pneumonia	63	74	0.46	0.88	0.61 -	1.28
watery eyes	83	74	1.28	1.22	0.85 -	1.73
dry throut	115	92	4.83*	1.41	1.03 -	1.93
headache	182	168	2.27	1.22	0.93 -	1.58
fatigue	198	154	11.96*	1.57	1.21 -	2.05

*$p<0.05$

The old mattress were significantly associated with respiratory symptoms (nasal congestion OR-1.77; 1.20 to 2.62; nasal secretion OR-1.54; 1.15 to 2. 08; dispnea OR-1.79; 1.20 to 2.62; wheezing OR-1.44; 1.06 to 1.97; cough OR-1.64; 1.16 to 2.33), bronchitis (OR-1.39; 1.02 to 1.88), and nonspecific symptoms (watery eyes OR-2.05; 1.41 to 3.00; and dry throut OR-1.49; 1.05 to 2.12). Table 6 shows statistical significance of differences between an exposure to biological agents from old mattres and children health.

Table 6 Exposure to biological agents from old-time of mattress (more than 7 years) and influence on the children health

Symptoms and diseases	exposed	nonexposed	χ2	OR	CI	
nasal congestion	211	616	9.22*	1.77	1.20 -	2.62
nasal secretion	151	407	8.83*	1.54	1.15 -	2.08
dyspnea	48	96	9.22*	1.79	1.20 -	2.66
wheezing	90	230	5.75*	1.44	1.06 -	1.97

cough	64	142	8.43*	1.64	1.16 -	2.33
sinusitis	9	19	1.24	1.57	0.65 -	3.72
bronchitis	99	263	4.82*	1.39	1.02 -	1.88
asthma	10	21	1.41	1.58	0.69 -	3.59
pneumonia	37	100	1.16	1.25	0.82 -	1.91
watery eyes	56	101	15.53*	2.05	1.41 -	3.00
dry throut	61	146	5.32*	1.49	1.05 -	2.12
headache	85	265	0.24	1.08	0.79 -	1.47
fatigue	86	266	0.33	1.09	0.80 -	1.49

* $p<0.05$

4. Discussion

We identified the significant effects of exposure to biolodical agents on exposed children health in this study.

Biological agents from pets didn't have any impact on children health in our investigation. Nasal congestion was only a symptom which established significantly difference. This symptom can be part of allergic rhinoconjunctivitis which is oftener occurs in children exposed to pets [7]. Results of the other studies show that the largest influence on health have dogs and cats. In our sample the most number of children have kept birds. It is probably a reason for these defferent results.

The effects of pet-keeping in childhood varied according to the type of pet, the allergic sensitization of the individual, and the wider environmental exposure to allergen. Domestic animals such cats, dogs, birds and rodents may cause allergic asthma and rhinoconjunctivitis [1].

The great part of total indoor biological air pollution, besides pets, have insects, rats, and dust mites. It is established that excrets of insects and rats as well as parts of their body, have very important allrgen's characteristics [8-10]. The domestic cockroach has been identifed as an important source of indoor aeroallergens worldwide. The results of this investigation show that presence of insects and rats at homes of children is very important risk factor for the all examined symptoms as well as respiratory diseases (sinusitis and bronchitis). Incrising prevalence of asthma isn't established, but symptoms which caracteristic for asthma (wheezing, dyspnea and cough) are more frequent in exposed children. Recent studies suggest that the increase morbidity and mortality for asthma and alergies, may be due to an increase in exposure to allergens in the modern indoor environment. Indoor allergen exposure is recognised as the most important risk factor of asthma in children [8-10].

Investigation in New England showed that cockroaches were in more than half homes and children who lived in homes with cockroaches had asthma three times more than the others [11] Litonjua and colleagues showed that exposure to cockroach allergen early in life may contribute to the development of asthma in susceptible children [12].

The major allergen in house dust is derived from mites, and a recent review concluded that the environmental control of allergens should be an integral part of the menagment of sensitised patients. Mite allergens are present on larges particles in beds, soft furnishings, and carpets, which become airborn only after vigorous disturbance and settle quickly [5].

In our investigation, it is established that respiratory and nonspecific symptoms more frequent in children which had much amounts of textile materials. Jakkola et all [13] also have examined impact of textile materials on respiratory simptoms and they established that risk for bronhial opstruction was 1.58 (CI-0.98 to 2.54).

Matresses as well as textile materials are very important because they can consist of several thousands to milions of mites, and on the other side the children spend at least eight hours on them. Time of using a matress is very important too. The older matress can consist of more mites [11]. Children who used the older matress (more than seven years old) had more prevalence for all respiratory symptoms, bronchitis and nonspecific symptoms (conjunctival irritation and dry throut).

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Health Risk Assessment of Indoor HAPs in New Apartments

[1]Yoon-Shin Kim, [1]Young-Man Roh, [1]Cheol-Min Lee, [1]Jong-Cheol Kim,
[1]Hyung-Jin Jun, [1]Min-Kyoung Song, [2]Jong-Ryeul Son, [3]Bu-Sun Son,
[4]Won-Ho Yang, [5]Seung-Cheol Hong

[1] Institute of Environment & Industrial Medicine, Hanyang University, Seoul, Korea
[2]Department of Environmental Health Korea University, Seoul, Korea
[3]Soonchunhyang University, Asan, Korea, [4]Catholick University of Daecu, Daecu, Korea
[5]Inje University, Kimhae, Korea
e-mail : yoonshin@hanyang.ac.rk

Summary: This study was accomplished to recognize the present condition of Hazardous Air Pollutants(HAPs) in new apartments and to examine efficiently carcinogenic and non-carcinogenic health effects for residents through health risk assessment from June, 2004 to May, 2005. Target pollutants were 5 carcinogenic HAPs that are benzene, carbon tertachloride, chloroform, 1,2-dichloroethane, and formaldehyde and 7 non-carcinogenic HAPs that are 1,4-dichlorobenzene, 1,2-dichloropropane, ethylbenzene, styrene, toluene, m,p-xyrene, and o-xyrene. Total cancer risk of carcinogenic pollutants for case of male in new apartments was 1.98×10^{-5} and for female was 4.72×10^{-5} exceeded the permitted standards. Total hazard index of non-carcinogenic pollutants for male in new apartments was 7.1×10^{-1} and for female were 1.5, respectively.

Keywords: health risk assessment, HAPs, Monte-Carlo analysis, sensitivity analysis
Category: *Risk assesment in relation to indoor exposures*

1 Introduction

Currently, many studies are being conducted on indoor air pollution because most people spend a lot of time indoors. Furthermore, in most cases, the concentrations of air pollutants are much higher indoors than outdoors[1].

Moreover, people are typically exposed to complex mixtures of volatile organic compounds(VOCs), with hundred or more different compounds present in the indoor air[2].

Especially, concern about indoor air quality(IAQ) is increasing with the advent of sick house syndrome (SHS) in Korea. However, the studies about health effects for indoor air pollutants lack in Korea[3].

The purpose of this study is to perform heath risk assessment to grasp health effect from HAPs and to provide the informaiton of health effect.

2 Methods

2.1. Investigation of HAPs in new apartments.

The objects of this study were 40 new apartments that were under 6 months after construction from June, 2004 to May, 2005.

Target pollutants are 5 carcinogenic and 7 non-carcinogenic HAPs that are benzene, carbon tertachloride, chloroform, 1,2-dichloroethane, and formaldehyde and 7 non-carcinogenic HAPs that are 1,4-dichlorobenzene, 1,2-dichloropropane, ethylbenzene, styrene, toluene, m,p-xyrene, and o-xyrene.

We used personal air samplers(GilAir-3, Gilian, U.S.A.) with Tenax tube(Supelco, U.S.A.) to sample VOCs. Flow rate of sampling was 200ml/min and sampling time was 30 minutes. We analyzed VOCs by GC/MS(HP-5973N / Agilent6890 Inert, U.S.A.). Personal air samplers with 2,4-DNPH cartridges and ozone scrubbers were used to sample formaldehyde with 500ml/min flow rate and 30min sampling time. Sampling points for VOCs and formaldehyde were at bedrooms, living rooms, and kitchens in new apartment.

2.2. Risk assessment

For hazard identification and dose-response assessment, the data of IRIS(integrated risk information system) at U.S. EPA were used[4].

Table 1 shows values of exposure factors for exposure assessment. We used statistical data for exposure factors such as body weight(BW) and average time(AT) from data of Korea Research Institute of Standards and Science and inhalation rate(IR) from U.S. EPA, respectively. Moreover, personal activity pattern, exposure duration(ED) and exposure frequency(EF), was investigated by personal questionnaire.

We assessed health risk assessment that are used index of cancer risk(CR) for carcinogenic HAPs and index of hazard index(HI) for non-carcinogenic HAPs, respectively.

$$CR = LADDs \times CPF$$

where:
CR : cancer risk
LADDs : lifetime average doses(mg/kg-day)
CPF : cancer potency factor

$$HI = ADDs/RfD$$

where:
HI : cancer risk
ADDs : average doses(mg/kg-day)
RfD : reference dose(mg/kg-day)

We performed Monte-Carlo simulation to reduce uncertainty and variety for steps of risk assessment. We simulated 10,000 times by computer software (Crystal ball 2000, Decisioneering, Inc).

Table 1. Values of exposure factors and distributions for risk assessment.

Parameter		Unit	CTE	RME	Distri-bution type	Distribution parameters	Source
Body weight	Male	kg	68.8	71.6	TR	Max:71.6 Min:64.9 Likeliest : 68.8	MOE, 2001
	Female	kg	56.0	61.6	TR	Max:61.6 Min:52.1 Likeliest:56.0	MOE, 2001
Exposure duration	Male	yr	30	70.56	TR	Max:70.56 Min:0 Likeliest:30	MOE, 2001
	Female	yr	30	78.12	TR	Max:78.12 Min:0 Likeliest:30	Survey data
Exposure frequency	Male	min/ day	0.52	0.92	NM	Mean:0.52 SD:0.21	MOE, 2001
	Female	min/ day	1307	1440	NM	Mean:1307 SD:147.9	Survey data
Lifetime	Male	yr	70.56	70.56	Point	70.56	MOE, 2001
	Female	yr	78.12	78.12	Point	78.12	MOE, 2001
Inhalation rate	Male	m^3/ day	20	30	TR	Max:46.32 Min:12.96 Likeliest:34.80	MOE, 2001 Adams.W.S., 1993[5]
	Female	m^3/ day	20	30	TR	Max:66.24 Min:10.32 Likeliest:31.92	MOE, 2001 Adams.W.S., 1993

NM : normal distribution, TR : triangle distribution, SD : standard deviation, Max : maximum, Min : Minimum, MOE : ministry of environment, Korea [6]

3 Results and discussions

3.1. Concentrations of HAPs in new apartments

Table 2 shows concentrations of carcinogenic HAPs in new apartments. I/O ratios of benzene, carbon tetrachloride, chloroform, and 1,2-dichloroethane exceeded 1 that means concentration of indoor is higher than concentration of outdoor for each pollutant. However, it is not significant statistically.

Table 2. Concentrations of carcinogenic HAPs in new apartments. (unit:$\mu g/m^3$)

Pollutant	Site	N	Mean	S.D.	Max.	Min.	p-Value	I/O
Benzene	Indoor	113	5.48	3.17	18.01	0.16	0.267	1.20
	Outdoor	36	4.83	2.52	11.36	0.14		
Carbon tetrachloride	Indoor	97	1.63	0.98	4.68	0.03	0.592	0.91
	Outdoor	30	1.74	1.11	5.26	0.2		
Chloro form	Indoor	104	2.39	1.24	6.32	0.06	0.140	1.35
	Outdoor	31	2.02	1.19	5.55	0.18		
1,2-Dichloroethane	Indoor	98	1.92	1.68	9.42	0.06	0.249	1.22
	Outdoor	30	1.55	0.96	4.13	0.17		
Form aldehyde	Indoor	108	71.70	42.41	210.52	4.66	0.001	6.48
	Outdoor	33	16.27	17.08	91.64	3.1		

I/O : indoor/outdoor ratio

However, for formaldehyde, concentration of indoor was 71.71 $\mu g/m^3$ and outdoor was 16.27 $\mu g/m^3$, respectively also it is significant between them statistically(p=0.001). I/O ration was 6.48. Maximum concentration of formaldehyde is very high level that is 210.52 $\mu g/m^3$.

Table 3 shows concentration of non-carcinogenic HAPs in new apartments. All of I/O ratio for pollutants exceed 1 but only I/O ratio of 1,2-dichloropropane and o-xyrene is significant between concentration of indoor and outdoor statistically. Maximum concentration of Toluene is very high level that is 210.52 $\mu g/m^3$. It is over than the law for indoor air quality in Korea that is 120 $\mu g/m^3$.

Table 3. Concentrations of non-carcinogenic HAPs in new apartments. (unit:$\mu g/m^3$)

	Site	N	Mean	S.D.	Max.	Min.	p-Value	I/O
1,4-Dichloro-benzene	Indoor	61	3.39	1.56	7.19	0.01	0.130	1.04
	Outdoor	18	2.73	1.78	5.66	0.01		
1,2-Dichloro-propane	Indoor	77	2.35	1.53	6.76	0.02	0.001	1.02
	Outdoor	19	2.10	1.38	4.05	0.04		
Ethyl benzene	Indoor	113	22.37	36.10	219.42	0.49	0.034	2.61
	Outdoor	36	9.01	17.47	107.09	0.38		
Styrene	Indoor	111	15.25	30.19	185.86	0.16	0.247	2.36
	Outdoor	35	8.60	27.38	165.17	0.1		
Toluene	Indoor	113	274.62	1075.10	7615.72	1.34	0.089	5.61
	Outdoor	35	45.80	69.20	391.34	0.65		
m+p-Xylene	Indoor	112	24.60	44.07	289.27	0.06	0.056	5.84
	Outdoor	34	9.68	17.52	100.76	0.03		
o-Xylene	Indoor	112	13.95	22.26	148.6	0.43	0.037	2.18
	Outdoor	36	6.00	7.54	44.58	0.4		

3.2. Risk assessment

Cancer risks of carcinogenic pollutants for case of male for benzene, carbon tetrachloride, chloroform, 1,2-dichloroethane, formaldehyde were 7.66×10^{-7}, 4.38×10^{-7}, 9.85×10^{-7}, 8.94×10^{-7}, 1.67×10^{-5} in CTE(central tendency exposure) of point estimation that used mean value of every factor, respectively. Only cancer risk of formaldehyde exceeded “10^{-6}” of permitted standards in US EPA. However, all cancer risks exceeded 10^{-6} in RME(reasonable maximum exposure). Mean of “1×10^{-6}” is that one person can be stricken with cancer among one million people. Especially, the highest cancer risk was formaldehyde that was 1.67×10^{-5}. For case of female, every cancer risk of benzene, carbon tetrachloride, chloroform, 1,2-dichloroethane, and formaldehyde exceeded permitted standards in US EPA.

In the results, cancer risks of female are higher than cancer risks of male for each pollutant because exposure factors of male and female are different in risk assessment such as exposure duration, body weight, inhalation rate, and average time. Even male and female are exposed same concentration of HAPs, they are exposed different period in indoor. Female stayed much times in indoor than male from investigation of activity pattern. Moreover, health effects are not same by sex. Average time of female is longer than male and body weight of male is higher than female. Therefore, cancer risk of female is much higher than cancer risk of male for these factors commonly.

Table 4. Cancer risk for carcinogenic HAPs in new apartments.

Sex	Pollutants	Cancer risk				
		Fixed point		Monte-Carlo		
		CTE	RME	Mean	Max	Min
Male	Benzene	7.66E-07	8.98E-06	1.68E-06	2.60E-05	9.57E-12
	Carbon tetrachloride	4.38E-07	4.53E-06	8.00E-07	8.71E-06	1.08E-11
	Chloroform	9.85E-07	9.96E-06	1.75E-06	1.89E-05	1.31E-10
	1,2-Dichloroethane	8.94E-07	1.48E-05	1.53E-06	2.39E-05	2.40E-11
	Formaldehyde	1.67E-05	2.94E-03	2.87E-05	4.07E-04	1.14E-09
Female	Benzene	1.83E-06	1.39E-05	5.52E-06	9.11E-05	8.06E-11
	Carbon tetrachloride	1.05E-06	7.03E-06	2.63E-06	2.32E-05	4.59E-11
	Chloroform	2.35E-06	1.55E-05	5.72E-06	4.61E-05	2.17E-11
	1,2-Dichloroethane	2.13E-06	2.30E-05	4.99E-06	7.29E-05	1.80E-10
	Formaldehyde	3.98E-05	3.93E-03	9.40E-05	9.93E-04	8.86E-08

CTE : central tendency exposure,

RME : reasonable maximum exposure

Mean cancer risk of Monte-Carlo analysis for male were 1.68×10^{-6}, 8.00×10^{-7}, 1.75×10^{-6}, 1.53×10^{-6}, 2.87×10^{-5} for benzene, carbon tetrachloride, chloroform, 1,2-dichloroethane, formaldehyde, respectivelly. Every cacner risk is over than permitted standard in U.S. EPA except carbon tertachloride. Cancer risk of Formaldehyde was the highest and about 3 people among 10,000 people can be stricken with cancer from formaldehyde. Mean cancer risk of Monte-Carlo analysis for male were 5.52×10^{-6}, 2.63×10^{-6}, 5.72×10^{-6}, 5.99×10^{-6}, and 9.40×10^{-5} for each carcinogenic HAPs. Every cancer risk including carbon tetrachloride was over than “10^{-6}”. In case of female for Monte-Carlo analysis, every case exceed permitted standard in U.S. EPA. The highest cancer risk is 9.40×10^{-5} from formaldehyde. The worst case of Monte-Carlo analysis is cancer risk of formaldehyde for both of male and female that are 4.07×10^{-4} and 9.93×10^{-4}, respectively. These results exceed “10^{-4}”(Table 4).

Table 5 shows Hazard index for non-carcinogenic HAPs in new apartments. Hazard index for case of male in CTE for 1,4-dichlorobenzene, 1,2-dichloropropane, ethylbenzene, styrene, toluene, m,p-xyrene, o-xyrene were less than permitted standard that is “1” of U.S. EPA, respectively. It means that there are no health effects from non-carcinogenic pollutants to male in new apartment. However, hazard index of 1,2-dichloropropane and toluene for male in RME exceeded “1” that were 1.3 and 2.0, respectively. It means that toxic effect of 1,2-dichloropropane and toluene can be harmful to human but it is not quantitative.

All hazard index for case of female in CTE less than “1”. However, in RME, hazard index of 1,2-dichloropropane and toluene were over than “1” that were 1.7 for 1,2-dichloropropane and 2.6 for toluene in RME. It means that only 1,2-dichloropropane and toluene are harmful to human in new apartment in worst case.

Mean of Monte-Carlo analysis for male and female were less than “1” except 1,2-dichloropropane for case of femal. Hazard index of 1,2-dichloropropane for femal is 2.0. In mean of Monte-Carlo analysis, Only 1,2-dichloropropane is can give health effect to female in new apartments. For the worst case of Monte-Carlo analysis, hazard indexs of 1,2-dichloropropane, ethylbenzene, styrene, toluene, m,p-xyrene exceeded “1”

However, for the worst case of Monte-Carlo analysis, hazard indexs of o-xyrene also over than “1”. It means that female could be taken health effect from these pollutants in new apartment.

Table 5. Hazard index for non-carcinogenic HAPs in new apartments.

Sex	Pollutant	Hazard index				
		Fixed point		Monte-Carlo		
		CTE	RME	Mean	Max	Min
Male	1,4-Dichlorobenzene	2.1E-03	9.3E-03	3.8E-03	4.0E-02	7.4E-08
	1,2-Dichloropropane	3.0E-01	1.3E+00	7.0E-01	8.9E+00	4.5E-05
	Ethylbenzene	1.1E-02	1.2E-01	1.9E-02	2.8E+00	1.9E-06
	Styrene	7.7E-03	1.1E-01	1.2E-02	1.3E+01	3.8E-07
	Toluene	3.5E-01	2.0E+00	3.6E-01	6.1E+01	1.5E-06
	m-p-Xylene	4.3E-02	4.0E-01	9.2E-02	2.5E+01	1.1E-06
	o-Xylene	2.7E-03	1.8E-02	4.0E-03	2.8E-01	3.8E-07
Female	1,4-Dichlorobenzene	4.6E-03	1.2E-02	1.1E-02	8.8E-02	1.4E-07
	1,2-Dichloropropane	6.4E-01	1.7E+00	2.1E+00	2.2E+01	8.8E-03
	Ethylbenzene	2.4E-02	1.5E-01	5.6E-02	8.8E+00	3.6E-05
	Styrene	1.7E-02	1.4E-01	3.7E-02	4.5E+00	8.0E-06
	Toluene	7.5E-01	2.6E+00	9.5E-01	3.3E+02	1.8E-04
	m-p-Xylene	9.3E-02	5.0E-01	2.7E-01	7.9E+01	3.8E-05
	o-Xylene	5.2E-03	2.3E-02	1.2E-02	1.0E+00	5.3E-06

CTE : central tendency exposure,
RME : reasonable maximum exposure

Table 6 shows Total cancer risk in new apartments. Total cancer risk of carcinogenic pollutants for case of male was 1.98×10^{-5} in CTE of point estimation and was showed 2.98×10^{-3} in RME. It means that 2.98 people of male can be stricken with cancer among 1,000 people by target HAPs of this study. This is over than "10^{-4}" which exceeds maximum permitted standard in U.S. EPA and is very high cancer risk level.

Table 6. Total cancer risk in new apartments.

Site	Sex	Total cancer risk				
		Fixed point		Monte-Carlo		
		CTE	RME	Mean	Max	Min
New apart.	Male	1.98E-05	2.98E-03	3.43E-05	3.88E-04	5.63E-07
	Female	4.72E-05	3.99E-03	1.13E-04	1.10E-03	4.52E-06

Mean of cancer risk from Monte-Carlo analysis was 3.43×10^{-5} that exceeded 10^{-6} of permitted standards in US EPA and cancer risk in RME of Monte-Carlo analysis is over than 10^{-4}. For case of female, cancer risk was 4.72×10^{-5} in CTE that exceeded the permitted standards and cancer risk in RME was 3.99×10^{-5} that is higher than cancer risk of male. Both of female cancer risk for point estimation and Monte-Carlo analysis were higher than cancer risk of male that's why, difference of exposure factors for male and female.

Table 7 shows Total hazard index in new apartments. Total hazard index of non-carcinogenic pollutants for case of male was 7.1×10^{-1} that was less than permitted standards of hazardous health effects in CTE. It means this result doesn't have health effects from non-carcinogenic HAPs to male. However, in RME, total hazard index was 4.0 that exceeded "1". Cases of female were 1.5 in CTE and 5.1 in RME. Both of them exceeded "1".

The results of hazard index of Monte-Carlo analysis was 1.2 for Mean for case of male. It is over than "1" of permitted standards. Total hazard indexes of female were 3.4. Both of hazard index of male and female can give hazardous health effects. Moreover, total hazard index in Monte-Carlo analysis were 6.0 for male and 3.8 for female in new apartments.

Table 7. Total hazard index in new apartments.

Site	Sex	Total hazard index				
		Fixed point		Monte-Carlo		
		CTE	RME	Mean	Max	Min
New apart.	Male	7.1E-01	4.0E+00	1.2E+00	6.0E+01	2.7E-02
	Female	1.5E+00	5.1E+00	3.4E+00	3.8E+02	8.9E-02

There were many kinds of uncertainty of assumption of each step for this study. Therefore, we have to reduce them and we must use more exact exposure factors for risk assessment.

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Impact of Attached Garages on Indoor Residential BTEX Concentrations

R.E. Dodson[1], J.I. Levy[1], J.P. Shine[1], J.D. Spengler[1], and D.H. Bennett[1,2]

[1]Harvard School of Public Health, Department of Environmental Health, 401 Park Drive, Boston, MA 02215
email: rdodson@hsph.harvard.edu
[2]University of California, Department of Public Health Science, TB 168, Davis, CA 95616

Summary: *Attached garages can act as potential source areas of volatile organic compounds to indoor residential environments. Integrated concentration measurements of several VOCs were collected over 48 hour periods in residences and in corresponding attached garages at 11 homes around the Boston, Massachusetts area across two seasons. Continuous air exchange measurements were also collected using sulfur hexafluoride. Concentrations of VOCs associated with gasoline were much greater in the garage than inside the house, and there is enough air flow to the home attributable to the attached garage that the attached garages represent a potentially important contribution to indoor VOCs.*

Keywords: *volatile organic compounds (VOCs), indoor air, attached garages*
Category: *Indoor Air exposure*

1 Introduction

Attached garages can contribute to elevated indoor volatile organic compound (VOC) concentrations in residences. Several studies have found an association between elevated VOC concentrations within the home and the presence of an attached garage [1-6]. The potential impact of an attached garage on the main living area may be the result of elevated concentrations within the garage from various sources coupled by infiltration from the garage into the home.

The VOC concentrations within attached garages may be elevated with respect to the primary living area of the home. Attached garages often house cars and other gasoline-powered equipment, which can be a strong source of VOCs such as benzene, toluene, ethylbenzene and xylenes (BTEX). Starting a car within an attached garage as well as the evaporative emissions from a previously running car can lead to increased levels of the BTEX compounds within the garage. A study in Canada evaluated the impact of 'cold start' and 'hot soak' emissions in attached garages on the living area [7]. Graham et al. estimated that between 9 and 85% of the measured VOC concentrations within the home were vehicle emissions infiltration during the test periods. In addition, other gasoline-powered equipment such as lawnmowers and snow blowers and gasoline containers could be stored within attached garages, which could lead to higher, chronic concentrations.

There often exists a pressure and temperature difference between the attached garage and the home that can result in infiltration from the attached garage. Few studies have attempted to quantify the amount of air flow between the attached garage and the home. Fugler et al. found that, on average, 11% of the air leakage within a home comes from the attached garage [8]. Given the anticipated concentrations of BTEX compounds in the garage, this may contribute significantly to indoor exposures.

Little has been done to quantify the relative contribution of attached garages to indoor concentrations of VOCs under typical residential conditions. The aim of this study was to quantify the relative amount of BTEX compounds attributable to the attached garage for homes in the Boston (Massachusetts, USA) area.

2 Methods

Indoor residential air VOC measurements were collected in the primary living areas and attached garages in 11 homes in the Boston area during the summer of 2004 and/or the winter of 2005, as part of the Boston Exposure Assessment in Microenvironments (BEAM) study. The study was designed to estimate exposure under "typical" conditions and so the participants were encouraged to conduct their lives in their normal fashion for the 48 hour sampling period. These 11 homes were a subset of a larger study population of a total of 55 homes.

Each home within this analysis can be separated into three zones. Zone 1 is the area of the home in which the residents live. This zone includes the living area, kitchen, and bedrooms. Zone 2 is defined as the basement area of the home, which is typically not used as a residential space. The final zone is the attached garage, which can either be attached directly to Zone 1 or Zone 2.

VOC measurements were collected actively using triple-sorbent thermal desorption tubes and analyzed using GC/MS according to US EPA

Method TO-17. Two types of perflourocarbon tracers (PFTs) were released in the home: p-methylcyclohexane (PMCH) in Zone 1 and p-dimethylcyclohexane (PDCH) in Zone 2. Measured concentrations of both tracers in each zone were used to calculate air flows within the home. Because the air exchange rate in an attached garage cannot be assumed to be in steady state due to large, sudden changes in air exchange rate during garage door use, a continuous measurement using sulfur hexafluoride (SF6) was used. SF6 was continuously released into the garage via a pressurized dispersion system. After 24 hours of equilibration, two Bruel & Kjaer (B&K) gas monitors were set up to measure for SF6: one monitor was placed in the attached garage while the other was placed in the room within the home immediately adjacent to the attached garage. If the garage was attached to the home via the basement (Zone 2), the monitor was placed in the basement (with one exception); however, if the garage was attached to Zone 1, (and thus was on the same level as the living area), then the monitor was placed in the adjacent room in Zone 1.

Air exchange rates were estimated for the attached garage and between the garage and the home using a dynamic model with discrete time intervals. Concentration profiles were fit using a Bayesian spline model from which slopes (dC/dt) were calculated. The slopes were used in the dynamic mass balance models for air exchange associated with garage. Air flow rates (in units of m^3/hr) were calculated between the attached garage and the adjacent zone over the entire sampling period. The median flow rates were incorporated into steady-state mass balance equations representing the first and second floors of the home (Zone 1) and the basement area of the home (Zone 2) in order to estimate the air flows throughout the home. The flow rate between the garage and adjacent zone was calculated using two different mass balance equations: one estimated the air flow between the garage and the adjacent zone while the other estimated the entire air flow out of the garage. If the calculated air flow between the garage and the adjacent zone was greater than the total air flow out of the garage, which could happen if either zone is not well mixed, then the average of two flow estimates was used and represents a reasonable estimate of the actual flow rate.

Using BTEX concentrations and air flow estimates, the percent contribution of the attached garage on indoor concentrations was estimated. If the attached garage was attached to the home via the basement, then the impact on the indoor environment was adjusted to account for the transport through an intermediate zone using previously estimated air flows. To estimate the impact, the indoor concentration was separated into the contributions from the garage, basement, outdoors and the sources within the indoors. The impact of the garage was assessed as its concentration contribution over the total estimated indoor concentration.

3 Results

The concentration ratios of the measured garage and indoor concentrations were calculated for each home (n=15 across two seasons). The distributions of ratios are presented in Figure 1.

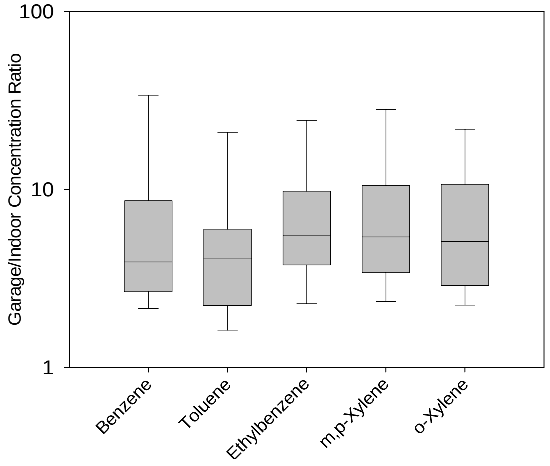

Figure 1. Garage/Indoor Concentration Ratios (n=15) (note: log scale; boxplots provide median and 10th-90th percentiles).

The BTEX concentration ratios are significantly greater than 1, indicating that the measured garage concentrations are significantly higher than the indoor concentrations.

As this study is part of a larger study that also included homes without attached garages, we can look at the impact of an attached garage on indoor concentrations by comparing those homes with (n=15) and without (n=68) attached garages across both seasons. The mean indoor BTEX concentrations in homes with attached garages are significantly higher for each compound than in homes without an attached garage ($p<0.05$), as shown in Figure 2.

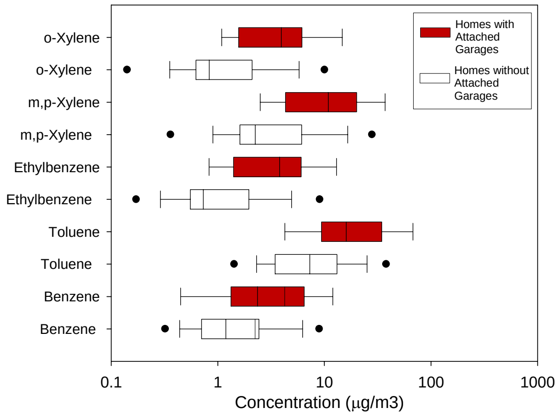

Fig. 2. Indoor BTEX concentrations in homes with (solid) and without (empty) attached garages.

Due to issues with SF6 dispersion, air flows are evaluated in only 9 homes. Median air flow estimates from the attached garage and into the adjacent zone are presented in Table 1.

Table 1. Estimated Median Air Flow from Garage to Adjacent Zone.

Household ID	Estimated Air Flow (m^3/hr)	
	Summer	Winter
Sub 1	49	74
Sub 2	NM	156
Sub 3	0.6	856
Sub 4	NM	89
Sub 5	61	243
Lateral 1	1.4	NM
Lateral 2	23	69
Lateral 3	16	58
Lateral 4	NM	42

Note: NM means 'not measured' (9 shown)
Potential statistical outliers not excluded

The air flow rates from the garage to the adjacent zone tend to be lower in the summer season than in the winter season. Some of the sub garages (below the living area) have large air flows in the winter months suggesting that air is being pulled into the lower levels of the home and circulating up into the living area as a result of a stack effect in the home. The rates tend to be lower for those homes where the garage is laterally attached (on the same level as main living area) instead of below the main living area. We note that only a portion of the air going into the basement then goes into the house in these cases. Also, note that for Sub 3 the monitor was placed in the living area of the home for the summer season and so the median air flow represents the flow from the garage, through the basement, and up into the main living area of the home, which results in a lower value when compared to the other homes.

Using both the measured concentrations and the estimated air flow estimates, the mean and standard deviation (SD) of the percent contribution of BTEX compounds within the primary living zone were calculated and are presented in Table 2.

Table 2. Percent of Estimated Indoor Concentration Attributable to the Attached Garage.

	Sub		Lateral	
Compound	Mean	SD	Mean	SD
Benzene	31	17	50	29
Toluene	23	9	54	22
Ethylbenzene	32	13	62	24
m,p-Xylene	31	13	62	22
o-Xylene	31	16	61	26

Note: Potential statistical outliers not excluded

Due to analytical issues with some of the VOC samples in the summer sampling season, the number of homes evaluated to determine the contribution on the indoor environment is reduced (n_{sub} = 5 and $n_{lateral}$ = 4) and weighted towards winter samples. The impact of an attached garage on the indoor BTEX concentrations is comparable for sub and lateral garages.

4 Discussion

Infiltration of elevated BTEX concentrations from an attached garage can result in significantly higher levels of BTEX within the living area of a home. This is observed by comparing the indoor concentrations measured in homes with and without attached garages. Homes in this study with attached garages had significantly higher measured BTEX compounds than those homes without attached garages. Furthermore, the garage concentrations tend to be much higher than the indoor concentrations, setting up a concentration gradient in the home and the potential for infiltration.

Home design, the orientation of the garage to the living area of the home, impacts the air flow rates to the adjacent zone. The homes in our study with a sub orientation below the home and attached directly to the basement tended to have higher air flow rates than those homes in which the garage was attached directly to the living space. This difference is likely due to a "stack effect" in the home in which air is drawn up from the lower levels. The stack effect is usually enhanced in the winter since the air in the living area is being heated and rising up which then draws air up from the lower levels.

Despite the higher air flow rates into the adjacent zone, the orientation of the attached garage does not appear to significantly affect the impact of the attached garage on the indoor concentrations. This is likely due to the fact that the garage air has to travel through an intermediate zone before entering the living space of the home in cases when garages attached below. Both types of garages account for between 40 to 60% of the indoor BTEX concentrations within a home.

Using a chemical mass balance model and test results from Canada, Graham estimated that 11 to 75% of the garage air infiltrated into the homes during a hot soak test and that 18 to 82% of the garage air infiltrated into the homes during a cold start test [9]. In our study, we found that for lateral garages 1 to 35% while for sub garages 30 to 100% of the garage air infiltrated into the homes. Both studies highlight the variability in the impact of an attached garage.

There are several limitations to this work. The first limitation is the small sample size. A second limitation is related to the assumptions for the mass balance equations; each zone was assumed to be well mixed. If a zone is not well mixed, then the flow rates may not represent the actual flow rates within the home, thus limiting our ability to accurately predict the impact on the indoors.

A strength of this work is the ability to estimate the flow rate between the garage and the living area of the home by measuring SF6 concentrations in both the home and the garage. A recent study conducted with attached garages in Michigan estimated the total air exchange of the garage but was not able to separate out the flow rate between the garage and the home [10]. They, however, found similar results to our study with those garages oriented below the living space having higher air exchange rates.

Since approximately half of the indoor BTEX concentrations result from concentrations within the attached garage, reducing concentrations within the attached garage can greatly reduce indoor concentration levels. Making homeowners aware of the impact of their activities, such as motor vehicle idling and gasoline storage, within the garage can also help reduce concentration levels within the home. Reducing the flow rates between the garage and the home with proper fitting and sealed doors will also help reduce the migration of BTEX concentrations into the home.

5 Acknowledgements

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Semi-Volatile Organic Compounds in Residential House Dust - Potential Human Exposure to Phthalates

J.Zhu and X.Yang

Chemistry Research Division, Health Canada, Ottawa, Ontario, Canada email: jiping_Zhu@hc-sc.gc.ca

Summary: *Levels of phthalates, including di(2-ethylhexyl) phthalate (DEHP), in residential house dust (sieved down to 150 µm) have been measured. In contrast to the patterns in residential air, phthalates in house dust were dominated by DEHP, and other "heavy" congeners. Several unknown chromatographic peaks of phthalates were also observed. Compared with other classes of semi-volatile organics (SVOCs), phthalates had much higher levels in house dust, with a median value for total phthalates approaching 1 mg/g, and a maximum level of 3452 µg/g. Po tential exposure to phthalates through ingestion of dust might be significant, especially for children who intake larger amount of dust on a per body weight basis.*

Keywords*: phthalates, DEHP, human exposure, house dust, residential homes*
Category: *Case Studies*

1 Introduction

House dust is increasingly being recognized as an important source of human exposure to environmental pollutants, especially for children who intake larger amount of dust on a per body weight basis [1]. Phthalates are lipophilic chemicals with vapour pressures similar to those of polyaromatic hydrocarbons and polychlorinated biphenyls. Phthalates are widely distributed in the environment, and have been detected in many different matrices, including various foods, as well as human body tissues and fluids. For indoor environments, the concentrations of phthalates in air are very low because of their low vapour pressure [2]. However, these environmental contaminants may be readily absorbed on surfaces, and accumulated in indoor dusts. For example, a pilot study results based on 6 homes have indicated high levels of phthalates in house dust [3].

In this paper, we are reporting measured levels of phthalates in house dust collected during the winter of 2002/2003 from 56 randomly selected homes in the city of Ottawa, Canada. These houses are a subset of the 75 homes for which we reported the phthalate levels in indoor air [2].

2 Methods

The study design of house selection [4] and procedures for collecting and sieving vacuum bag dust samples [5] have been described elsewhere. 0.3 grams of sieved dust (150 µm) were solvent extracted (hexanermethylene chloride, 1:1) using an Accelerated Solvent Extractor, and further cleaned up through gel permeation chromatography (GPC). The GPC fraction containing phthalates was evaporated down to 1 mL and analyzed by GC/MS in full scan mode (35 - 450 amu) using a HP-5MS capillary column (30 m χ 0.25 mm x 0.25 um) to separate the analytes. Deuterated phthalate, DBP-d4 was used as internal standard.

3 Results

In addition to commonly monitored phthalates such as dimethyl phthalate (DMP), diethyl phthalate (DEP), dibutyl phthalate (DBF), benzylbutyl phthalate (BBP), di(2-ethylhexyl) phthalate (DEHP) and dioctyl phthalate (DOP), several more phthalates were also measured. They were diisobutyl phthalate (DiBP), di(2-ethylhexyl) adipose (DEHA), didecyl phthatlate (DDcP) and Trioctyl trimelitate (TOTM). Table 1 summarizes the levels of these target phthalates in dust samples. Four phthalates that were not previously reported have been detected in dust samples. They are coded as "DOP like", U-l, U-2 and U-3.

The mean and median values of the total phthalates were 989 ± 582 µg/g and 950 µg/g, respectively, with a maximum value of 3452 µg/g. Of the phthalates measured, DEHP was the predominant compound detected in samples with the mean and median values of 521 ± 395 µg/g and 406 µg/g respectively. The maximum value of DEHP was 2500 µg/g. The other major phthalates included BBP, DDcPand U1.

4 Discussion and Conclusion

Compared to the levels of phthalates in indoor air from the same homes where DEP was the principal phthalate [2], house dust was dominated by congeners with lower vapor pressure, such as DEHP and DOP. Similar distribution of phthalate congeners in indoor air and dust was also observed by other research groups [6].

Table 1. Concentrations (μg/g) of phthalates in residential house dust samples (n=56)

	Mean	S.d.	Min	25th	50th	75th	90th	95th	Max
DMP	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.4	1.9
DEP	4.7	5.6	0.0	2.0	3.7	4.9	9.0	12	34
DiBP	5.8	3.8	0.8	3.2	4.2	7.5	9.3	13	17
DBP	28	21	3.8	14	23	33	55	61	85
BBP	102	150	5.5	22	54	124	207	307	961
DEHA	11	12	0.0	6.3	8.9	13	17	19	92
DEHP	521	395	66	265	406	617	928	1060	2500
DOP like	30	41	0.0	0.0	15	43	82	133	153
DOP	45	91	0.0	0.0	0.0	43	205	278	309
DDcP	89	102	0.0	23	55	136	256	345	408
TOTM	1.6	7.9	0.0	0.0	0.0	0.0	0.0	0.0	30
U1	97	195	0.0	0.0	0.0	95	439	593	675
U2	28	49	0.0	0.0	0.0	54	81	135	205
U3	24	48	0.0	0.0	0.0	45	88	141	194
Total	989	582	129	570	950	1265	1770	1915	3452

A “DOP like” compound eluted with almost the same retention time as DOP (*m/z* 149, 261/279), but its characteristic ions were m/z 247, 265, 275 and 293, corresponding to a possible C7/C9 phthalate ester [6]. U1, U2 and U3 eluted closely to each other at around 36 min (Fig. 1.), between DOP (RT = 32.7 and DDcP (RT = 40.8). The molecular weight of U-1 was confirmed by a positive chemical ionization mass spectrum to be 418.6. Its electron impact MS produced characteristic ions of m/z 261, 279, 289 and 307, which corresponding to a possible C8/C10 phthalate ester. Similarly, the characteristic ions of U-2 (m/z 293) and U-3 (m/z 247, 265 and 321) have pointed to di-C9 and C7/C11 phthalate esters respectively. The exact structures of these chemicals have to be confirmed in future studies.

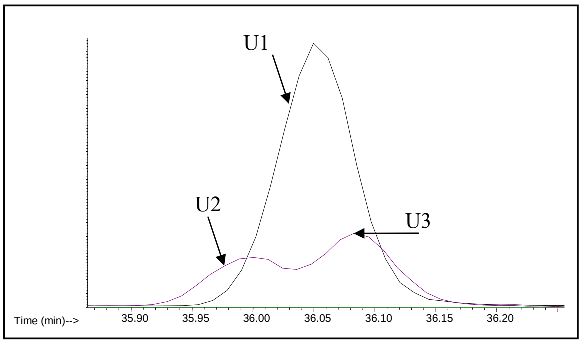

Fig. 1. The overlap of chromatograms from two different samples showing the retention times of U1, U2 and U3 on an HP-5 capillary column.

The concentration of DEHP accounted for about half of the total phthalates concentration, indicating a more extensive use of DEHP than that of the other phthalate congeners. The concentration distribution curves of several selected phthalates (DEP, DBP, DEHP and DDcP) and the total phthalates are plotted in Fig. 2. They exhibit a near log-normal distribution. The other individual phthalates also roughly follow the same pattern.

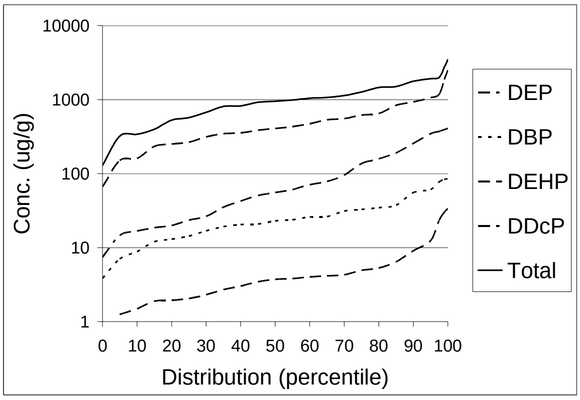

Fig. 2. Concentration distributions of selected phthalates and total phthalates among measured house dust samples.

The concentrations observed in this study were in the same range as those measured in Cape Cod, Massachusetts, United States [7]. However, the levels found in the previously mentioned German study were higher, except for BBP [1]. For example, both DBP and DEHP concentrations in German homes were about twice the levels found in North America (Table 2). These higher concentrations might be partially attributed to the different size of sieved dust used in this study. However, these higher levels could also be an indication of the variation in the environmental levels of phthalates between the two geographic areas. The ten-fold higher concentration of DiBP found in German homes may also be suggesting that the use of DiBP in Germany is much more prevalent than in North America.

The overall levels of phthalates in house dust may raise concerns about potential human exposure to these chemicals, especially in children. Using the daily dust ingestion estimates provided by United States Environmental Protection Agency (USEPA) [8], the mean and high exposure to phthalates through dust ingestion were estimated for both adults and children (Table 3). For example, the median daily intake of DEHP for adults from ingestion of dust was estimated at 1.7 µg/d, based on their mean dust ingestion value, and 41 µg/d, on the high dust ingestion value for the US population. Although the high dust ingestion amount in children is only twice that of adults, the mean ingestion value among children was more than ten times the value of adults. This resulted in a much higher phthalates daily intake for children aged 6 months to 2 years old. The median daily intake values of DEHP (22 µg/d) and total phthalates (52 µg/d) were therefore calculated for children, with mean dust intake of 50 mg/d.

Table 2. Comparison of median values of phthalates measured in three studies.

	This study	MA study[5]	German study[1]
Homes (n)	n=56	n=120	n=286
Dust size (µm)	(<150)	(<150)	(<65)
DEP	3.7	5.0	-
DBP	22.9	20.1	49
DiBP	4.2	1.9	34
BBP	54.2	45.4	31
DEHP	406	340	740
DEHA	8.9	6.0	-

Assuming a 70 kg body weight, the median daily intake of DEHP for adult population has been estimated at about 966 µg/d from its urinary metabolites [9]. The proportion of DEHP intake through dust digestion in the total daily intake could therefore be calculated at 0.2% for adults, with mean dust ingestion of 4.2% for adults with high dust ingestion value. It has been recognized that the predominant phthalates exposure route is food intake [10]. Although total daily intake of phthalates for children has not been studied, the figures could be estimated in the vicinity of 2% and 8%, based on mean and high dust ingestion values respectively. Therefore, human exposure to phthalates through possible ingestion of house dust may constitute a significant portion of the total intake of these environmental contaminants; this particularly applies to children.

Phthalates are endocrine disruptor chemicals (ECD). The human health effects and body burden of phthalates has been documented [9,10]. However, the effects of the exposure and the health impact of phthalates on humans are not well understood yet; this applies particularly to fetus growth and infant development. Further studies on human health effects resulting from long-term and chronic environmental exposure in the general population, (especially in children) are needed for better health protection.

Table 3. Estimation of daily intake (µg/d) of DEHP and total phthalates through ingestion of house dust.

	Adult		Children*	
Dust Ingestion	Mean	High	Mean	High
(mg/d)	4.16	100	55	200
Exposure to DEHP (µg/d)				
25th Percentile	1.1	26	15	53
Median	1.7	41	22	81
95th Percentile	4.4	106	58	212
Exposure to Total phthalates (µg/d)				
25th Percentile	2.4	57	31	114
Median	4.0	95	52	190
95th Percentile	8.0	191	105	383

*: Age group: 6 months to 2 years

Information on the levels of individual phthalates in house dust is an important part of the body of scientific knowledge on these pollutants present in the environments and in human tissues. The identification of several phthalate congeners not previously observed in earlier studies will help the scientific community design future monitoring programs on phthalate congeners.

Acknowledgement

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MCS/IEI and Personal Exposures of VOCs by Job Groups in Construction Worker

C. Chun[1], E. Kim[2], J. Park[3] and K. Sung[1]

[1]Yonsei University, Dept. of Housing and Interior Design, Sinchon-dong, Seodaemun-gu, Seoul, Korea
email: chun@yonsei.ac.kr http://suny.yonsei.ac.kr/~ecodesig
[2]Korea Institute of Ceramic Eng. & Tech., 233-5, Gasan-dong, Geumcheon-gu, Seoul, Korea
[3]Hanyang University, Dept. of Architecture, Haengdang-dong, Seongdong-gu, Seoul, Korea

Summary: *A relation between new houses' high VOCs concentration with SBS and asthma has been a social issue in Korea now. However, people who are exposed to high concentration of chemical compounds from construction materials as well as occupants of new houses are the workers for construction business. Self reported symptom surveys and personal exposure concentration measurement research were conducted to three job groups of construction business such as Exterior Worker, Interior Worker, and Office Worker. As a result, the job group which is most highly exposed to taking VOCs concentration is Interior Worker followed by Office Worker and Exterior Worker. However, in self-reported symptoms suggestive o f MCS/IEI, office worker are relatively frequent in three job groups.*

Keywords: *multiple chemical sensitivity, idiopathic environmental intolerance, job groups, construction worker, VOCs*
Category: *environmental illness*

1 Introduction

A relation between new houses' high VOCs concentration with SBS and asthma has been a social issue in Korea now. According to such reason, though the study about health for the house resident is proceeding actively, but since a study regarding to the Worker for Construction Business who is disclosed to chemical material in high concentration is wholly lacking state. However, people who are exposed to high concentration of chemical compounds from construction materials as well as occupants of new houses are the workers for construction business.

Based upon this background, self reported symptom surveys and personal exposure concentration measurement research were conducted to three job groups of construction business.

This result could clarify how much harmful circumstance they are working.

2 Methodology

After classification on Worker for Construction Business into 3 job groups as Exterior Worker, Interior Worker, Office Worker, the questionnaire inquiry and measurement research have been conducted. At the questionnaire inquiry, the questioning table developed by Black et al. was used [1]. Total 330 surveys were distributed and 318 answers were returned. 305 answers which answered sincerely were analyzed. Survey was conducted from the 31st August until 30th September in 2004.

At the measurement research, after random sampling of total 15 persons selected from 5 persons each per job group among 305 persons of questionnaire subjects, personal exposures of VOCs concentraion within the working hour during a week was measured by utilizing Passive Sampling Method. Collected samplers were extracted with 2ml carbon disulfide from the charcoal tube by shaking and then analyzed by GC FID. TVOC and five differenet VOCs (Benzene, Toluene, Ethylbenzene, M.P-Xylene, O-Xylene) were analysed.

3 Results

At the questionnaire inquiry we used the questioning table developed by University of Iowa Team (Table 1) [1]. This table gives the operational definition for MCS. The criteria require that a person report illness from chemical sensitivity, report sensitivity to 2 or more types of incitants, have symptoms in at least 2 organ systems, and manifest evidence of impairment or behavioral change in response to the perceived sensitivity.

Fig. 1. Personal exposed compounds measurement

As the result, the number of persons who met the operational criteria of multiple chemical sensitivity was 16.8% of interior workers, 5.1% of exterior workers, and 24.5% of office workers. After statistical analysis, there were significant differences between exterior workers and interior/office workers. (Table 2) Black reported 3.4% of American participants met operational criteria for MCS in his study [1]. From this comparison, we can see the high risk of MCS in construction workers.

And we tried to search the significant factors which influencing to their symptoms. As the result of analysis after carrying out Logistic Regression Statistics on the factors such as gender, age, education, period of the continuous service, job group, it was found that the nearer to younger, the nearer to woman, and Interior Worker/Office Worker than Exterior Worker are in highly probable to be attacked by Multiple Chemical Sensitivity .

Table 1. Criteria for MCS

A. Routine or normal levels of exposure to chemical agents/substances(eg, gasoline, hair spray, paint, perfume, and soap)caused respondent to feel ill

B. Sensitivity (or illness after exposure) is reported to ≥2 of the following:
1. Smog/air pollution
2. Cigarette smoke
3. Vehicle exhaust/fumes
4. Copiers, printers, and office machines
5. Newsprint
6. Pesticides, herbicides, and fertilizers
7. New buildings
8. Carpeting and drapery
9. Organic chemicals, solvents, glues, paints, And fuel
10. Cosmetics, perfumes, hair spray, deodorants, and nail polish
11. Other

C. Symptoms are reported from ≥2 of the following categories:
1. Constitutional (eg, fever, night sweats, fatigue, weight loss, and weight gain)
2. Rheumatologic (eg, joint pain and muscle aches)
3. Neurologic (eg, headaches, sensory loss, tingling, and paralysis)
4. Cardiovascular (eg, palpitations)
5. Gastroenterological (eg, gas, bloating, and abdominal pain)
6. Dermatologic (eg, rash and blisters)
7. Pulmonary (eg, shortness of breath, cough, and wheezing)
8. Cognitive (eg, confusion, difficulty concentrating, and memory loss)

D. Symptoms lead to a behavioral change in ≥1 of the following ways:
1. Wearing a mask, gloves, or special clothes
2. Changing one's lifestyle to minimize chemical exposure
3. Moving to a new home/location
4. Use of special vitamins, supplements, or diets
5. Use of oxygen, antifungal agents, or neutralizing injections/drops

At the personal exposed VOCs measurement, average of TVOC concentration was appeared high state by order of Interior Worker, Office Worker, and Exterior Worker. Especially, in case of Interior Worker, the average exposure concentration of Benzene was at 128.76 $\mu g/m^3$, Toluene at 485.68 $\mu g/m^3$, TVOC at 4935.59 $\mu g/m^3$, respectively.

In consideration of the recommended numerical value by WHO is Toluene at 269 $\mu g/m^3$, TVOC at 300 $\mu g/m^3$ respectively, it was able to find that Interior Workers under such working environment everyday are being disclosed to harmful environment. As its average exposure concentration of TVOC at 447.84 $\mu g/m^3$ for Office Worker also, it was exceeding WHO's guideline, and also displayed higher concentration than Exterior Worker in Benzene and O-Xylene. The results of personal VOCs exposure concentration for 15 subjects were shown in Table 3.

As control group, we measured 4 office worker's personal exposure concentraion during out of work. The compared results between working and out of working are shown in Table5. It was appeared lower level in 5 compounds except Benzene compare with the working circumstance, and in average case of TVOC it was recorded as 280.4 $\mu g/m^3$.

Table 2. Results of Logistic Regression Analysis

Factors	B	S.E	Wald	df	Sig.	Exp(B)
gender**	1.036	.373	7.712	1	.005	2.818
age*	-.074	.033	5.072	1	.024	.929
education	.126	.284	.196	1	0.658	1.134
Years of continuous service	.010	.034	.083	1	.773	1.010
constant	.286	1.399	.042	1	.838	1.331
interior/ office	.474	.349	1.844	1	.175	1.606
interior / exterior*	-1.324	.530	6.235	1	.013	.266
constant	-1.598	.266	36.087	1	.000	.202
exterior / office***	1.798	.511	12.363	1	.000	6.307
exterior / interior*	1.324	.530	6.235	1	.013	3.759
constant	-2.922	.459	40.557	1	.000	.054

* $p < 0.5$

** $p < 0.05$
*** $p < 0.001$

Table 3. Concentrations of each chemical compound according to subjects (㎍/㎥)

Job group	S.N	Benzene	Toluene	Ethyl-benzene	MP-Xylene	O-Xylene	TVOC
interior	A	16.3	369.1	10.4	133.2	36.8	6940.5
	B	322.4	654.9	15.9	174.6	38.9	7343.1
	C	305.1	1158.4	73.3	5.6	50.4	9966.8
	D	n.d	159.0	15.2	12.3	10.9	272.3
	E	n.d	87.0	9.4	7.5	7.4	155.3
average		130.0	485.7	24.8	66.6	28.9	4935.6
exterior	F	n.d	46.6	19.6	16.7	13.3	35.5
	G	n.d	54.0	20.5	18.1	14.3	40.0
	H	n.d	218.4	50.7	13.6	19.9	473.1
	I	3.86	66.7	28.4	25.5	18.7	152.0
	J	18.69	44.6	7.8	6.4	6.8	187.8
average		3.0	66.9	11.8	9.5	8.5	171.7
office	K	n.d	66.9	11.8	9.5	8.5	171.7
	L	-	-	-	-	-	-
	M	26.4	87.2	17.6	5.0	20.5	509.2
	N	n.d	81.1	10.6	18.5	20.0	762.1
	O	n.d	98.1	18.6	17.1	15.5	348.3
average		8.8	83.3	14.7	12.5	16.1	447.8

*n.d. was concerned as 3 ㎍/㎥ (detected limitation) to calculate average value.

Table 5. Comparison of VOCs exposure during work and out of work. (㎍/㎥)

S.N	Benzene	Toluene	Ethyl-benzen	Mp-xylene	O-xylene	TVOC
K work	n.d	66.9	11.8	9.5	8.5	171.7
K out	13.1	44.6	7.7	6.8	6.1	289.0
M work	25.4	87.2	17.6	5.0	20.5	509.2
M out	10.2	37.5	8.1	6.3	6.0	128.4
N work	n.d	81.1	10.6	18.5	20.0	762.1
N out	14.3	44.8	7.6	8.9	7.1	213.3
O work	n.d	98.1	18.6	17.1	15.5	348.3
O out	9.8	37.3	6.9	6.2	5.6	490.9

4 Discussion

As known from the study result as above-mentioned, in self-reported symptoms suggestive of MCS/IEI, office worker are relatively frequent in three job groups. However, there was no statistical significance between office worker and interior worker.

The job group among construction business workers which is most highly exposed to taking VOCs concentration is Interior Worker, next following by order of Office Worker, Exterior Worker. The degree

Table 4. Subjects' main business and predicted VOCs sources during working

Job group	S.N	business	VOCs sources	open degree / ventilation system
Interior worker	A	wood	wood like a plywood, corkboard, wood working glue	window open
	B	paint	paint, lacquer, varnish, putty, thinner	window open
	C	floor	glue, wax, carpet, PVC flooring	window open
	D	ceiling	wood, gypsum board, glass fiber, PVC ceiling	window open
	E	mortar	mortar compound	window open (closing in winter-prevention of frost damage)
Exterior worker	F	ferroconcrete	heat insulator	completely open
	G	Brick	heat insulator	completely open
	H	piping	PVC pipe laying, heat insulator, lagging, glue	completely open
	I	ferroconcrete	fire- steel coating	completely open
	J	window	PVC window	completely open
Office worker	K	Design	office machine like a duplicator, printer, etc. paper, partition, construction site visiting	close / AC
	L	Maintenance	office machine like a duplicator, printer, etc. paper, partition, Construction site visiting	close / AC
	M	Trade	office machine like a duplicator, printer, etc. paper, partition, vehicle	close /central HVAC
	N	Design	office machine like a duplicator, printer, etc. paper, partition,	close / central HVAC
	O	Plan	office machine like a duplicator, printer, etc. paper, partition,	close / central HVAC

how much the working environment is opened to the outside, and whether the resource of high concentration is handled or not when working were appeared as the elemental factors that deciding such degree of danger, and it was exhibited that the laboring environment for both Interior Worker and Office Worker is being exposed to TVOC in high concentration that exceeding over the guideline by WHO.

In viewing of this Study based on the Result, the use of low VOCs emission material to workers not only residents should be induced positively, and since it is being appeared that the degree how much it is opened to the outdoor greatly effects on the exposure volume to be attacked, therefore for the sake of this, the continuous exposure in high concentration must be prevented by the measures for Interior Worker also to be bestowed a compulsory break during working hour for regular exposure to the open air, as well. Likewise, the inquiry as well as medical examination and treatment by the government-dimensional expert must be provided, and though the measurement survey is restricted as 15 persons, when make allowance for the fact that the VOCs exposure volume of construction site worker exceeds over 9~13 times in maximum than the recommended numerical value by WHO, a study on the exposure volume with more deepened, based on vast data should be continued.

Such result and proposal is grasping of dangerous degree to be taken ill of MCS/IEI by the job groups with its measurement of VOCs exposure volume in working environment of construction business worker, it would be mentioned as the significance of this study, in view to be able to furnish a fundamental data for better construction working environment.

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Studies on Formaldehyde Removal Rates of Domestic Air Cleaners and the Indoor Concentration Prediction

A.Nozaki[1], Y.Ichijo[1], T Hayasaka[1] A.Kikkawa[1], H.Honma[2] K.Ikeda[3] and S.Yoshizawa[3]

[1]Graduate School of Health and Environmental Science, Tohoku Bunka Gakuen University, 6-45-1 Kunimi, Aoba-ku, Sendai, Miyagi 981-8551, Japan. email:nozaki@ept.tbgu.ac.jp
[2]Komyo Rikagaku Kogyo k. k., 1-8-28 Shimonoge, Takatu-ku, Kawasaki, Kanagawa 213-0006, Japan
[3]Dept. of Architecture, Hygiene and Housing, National Institute of Public Health, 2-3-6 Minami, Wako, Saitama 351-0197, Japan.

Summary: *The mitigation techniques have been developed against the indoor air pollution. And the domestic air cleaner has been expected as one of the effective technique. So we have proposed the equivalent clean air rates or ECAR[m^3/h] as air cleaner's performance evaluation index[1), and we have already investigated the air cleaner's performance by using this index. And this ECAR is equal to the CADR or clean air deliver rate. These indexes mean air cleaners performace on pollutant removal rates.*
In this research, air cleaner's performance evaluation was done by using environmental chambes with the volume of about 5[m^3]. It turned out that the ECAR or CADR obtained from chamber experimenst indicated 36.6[m^3/h]. And the concentration prediction indoor with air cleaner was conducted. We can get the prediction value by adoptation ECAR or CADR [m^3/h] into ou mathematical prediction model. The correspondence rate between the predicted formaldehyde concentration and measured one indicated 88.9[%], the predicted value was almost coincident with the measured one.

Keywords: *Air cleaner, CADR, Concentration prediction, Pollutant-emission device, Instantaneous evaporation type,*
Category: *Case Studies*

1 Introduction

Nowadays, to solve indoor air pollution caused by harmful chemical substances, various products that prevent for indoor air pollution have been available in Japan.

In these products, the domestic air cleaners have been expected as one of the effective measures to remove chemical substances that sometimes cause SBS.

However, as each air cleaner fabricator in Japan uses the different performance evaluation test method for their products, it is difficult for us to judge the performance mutually. So, the scientific research on performance evaluation test and the grasp of air cleaners performance are required, and to develop the indoor contaminant concentration predicting method is necessary to solve the social problem or sick building.

Authors (Nozaki et al. 2006) determined the formaldehyde removal rates of domestic air cleaners using the pollutant constant-emission test by chamber with the volume of about 5 [m^3], and reported that the formaldehyde removal rates ware in the range of 27.2 to 33.1 [m^3/h] as shown in Fig.1. This value indicates that some of the domestic air cleaner may be an effective measure against indoor formaldehyde pollution.

However, this rate does not become sure in the actual environments.

In this study, we perform comparison with the prediction model which measured value in the experiment chamber which assumed the actual environments and we suggest.

2 Research method

The outlines of domestic air cleaners are shown in Table. 1.

In performance evaluation methods for removal products, the pollutant constant-emission test is the most ideal of all the ones. When we realize the pollutant constant-emission test, the technology of generating pollutant-gas constantly is required.

So we developed the pollutant constant-emission device. (Photo. 1) This device has the heating furnace where the solution of the object pollutants is vaporized instantly. And the gas vaporized in the heating furnace is carried by purified air. With this newly developed device, we can provide an amount of gas-phase contaminants to test chamber. The outline of the pollutant constant-emission device is shown in Fig.2.

The experimental system is consisted by the pollutant constant-emission device and the stainless-steeled chamber where environmental conditions are intentionally controlled. The environmental condition was controlled in temperature of 28±0.5℃, relative humidity of 50±5 [%], ventilation rate of 0.50±0.05 [1/h] and air flow rate from 0.2 to 0.3 [m/s]. Fig.3 shows the outline of environmental test-chamber and this newly developed device. The condition of gas generator is shown in table 2.

3 Results & discussion

By the predict equation (1), we can predict the pollutant concentration in the room where the domestic air cleaner is operated. We can also determine the amount of ECAR or CADR of each air cleaner under the constant-emission method.

$$C = C_1 e^{-(\frac{Q+\alpha R+Q_{eq}}{R})t} + \frac{M+QC_0}{Q+\alpha R+Q_{eq}}(1-e^{-(\frac{Q+\alpha R+Q_{eq}}{R})t}) \tag{1}$$

M : contaminant emission rate [μg/h], Q : amount of room ventilation [m^3/h], C_0 : outdoor contaminant concentration [μg/m^3], α :adsorption rate to surface (include chemi-sorption and react in the air)[1/h], R : room volume [m^3] and Q_{eq} : equivalent clean air rates(ECAR or CADR) [m^3/h]

Steady state concentration C_{ss} is obtained by putting $t=\infty$ into equation (1).

$$C_{ss} = \frac{M+QC_0}{Q+\alpha R+Q_{eq}} \tag{2}$$

Equation (3) is obtained from equation (2). Using equation (3), ECAR or CADR (Q_{eq}[m^3/h]) is determined.

$$Q_{eq} = \frac{M}{C_{ss}} + Q(\frac{C_0}{C_{ss}} - 1) - \alpha R \tag{3}$$

We made an experiment on the formaldehyde removal performance in the pollutant constant-emission test. The results are shown in Fig. 2. The averaged ECAR or CADR (Q_{eq}) of formaldehyde was 15.1 [m^3/h] for pull-down test method, and the value was 16.7 [m^3/h] for constant-emission test. The value derived by constant-emission test reflects the actual performance of air cleaner that are set in houses. It turned out that the value derived by pull-down test is smaller than the one derived by the constant-emission test. The pull-down test's value is 0.9 times smaller than the one derived by constant-emission test.

We carried out the confirmation test in the steady-state of formaldehyde concentration in an environmental chamber. In this test some of the technologies are needed, one is pollutant constant-emission technology, and the other is room-environmental control techniques. In this environmental chamber, we succeeded in constructing it as shown in Fig.4.

The performance evaluation test was examined twice to check reproductions. With air cleaner operations, a remarkable reduction of formaldehyde concentration was shown as indicated in Fig. 5 to 6.

The predicted value of formaldehyde concentration was calculated by adapting the ECAR or CADR into prediction equation (1). This ECAR is the rates that we showed in Fig.2. And moreover, this predicted value and the measured one were compared and the correspondence rate was also calculated as shown in Table. 4.

The averaged correspondence rate between predicted value and measured one in the constant-emission test was 88.9[%]. The correspondence rates agreed at a high level in the performance evaluation test by two times. Besides, Environmental formaldehyde concentrations were built up in about 150[μg/m^3].

4 Summary & conclusions

In this research, the following findings were obtained:

1. We succeeded in the construction of the steady-state formaldehyde concentration in a large chamber using the newly developed the chemical substance constant-emission device.
2. The formaldehyde removal rates of the air cleaner with constant-emission test were quantitatively determined.
3. The correspondence rate of the formaldehyde concentration between the predicted value and the measured one was 88.9 [%], and it was proved that the accuracy of this predicting method is very high.

5 Acknowledgements

This study was done as a part of activity of the indoor environmental technical research society that was non-profit organization in Japan. In addition, it was done by the "A general study about risk evaluation of a chemical substance emitted from house-products" which was done as public welfare scientific research. The authors express appreciation to Prof. M. Ando who was the head investigator on this study. And we show gratitude to the members concerned.

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Table.2 Settled condition of the pollutant constant-emission device

Chemical substances	Formaldehyde
Settled temperature of the heating furnace	130[℃]
Settled temperature of the mantle heater	130[℃]
Solution supply (γ)	0.1[mL/h]
Emission rate of vaporized gas	0.10[L/min]

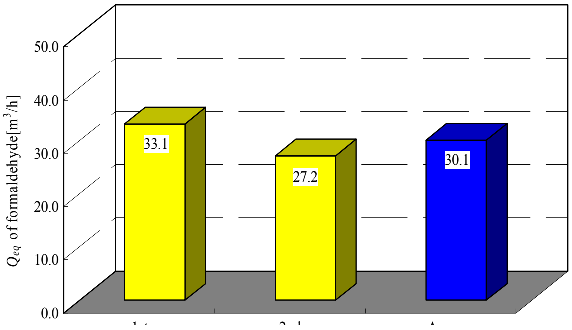

Fig.1 ECAR or Q_{eq} of tested air cleaner

Table.1 Outline of air cleaner

Device	Air flow rate[m^3/h]					Removal principle
	Extra large	Very large	Large	Normal	Small	
AC-1	420	330	240	150	60	Streamer plasma discharge+Filtration

Photo.1 The pollutant constant-emission device of instantaneous evaporation type

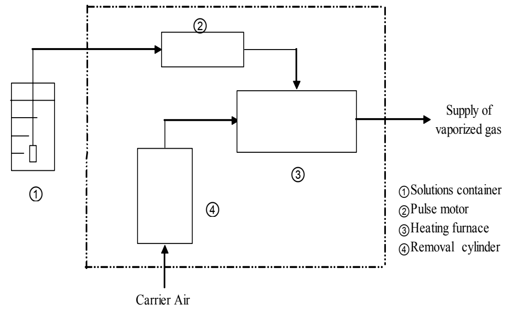

Fig.2 Outlines of the pollutant constant-emission device

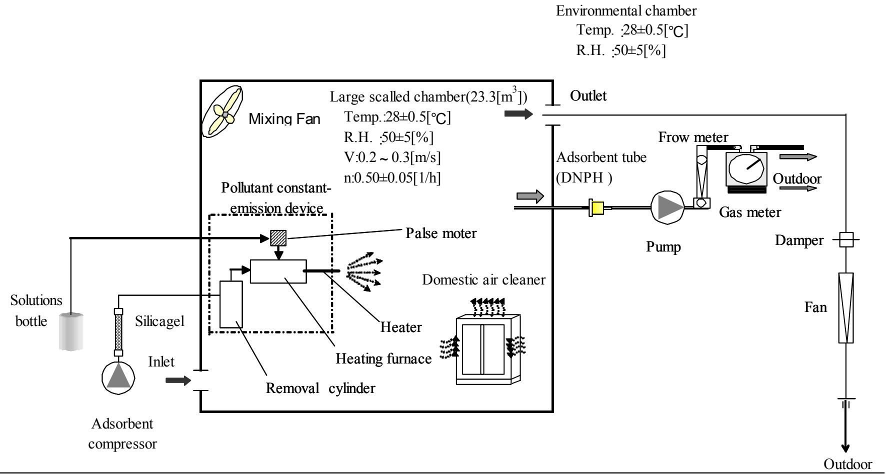

Fig.3 Measuring system

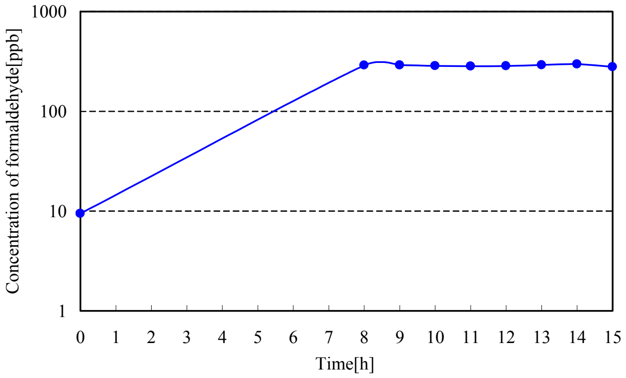

Fig.4 Confirmation of formaldehyde concentration in steady state

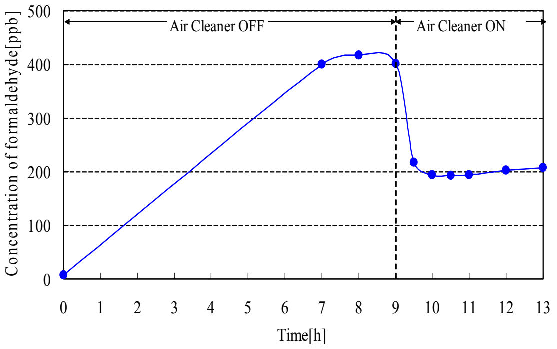

Fig.5 Formaldehyde concentration with air cleaner operation (1st)

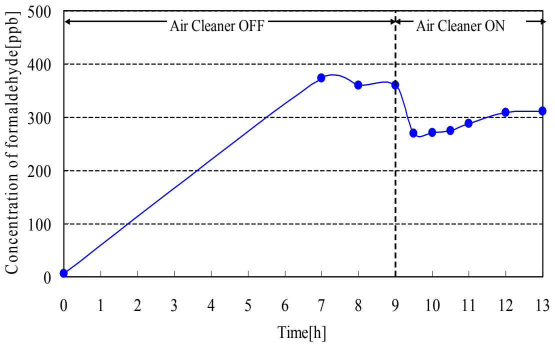

Fig.6 Formaldehyde concentration with air cleaner operation (2nd)

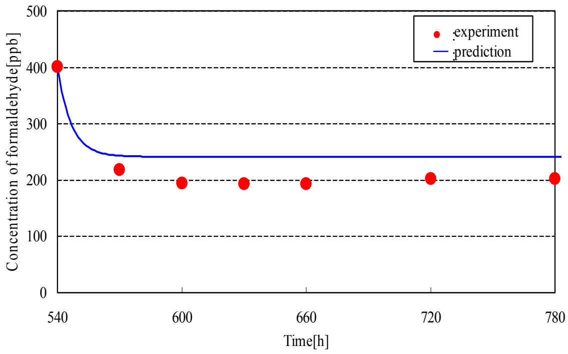

Fig.7 Comparison between measured formaldehyde concentration and predicted one (1st)

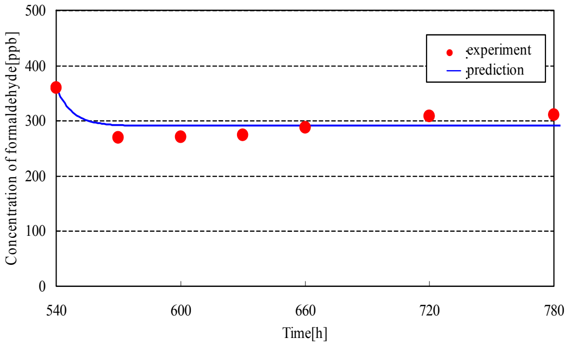

Fig.8 Comparison between measured formaldehyde concentration and predicted one (2nd)

Table.3 Correspondence rate between measured formaldehyde concentration and predicted one

	Correspondence rate[%]						
	30[min]	60[min]	90[min]	120[min]	180[min]	240[min]	Ave.
1st	89.6	80.6	79.9	80.2	83.8	86.1	83.4
2nd	92.4	92.9	94.3	98.9	94.3	93.6	94.4
Average	88.9						

VOC Concentrations of Interest in North American Offices and Homes

H. Levin[1] and A.T. Hodgson[2]

[1]Building Ecology Research Group. Santa Cruz, California, USA 95060
email: hal.levin@buildingecology.com http://www.buildingecology.com
[2]Indoor Environment Department, Lawrence Berkeley National Laboratory, Berkeley, California USA 94720

Summary: *Indoor air quality investigators often sample many volatile organic chemicals but with insufficient knowledge of their potential impacts on occupants. Studies performed in North American offices and residences since 1990 were reviewed and central tendency and maximum VOC concentrations were summarized by building type. These concentrations were assessed relative to various guideline values for odor, sensory irritancy and noncancer chronic toxicity to identify compounds that may reach levels of concern. These comparisons revealed that less than one-fifth of the 106 VOCs studied reached levels that were ≥10% of guideline values. Guidelines are needed for other VOCs and other health endpoints.*

Keywords: *Indoor exposure, Guidelines, Chronic toxicity, Sensory Irritancy, Odor thresholds*
Category: *Chemical pollutants. Synergetic effects and indicators*

1. Introduction

Consideration of indoor exposures to air pollutants is critical to health hazard assessments. For many toxic volatile organic compounds (VOCs), indoor concentrations exceed outdoor concentrations due to numerous indoor sources, limited dilution volumes, and relatively low ventilation rates. The decade since 1990 has witnessed increased concern about the environmental consequences and adverse health effects of air pollution. In the U.S., the 1990 Clean Air Act (CAA) Amendments established programs to regulate emissions of air pollutants associated with cancer, reproductive harm, and other serious illnesses. Nearly 200 substances are classified as hazardous air pollutants (HAPs). Industry is regulated to reduce their emissions of HAPs and cleaner fuels and engines have been mandated. It is possible that indoor as well as outdoor exposure concentrations for some HAPs have been reduced as direct or indirect results of these programs.

Indoor VOC concentrations in residential and commercial buildings from about 1978 through 1990 have been summarized in several reviews. Much of this data is from North America (NA). We have updated this information by compiling and summarizing the data on the central tendency and upper limit indoor VOC concentrations measured in NA from 1990 through 2001 [1]. Data from existing residences, new residences and large office buildings were treated separately. Our primary objective was to generate a database of typical and maximum VOC concentrations that can be used as a comparative basis for evaluating measured concentrations.

In a companion paper [2], we assessed the summarized VOC concentrations in residences and office buildings with respect to odor thresholds, sensory irritation levels for the general population and noncancer chronic health risks. Our objective was to identify and broadly classify VOCs that are most likely to result in comfort and/or health concerns. We excluded cancer from consideration, as the risk assessment approach and the time period of interest for cancer are substantially different. Other effects, such as immunological responses, were not considered due to insufficient toxicological data. This assessment, while revealing the limitations of the available concentration data and present knowledge regarding health outcomes, can provide guidance for prioritizing indoor air pollutants for monitoring and for efforts to limit indoor exposures through combinations of ventilation and source controls.

2. Methods

We defined VOCs as chemical compounds with carbon chains or rings and vapor pressures greater than ~1 Pa at room temperature. Papers were gathered from journal literature with several exceptions. We focused solely on reported measurements made in NA residences, both new and existing, and office buildings from 1990 through 2001. Only cross-sectional studies that investigated five or more buildings were considered. Investigations of unusual environments or pollutant sources were excluded. In total, we identified 13 papers presenting the results for 12 studies of existing residences, 2 papers for new residences, and 3 papers for office buildings. Limited data editing was performed. Concentrations given as mass per unit volume ($\mu g/m^3$) were converted to ppb concentrations assuming standard indoor conditions. 106 VOCs were identified (see Table 1). Broad ranges of chemical functionality and volatility were represented. Central tendency and upper limit concentrations were summarized separately for residences and office buildings.

Odor Thresholds

Standardized human odor thresholds (OTs) for VOCs were obtained from Devos *et al.* [3]. One hundred percent odor detection thresholds were obtained from the Cometto-Muñiz and Cain research group [4]. These were divided by 10 to adjust for the difference between 100% recognition criteria and an assumed 50% recognition threshold for the Devos *et al*. values. For VOCs with OTs from both sources, we assumed the adjusted Cometto-Muñiz *et al*. values were more reliable because they were determined with a consistent contemporary methodology.

Sensory Irritants

Exposures to high levels of sensory irritants stimulate a response through the trigeminal nerve and cause a reflex change in breathing pattern. A mouse bioassay exploits this change as a measure of sensory irritancy. The procedure calculates the concentration producing a 50% decrease in frequency. These RD50s have been reported for a large number of individual VOCs. Human nasal pungency thresholds (NPTs) are a measure of the trigeminal response of the nose when exposed to airborne sensory irritants. The Cometto-Muñiz and Cain group has employed a uniform methodology with groups of anosmic subjects to determine NPTs for VOCs in different classes.

The California EPA Office of Environmental Health Hazard Assessment (OEHHA) has developed acute Reference Exposure Levels (RELs) for some hazardous airborne pollutants [5]. An acute REL is an exposure concentration unlikely to cause adverse effects in humans, including sensitive individuals, exposed to the concentration for one hour. Guidelines to protect workers from the adverse effects of exposure to chemicals have been developed over many years. Thresholds Limit Values (TLVs) constitute one of the most widely used sets of occupational exposures levels (OELs) in the U.S. and elsewhere. TLVs are intended to protect workers for an eight-hour workday assuming a typical 40-h workweek.

We endeavored to place the measures of sensory irritancy onto a comparable scale. Others have estimated sensory irritation effects in humans by applying an uncertainty factor to RD50s. These studies generally support an early proposal for estimating TLVs by setting them 1.5 orders of magnitude below their RD50s on a log scale. NPTs occur at elevated concentrations approximately equivalent to RD50s. Various agencies have attempted to establish inhalation exposure guidelines for the general population by applying uncertainty factors to TLVs and other OELs. Based on the work of Nielsen et al. [6] and others, we adopted the approach of adjusting the TLVs of compounds with irritancy as the sole or principal effect by dividing by 10 to account for sensitive sub-populations. By extension, RD50s were adjusted by 2.5 orders of magnitude (*i.e*., 1.5 orders of magnitude factor to equate RD50s with TLVs plus a factor of 10 for sensitive groups). The same factor was applied to NPTs. We assumed that sensory irritation response was best characterized by human measures (NPTs, TLVs, and RELs); that among the human measures NPTs were the most directly applicable; and, that acute RELs represented more current and thorough reviews of the literature on human response than TLVs.

Chronic Noncancer Effects

Several NA agencies have established health-based, noncancer guidelines for chronic exposures of the general population to toxic air pollutants. The U.S. EPA has developed noncancer, inhalation reference concentrations (RfCs) for some HAPs. The RfCs are concentrations to which it is believed humans including sensitive groups can be exposed over long periods without effects. The Environmental Health Directorate, Health Canada has developed analogous tolerable concentrations for inhalation for some VOCs. The U.S. Agency for Toxic Substances and Disease Registry (ATSDR) has developed acute, intermediate and chronic health effect guideline levels for inhalation exposures to a number of industrial chemicals. These Minimal Risk Levels (MRLs) are estimates of the daily human exposures unlikely to cause appreciable risk of adverse noncancer effects in sensitive populations over specified durations. For the ASTDR source, we selected the lowest inhalation MRLs derived for either the intermediate (>14 to 364 days) or the chronic (≥365 days) exposure period as the best measure. OEHHA has developed noncancer chronic RELs for 78 chemicals following the same general approach as used by the U.S. EPA for RfCs [5].

Noncancer chronic exposure guidance levels were estimated for the general population from TLVs that are not based on cancer or irritation as the primary effect. Following the suggestions of others, a factor of 1/40 was applied to account for the difference between a 40-h workweek and a constant 24-h a day exposure and including a factor of 10 uncertainty for sensitive groups. Then, a worst-case pharmacokinetic factor of 0.2 was applied to account for the lack of a recovery period for chemicals with a biological half-life of over eight hours. The total adjustment was TLV/200.

We assumed chronic REL, RfC and MRL concentrations were better measures of chronic toxicity than the TLV-based measures due to the uncertainty in the use of a universal adjustment factor with TLVs. We gave preference to the OEHHA chronic RELs since they generally were based on the most current toxicological literature for the largest set of compounds. Our second preference was the lower of the two other measures.

Comparison with Guideline Values

We next compared the best estimates of odor thresholds and protective sensory irritation and noncancer chronic health levels for the general population to the VOC concentrations measured in residences and office buildings. This was accomplished by dividing maximum, or the derived 95th percentile (95%ile), concentrations by the selected guideline values to produce indoor hazard quotients. Measured VOCs were classified with respect to the different effects based on these hazard quotients. We considered compounds with quotients in excess of unity to be of primary concern. Quotients within one order of magnitude of unity defined the next level of concern. Since this was a screening level assessment, we did not ascribe any particular importance to compound ranking within or between the two categories of concern.

3. Results and Discussion

Table 1 lists 106 VOCs for which concentration data were obtained. They are organized by chemical class and ordered by decreasing volatility within class. The U.S. EPA classifies 35 of these as HAPs.

Table 1. VOCs reported since 1990 for North American existing and new residences and office buildings, organized by chemical class and decreasing boiling point within class.

Chem. Class	Compound (CAS No.)
Alcohols	Ethanol (64-17-5), 2-propanol (67-63-0), 1-butanol (71-36-3), phenol (108-95-2), 2-Ethyl-1-hexanol (104-76-7), 1-ocatanol (111-87-5), butylated hydroxytoluene (128-37-0)
Ethers	*t*-Butyl methyl ether (1634-04-4), 1,4-dioxane (123-91-1)
Glycols	Ethylene glycol (107-21-1), 2-butoxyethanol (111-76-2), 1,2-propanediol (57-55-6), 2-(2-butoxyethoxy)ethanol (112-34-5)
Ketones	2-Propanone (67-64-1), 2-butanone (78-93-3), 4-methyl-2pentanone (108-10-1), cyclohexanone (108-94-1), 1-phenylethanone (98-86-2)
Aldehydes	Formaldehyde (50-00-0), acetaldehyde (75-07-0), propionaldehyde (127-38-6), acrolein (107-02-8), butanal (123-72-8), 3-methylbutanal (590-86-3), pentanal (110-62-3), hexanal (66-25-1), heptanal (111-71-7), 2-furaldehyde (98-01-1), octanal (124-13-0), benzaldehyde (100-52-7), nonanal (124-19-6)
Esters	Ethyl acetate (141-78-6), butyl acetate (123-86-4), 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate (25265-77-4), 2,2,4-trimethyl-1,3-pentanediol diisobutyrate (6846-50-0), diethylphthalate (84-66-2)
Acids	Formic acid (64-18-6), acetic acid (64-19-7), hexanoic acid (142-62-1)
Alkane HCs	n-Pentane (109-66-0), 2-methylpentane (107-83-5), 3-methylpentane (96-14-0), n-hexane (110-54-3), 3-methylhexane (589-34-4), n-heptane (142-82-5), 2,2,5-trimethylhexane (3522-94-9), n-octane (111-65-9), n-nonane (111-84-2), n-decane (124-18-5), n-undecane (1120-21-4), n-dodecane (112-40-3), n-tridecane (629-50-5), n-tetradecane (629-59-4), n-pentadecane (629-62-9), n-hexadecane (544-76-3)
Cyclic HCs	Methylcyclopentane (96-37-7), cyclohexane (110-82-7), methylcyclohexane (108-87-2), propylcyclohexane (1678-92-8), butylcyclohexane (1678-93-9)
Alkene & terpene HCs	1,3-Butadiene (106-99-0), isoprene (78-79-5), α-pinene (7785-70-8), camphene (5794-04-7), 3-carene (13466-78-9), β-pinene (18172-67-3), d-limonene (5989-27-5), p-cymene (99-87-6)
Aromatic HCs	Benzene (71-43-2), toluene (108-88-3), ethylbenzene (100-41-4), m/p-xylene, o-xylene (95-47-6), styrene (100-42-5), cumene (98-82-8), propylbenzene (103-65-1), 3/4-ethyltoluene, 4-ethyltoluene (622-96-8), 2-ethyltoluene (611-14-3), 1,3,5-trimethylbenzene (108-67-8), 1,2,4-trimetylbenzene (95-63-6), 1,2,3-trimethylbenzene (526-73-8), buylbenzene (104-51-8), naphthalene (91-20-3), 4-phenylcyclohexene (4994-16-5)
Halocarbons	Vinyl chloride (75-01-4), bromomethane (74-83-9), trichlorofluoromethane (75-69-4), dichloromethane (75-09-2), trichlorotrifluoromethane (76-13-1), chloroform (67-66-3), 1,1,1-trichloroethane (71-55-6), carbon tetrachloride (56-23-5), 1,2-dichloroethane (107-06-2), trichloroethene (79-01-6), tetrachloroethene (127-18-4), chlorobenzene (108-90-7), 1,4-dichlorobenzene (106-46-7), 1,2-dichlorobenzene (95-50-1), 1,2,4-trichlorobezene (120-82-1)
Miscellaneous	Carbon disulfide (75-15-0), acrylonitrile (107-13-1), pyridine (110-86-1), octamethylcyclotetrasiloxane (556-67-2), decamethylcyclopentasiloxane (541-02-6), benzothiazole (95-16-9)

The complete VOC concentration summaries are shown in the original report [1]. For existing residences, both central tendency values (geometric mean (GM), median, and/or mean) and upper limits (90%ile, 95%ile, and/or maximum) were summarized. For new residences, GM and maximum values were summarized. For office buildings, central tendency (GM or median) and maximum VOC concentrations were determined. VOC concentrations in buildings had wide distributions. Residential studies often reported standard deviations for arithmetic average concentrations that were about the same magnitude as the average values. Typical GM standard deviations for distributions of VOC concentrations in both residences and office buildings were about 2.0-2.2. Maximum concentrations in all buildings uniformly were <1 ppm.

Figure 1 compares central tendency and maximum concentrations of selected VOCs between existing residences (12 studies) and office buildings (3 studies). Central tendency concentrations of n-dodecane, 1,1,1-trichloroethane, trichloroethene and tetrachloroethene were more than three times higher in office buildings. Residences had higher central tendency concentrations of pentanal, α-pinene, d-limonene, 1,4-dichlorobenzene, and dichloromethane. Maximum concentrations of the six aromatics were more than three times higher in residences.

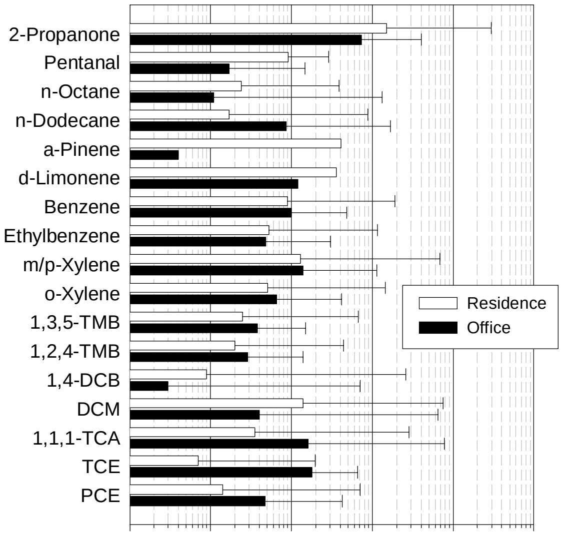

Figure 1. Comparison of central tendency and maximum concentrations (whiskers) of selected VOCs between existing residences and office buildings. TMB = trimethylbenzene, DCB = di-chlorobenzene, DCM = dichloromethane, TCA = trichloroethane, TCE = trichloroethene, PCE = tetrachloroethene.

In Figure 2, the central tendency concentrations for existing residences from the current review summarized as unweighted GMs are compared with the U.S. EPA's TEAM study unweighted GM concentrations for 17 VOCs from nine residential studies conducted prior to 1990 [7]. The current 1,1,1-trichloroethane concentration is more than three times lower than the TEAM study value. Other compounds with similar differences are benzene, 1,2-dichloroethane and tetrachloroethene. Such changes with time likely are due to the increased environmental regulations of the CAA that have targeted these compounds.

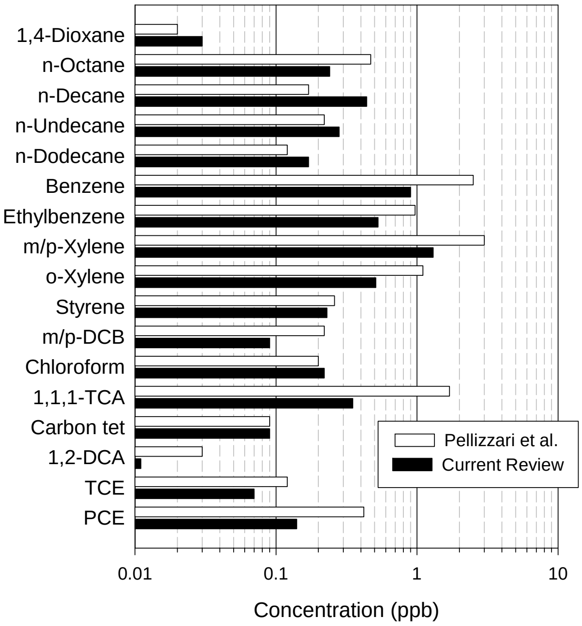

Figure 2. Comparison of geometric mean (GM) concentrations of 17 VOCs with GM concentrations from the U.S. EPA TEAM studies prior to 1990 as reported by Pellizzari et al. DCA = dichloroethane.

The reported maximum concentrations of 14 VOCs approached levels of concern with respect to odor. As shown in Table 2, VOCs with odor quotients exceeding one, indicating likely olfactory perception, were hexanoic acid and the aldehydes hexanal, heptanal, octanal, and nonanal in new residences and acetic acid in existing and new residences. Compounds in residences and office buildings with odor quotients between 0.1 and 1 were 1-butanol, formaldehyde, acetaldehyde, propionaldehyde, 3-methylbutanal, m/p-xylene, naphthalene, and 1,4-dichlorobenzene.

Only three VOCs with summarized maximum concentrations in residences and office buildings were considered to be relatively potent sensory irritants at the reported concentrations. The maximum concentrations of these compounds are listed by building type along with their respective sensory irritation quotients in Table 2. Due to its low sensory irritation threshold value, acrolein had the singularly highest quotient in residences. Formaldehyde and acetic acid with quotients near or in excess of unity also were indicated to be of relatively high concern with respect to sensory discomfort in residences.

Table 3 lists the central tendency concentrations and the chronic toxicity quotients for the most potent VOCs in the review. VOCs with hazard quotients >1 were formaldehyde, acetaldehyde and acrolein, for which only residential data were available. Of these, acrolein had the singularly highest hazard quotient. VOCs with hazard quotients >0.1 were the aromatic hydrocarbons, benzene, toluene and naphthalene, and the chlorinated solvent tetrachloroethene.

Table 2. Maximum concentrations of VOCs of potential concern in existing and new residences and in office buildings with their odor and sensory irritation quotients (maximum conc./odor or sensory irritation threshold).

	Maximum Conc. (ppb)			**Odor Quotient**			**Sensory Irr. Quotient**		
Compound	Exist Res.	New Res.	Office Bldg.	Exist Res.	New Res.	Office Bldg.	Exist Res.	New Res.	Office Bldg.
1-Butanol		21	0.5		**0.11**	0.03			
Formaldehyde	180	62		**0.21**	0.07		**2.3**	**0.81**	
Acetaldehyde	16	43		0.08	**0.23**				
Acrolein	13						**160**		
Propionaldehyde	5.6	19		**0.21**	**0.70**				
3-Methylbutanal	1.2			**0.55**					
Hexanal		36	2.4		**4.6**	**0.30**			
Heptanal		4.9			**1.5**				
Octanal		7.2			**18**				
Nonanal		7.6	1.4		**3.5**	**0.64**			
Acetic acid	81	280		**81**	**280**		**0.62**	**2.2**	
Hexanoic acid		5.5			**11**				
m/p-Xylene	67	11	10	**0.21**	0.03	0.03			
Naphthalene	0.95		1.9			**0.13**			
1,4-Dichlorobenzene	26		7.0	**0.54**		**0.15**	0.05		0.01

Table 3. Central tendency and derived 95th percentile concentrations of selected VOCs in existing residences and in office buildings with their noncancer chronic toxicity quotients (derived 95%ile conc./lowest chronic toxicity guideline).

	Central Tend. Conc.		**Derived 95%ile Conc.**		**Chronic Tox. Quotient**	
Compound	Exist Res.	Office Bldg.	Exist Res.	Office Bldg.	Exist Res.	Office Bldg.
Formaldehyde	17		61		**26**	
Acetaldehyde	3.0		11		**2.2**	
Acrolein	1.8		6.5		**217**	
Benzene	0.9	1.0	3.2	3.6	**0.17**	**0.19**
Toluene	3.3	2.1	12	7.6	**0.15**	0.09
Naphthalene	0.09		3.2		**0.19**	
Tetrachloroethene	0.14	0.47	0.51	1.7	**0.10**	**0.33**

4. Conclusions

We have presented a methodology for classifying the relative importance of VOCs commonly present in indoor air with respect to their odor and sensory irritation potency and noncancer chronic toxicity. Although both the concentration distribution and the health effects data upon which this methodology was based are imperfect, only a small number of the more than 100 reported VOCs were shown to exceed levels of potential concern with respect to the comfort and health endpoints considered. We recommend future studies characterizing VOC concentrations and exposures in buildings focus their resources on measurements of those compounds most likely to impact occupants as determined by the objectives of the investigations. The lists of target compounds likely would be relatively small. In addition to the compounds identified here, other compounds with similar physiochemical properties should be included in monitoring studies. For a few compounds, such as acrolein and formaldehyde, the evidence likely is sufficient to warrant efforts to reduce and otherwise control their sources in buildings.

5. Acknowledgements

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A Study for Measuring Emissions of Organophosphate Flame Retardants and Exposure Assessment

Y. Ni[1], K. Kumagai[1], Y. Yanagisawa[1]

[1] Graduate School of Frontier Sciences, The University of Tokyo, 7-3-lHongo, Bunkyo-ku, Tokyo,
113-8656, Japan e-mail: yueyong.ni@yy.t.u-tokyo.ac.jp
http://www.yy.tu-tokyo.ac.jp

Summary: *A simple, low cost, reliable passive flux sampler for measuring the emissions of organophosphate flame retardants was developed in this study. With this sampler, the emissions from polyvinyl chloride wall covering samples with different contents of tris(2-chloroisopropyl)phosphate (TCPP) in different temperatures were examined .Exposure assessment was also carried out. The results implied that there are possible high health risks while using high organophosphate flame retardants content materials in high temperature indoor environment.*

Keywords: *Organophosphate flame retardants, Flux, Exposure*
Category : *Materials as sources of indoor pollutants, Indoor Air exposure*

1. Introduction

In 1992, world wide usage of flame retardants was estimated at 600000 tons of which 102000 tons about 17% are organophosphate flame retardants 1) . By 2001, these numbers had risen to 1217000 and 186000 tons, respectively 2) . Polybrominated diphenyl ether (PBDE) and polybrominated biphenyls (PBB) the most frequently used 2 kinds of BFRs will be regulated by executive branch of EU in 2006. In recent years, organophosphate flame retardants were used as substitutes for polyminated flame retardants (BFRs). The consume amounts of organophosphate flame retardants in 2001 was 22000 tons about 5 times than that of 2000 in Japan 3). The organophosphate flame retardants are additives to polymeric materials that typically make up 1-30% of the composition with an average of 5-15%2) Reducing the risk of fire is the main advantage of using organophosphate flame retardants. However, there are possible health risks from the toxicity of organophosphate flame retardants.

Recently some study about the toxicity of organophosphate flame retardants have been carried out. Tris (chloropropyl) phosphate (TCEP), tris(l,3-dichloro-2-propyl) phosphate (TDCPP) are carcinogenic for animals, Tris(2-chloroisopropyl) phosphate (TCPP), tris(2-butoxyethyl) phosphate (TBEP) are possible carcinogens . Triphenyl phosphate (TPP) and trisbutyl phosphate (TBP) are supposed with delayed neurotoxicity . The acute effect of TCEP, an increase in the spontaneous ambulatory activity in male mice caused by neurochemical mechanism was also reported. Organophosphate flame retardants are of concern because they emits out of the products over the course of their lifetime with exposure to humans mainly through ingestion, inhalation of particles, gas phase and dermal sorption 1)4)5).

Many organophosphate flame retardants have been detected in indoor air 2) 6) 7) .and house dust8) 9) .TCPP and TCEP were the most predominantly detected organophosphate flame retardants in indoor air in Japan 7) .TCPP also be found in surface water range 100-400ng/L10).

Few study about indoor pollution of organophosphate flame retardants, especially exposure assessment about organophosphate flame retardants have been performed. In this study, a simple, low cost, reliable passive flux sampler for measuring the emissions of organophosphate flame retardants was developed. Using the passive flux sampler, The fluxes of wall covering samples with different TCPP contents (w/w) were measured. Personal exposure assessment has also been carried out using the emission data.

2. Methods and materials

2.1.Design of the passive flux sampler

A passive sampler for organophosphate flame retardants (PFS-OFR) was developed in this study. Structure of the passive sampler was shown in Fig.l. The PFS-OFR consisted of a circular glass plate (internal diameter 47mm, height 5mm) and an Empore C18FF disk adsorbent (diameter 47 mm, thickness 0.5mm; 3M Inc., USA). The structure of PFS-OFR is shown in Fig. 1.

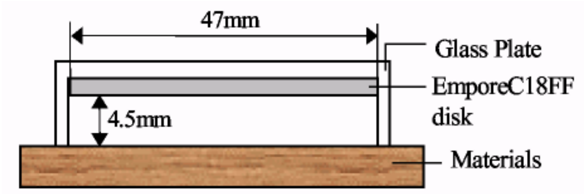

Fig. 1. Structure of PFS-OFR

2.2. Analysis

The organophosphate flame retardants adsorbed at the Empore C18FF disk were ultrasonic-extracted (W-l 13 MK-2, Honda Electronics Co. Ltd, Japan) for 30 minutes in 3ml acetone (HPLC grade, Wako Pure Chemicals Co. Ltd, Japan). Determination of the organophosphate flame retardants conducted by gas chromatography- Flame Photometric Detection (GC-FPD, HP6890, Hewlett-packard, USA) equipped with a HP-1 column (30m χ 0.25mm i.d., 0.32um film thickness). The column was maintained at 70°C for 2.0 minutes and then increased at 8.5°C/min to 290°C where it was held for 3 minutes. The injection temperature was held at 250 °C. An auto-sampler HP-7683 was used for sample injection. The injection volume was 3.0 ul and the plused splitless injection mode was used. Helium was used as carrier gas (20ml/min, constant flow mode), The hydrogen and air flow were 90ml/min and l00ml/min, respectively. The detailed detected conditions of GC/FPD is shown in table 1.

10 organophosphate flame retardants compounds under study- trimethyl phosphate (TMP), triethylphosphate (TEP), tris(chloropropyl)phosphate (TCEP), tris(2-ethylhexyl) Phosphate (TEHP), tris(l,3-dichloro-2-propyl) phosphate (TDCPP), tricresyl phosphate (TCP), Tris(2-chloroisopropyl)phosphate (TCPP), trisbutyl phosphate (TBP), tris(2-butoxyethyl)phosphate (TBEP) and triphenyl phosphate (TPP) were purchased from Wako Pure Chemicals Inc.

Table 1. The detected conditions of GC/FPD

Column	HP-l(Agilent, 0.32mmi.d*30m)
Carrier gas	He 20ml/min
Hydrogen flow	90ml/min
Airflow	l00ml/min
Injection temp.	250°C
Detector temp.	250°C
Oven temp.	70°C (2min)-8.5°C/min-290°C(3min)
injection volume	SuKplused splitless)

2.3. Sample materials

The wall covering samples with different TCPP content (1%, 3%, 5%, 10%, 20%, by weight) were donated by Kanto leather Ltd, Japan. The main content of the wall covering sample were polyvinyl chloride (PVC) and $CaCO_3$, 40% and 28%, respectively. All experiments started immediately after delivery of the wall covering samples.

3. Results and discussion

3.1 Quality assurance and quality control

No organophosphate flame retardant was detected in any of the blank samples. The limits of detection (LOD) and limits of quantification (LOQ) were defined as signal/noise ratios of three and ten, TMP (78.4%), TBEP (84.6%), the recovery rates of all the organophosphate flame retardants were in the range of 85%-105%.

3.2. TCPP emissions from wall covering samples

The fluxes of TCPP at 25 °C from different TCPP content wall covering samples and the temperature dependence of them were reported in our previous study[11]. The results were shown in table2and 3.

Organophosphate flame retardants emissions results in our study are significantly higher than found in other research [12]. The wall covering samples determined in this study were very new products. We bring them directly from a wall covering factory and all experiments were carried out immediately after delivery of the samples.

3.3. Long-term emission rate

The emissions of TCPP from a wall covering sample with 5% TCPP additive level as a function with time is shown in Fig.4. The experiment was carried out in room temperature (22-28 °C). Over the test period of 280 days, TCPP emissions decreased from 644.8 to 73.2ug $m^{-2}h^{-1}$ (Fig. 3). This experiment result shows there may be higher organophosphate flame retardants emissions from new plastic materials.

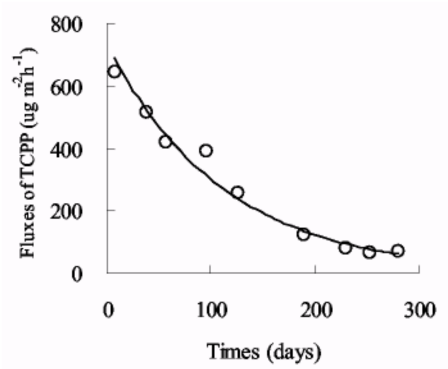

Fig.3. The relationship between elapsed time and TCPP emissions

Table 2. Fluxes of TCPP from different content wall covering materials (25°C,ug $m^{-2}h^{-1}$)

content (w/w)	mean	SD	RSD(%)
1%	262.3	29.3	11.2
3%	452.6	60.6	13.4
5%	644.8	94.2	14.6
10%	1119.1	116.3	10.4
20%	2166.8	146.3	6.8

Table 3. Temperature dependence of TCPP emission

temperture(°C)	emission (ug m^{-2} h^{-1})
25	644.8
40	1135.7
60	2841.2

3.4. Exposure Assessment

TCPP indoor air concentrations have been predicted using the emission data after 280days. The data of model room has been used upon JIS A1901. It is assumed that people spend their time 12hours/day in the model room. TCPP emitted from wall covering is permised as perfect diffusion in the room. Personal exposures were calculated using the predicted indoor air concentrations. The constrained conditions of exposure assessment were shown in table4. The results of exposure assessment were described in Fig.4.

Table4. Constrained conditions of exposure assessment

Cubic Volume of Room (m^3)	17.4
Area of Wall Covering (m^2)	7
Air Change rate (times/h)	0.5
Spend Time in Room(hrs/day)	12

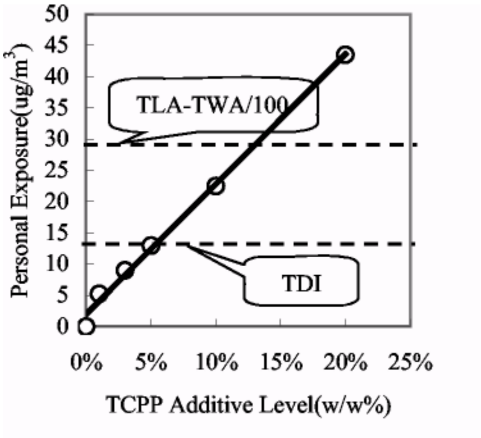

Fig.4. Exposure assessment of TCPP

The exposure was higher than 1/100 TLA-TWA (Threshold Limit Value-Time Weighted Average) . Assuming that a Japanese person inhales $15m^3$ air daily and the weight of an adult is 60 kg, the human daily intake of TCPP from air was estimated using the predicted TCPP personal exposure. The results were shown in table 4.

Table4. Estimation of TCPP human daily intake

additive level	personal exposure (ug/m^3)	daily intake (ug/kg/day)
1%	5.3	1.3
3%	9.0	2.3
5%	13.0	3.2
10%	22.5	5.6
20%	43.5	10.9

The tolerable daily intake (TDI: NOAEL/safety factor: 10000) of TCPP is 3.6 ug/kg/day. Comparing the estimated TCPP human daily intake of this study to TDI, the TCPP daily intake of 10% and 20% additive level were higher than TDI (Fig.4).

Little is known about mechanism of organophosphate flame retardants diffusion in indoor environment. TCPP was assumed as perfect diffusion in this study. The maximum exposures have been predicted. Although there were some excessive assessment, the result of this study indicate that there are potential high health risks in some special situations, for example, a new built residence with high organophosphate flame retardants content materials. An indoor air investigation research in Japan also showed the maximum indoor concentration of TCPP was higher than $10ug/m^3$in Tokyo residence (Saito et al.,2001).

4. Conclusion

The emissions from PVC wallpaper samples with different contents of TCPP in different temperatures were examined. Exposure assessment was also carried out. The results suggested that there are possible high health risks while using high organophosphate flame retardants content materials in indoor environment.

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Room Temperature and Productivity in Office Work

O. Seppänen[1], W. J. Fisk[2] and Q.H. Lei[2]

[1]Helsinki University of Technology, Laboratory of Heating, Ventilating and Air-conditioning, PO Box 4100,
FIN-02015 HUT, Finland
email: olli.seppanen@hut.fi http://www.hut.fi
[2]Lawrence Berkeley National Laboratory, USA

Summary: *Indoor temperature is one of the fundamental characteristics of the indoor environment. It can be controlled with a degree of accuracy dependent on the building and its HVAC system. The indoor temperature affects several human responses, including thermal comfort, perceived air quality, sick building syndrome symptoms and performance at work. In this study, we focused on the effects of temperature on performance at office work. . We included those studies that had used objective indicators of performance that are likely to be relevant in office type work, such as text processing, simple calculations (addition, multiplication), length of telephone customer service time, and total handling time per customer for call-center workers. We excluded data from studies of industrial work performance. We calculated from all studies the percentage of performance change per degree increase in temperature, and statistically analyzed measured work performance with temperature. The results show that performance increases with temperature up to 21-22 °C, and decreases with temperature above 23-24 °C. The highest productivity is at temperature of around 22 °C. For example, at the temperature of 30 $^{\circ C}$ the performance is only 91.1% of the maximum i.e. the reduction in performance is 8.9%*

Keywords: *productivity, performance, temperature, offices, cost-benefit analysis*
Category: *Occupant perception and work performance*

1 Introduction

In many commercial buildings, thermal conditions are not controlled well, due to insufficient cooling or heating capacity, high internal or external loads, large thermal zones, improper control-system design or operation, and other factors. Thermal conditions inside buildings vary considerably, both with time, e.g., as outdoor conditions change, and spatially. While the effects of temperature on comfort are broadly recognized, the effects on worker productivity have received much less attention.

Increased evidence shows that indoor environmental conditions substantially influence health and productivity. Building services engineers are interested in improving indoor environments and quantifying the effects. Potential health and productivity benefits are not yet generally considered in conventional economic calculations pertaining to building design and operation. Only initial cost plus energy and maintenance costs are typically considered. A few sample calculations have also shown that many measures to improve the indoor air environment are cost-effective when the health and productivity benefits resulting from an improved indoor climate are included in the calculations (Djukanovic et al. 2002, Fisk 2000, Fisk et al. 2003, Hansen 1997, van Kempski 2003, Seppänen and Vuolle 2000, Wargocki, 2003). There is an obvious need to develop tools so that economic outcomes of health and productivity can be integrated into cost-benefit calculations with initial, energy and maintenance costs. We assembled existing information on how temperature affects productivity, so that these productivity effects could be incorporated into cost-benefit calculations relating to building design and operation.

2 Linkage between productivity and temperature

Room temperature could influence productivity indirectly through its impact on the prevalence of SBS symptoms or satisfaction with air quality; however, for cost-benefit calculations it is most feasible to use the available data linking directly temperature, or thermal state, to productivity.

We have earlier developed (Seppänen et al. 2003) a relation between performance and temperature. It showed a decrease in performance by 2% per °C increase of the temperature in the range of 25-32 °C, and no effect on performance in temperature range of 21-25 °C.

Several studies have reported performance and temperature since the previous review. We have also been able to identify some old studies on performance related to office work, which were not included in our earlier review. Various metrics of performance were used in these studies. Field studies used a work task as metrics of performance, in call centers the talk time or the handling time per client was used as in indication of the speed of work. Laboratory studies typically measured performance in a single or combined task. Some studies measured a single task in the field conditions.

In this paper we present results of an analysis of available scientific findings on how temperature affects work performance. We considered only data from studies with objective measures of performance. The results of subjective assessments, such as self-assessments, of performance were neglected. The goal was to develop the best possible quantitative relationship between temperature and work performance for use in cost benefit calculations related to building design and operation.

3 Methods

We included in this review those studies that had used objective indicators of performance that are likely to be relevant in office type work, such as text processing, simple calculations (addition, multiplication), length of telephone customer service time, and total handling time per customer for call-center workers. We excluded data from studies of industrial work performance.

Through computerized searches and reviews of conference proceedings, we identified 24 relevant studies. In eleven of those, the data were collected in the field (i.e., workplace studies), and nine studies had data collected in a controlled laboratory environment. Most field studies were performed in offices and some in schools. The studies are summarised in Table 1. The table also shows the performance indicators used in each study. Most office studies were performed in call centres where the time required to talk with customers, the processing time between calls with customers, and other relevant information were automatically recorded in computer files. In these studies, the speed of work, e.g. average time per call or “average handling time”, was used as a measure of work performance. Laboratory studies typically assessed work performance by having subjects perform one or more tasks that simulated aspects of actual work and by subsequent evaluation of the speed and/or accuracy of task performance. We calculated the quantitative effect on performance from adjusted data given in the papers, when available. Some of the studies compared only two temperatures, while some provided data comparing several temperatures. We included in the summary all reported data points regardless of the level of statistical significance, which actually was not reported in all studies.

We calculated from all studies the percentage of performance change per degree increase in temperature, positive values indicating increases in performance with increasing temperature, and negative values indicating decreases in performance with increasing temperature. Each of the resulting slopes in the performance-temperature relationship was associated with a central value of temperature for that specific assessment.

The included studies also varied greatly in sample size and methods. In a meta-analysis, estimates from each study should be weighted by their precision. The precision of each estimate is inversely proportional to its variance. However, since variance information is not provided for most of the studies, principles of meta-regression cannot be applied properly to estimate the precision of the overall effect. Regression weighted by sample size was chosen as the best alternative, because in general the higher the sample size, the lower the variance. The sample sizes range from 9 to 500. Several studies reported multiple tasks for the same subjects. The results from these tasks may be highly correlated. In the case of multiple outcomes, i.e., multiple performance tasks, for the same set of subjects under the same conditions, sample sizes were divided by the number of outcomes used in the study resulting in a modified sample size. To prevent large studies from having excessive influence on the regression, their weight was reduced by giving the maximum weighting factor (1.0) to studies with one hundred or more subjects. Thus, the weighting factor for sample size is the modified number of subjects in the study divided by the number of subjects in the largest reference study (100).

Secondly we also applied a weighting factor based on the authors’ judgement of the relative relevance of the performance outcome to real work. For these judgments, we assumed that measurements of the performance changes of real work in office workers was more representative of overall real-world work performance, and should be weighted higher than performance changes in computerized tasks, such as proof reading or typing, that simulate a portion of work. We also, assumed that performance changes in simulated work tasks were more relevant (deserved more weight) than performance changes in school tests, manual tests and vigilance tests. The weighting factors for each outcome type rage from 0.15 to 1.0 (Table 1).

All data points derived by this way are presented in Figure 1 with percentage change in performance in vertical axis and average temperature of assessment in the horizontal axis. Positive values indicate improved performance and negative values deteriorated performance with increasing temperature.

Using command "regress" in Stata 8.2 for Windows (a program that selects the best fitting linear model of dependent variable on explanatory variables), we fit quadratic model to the data for normalized percentage change in performance vs. temperature unweighted, weighted by sample size, and weighted by combined final weight separately.

4 Results

The graph in Figure 2 shows that performance increases with temperature up to 21-22 °C, and that performance decreases with temperature above 23-24 °C. The intersection of horizontal axis occurs at temperature of 21.75 °C. The shaded area in the figure represents 90% confidence interval of the curve with composite weights. As can be seen, the confidence interval is positive up to temperature of 20 °C and negative at temperatures above 23 °C. The interpretation is that an increase of temperature up to 21 °C is associated with a statistically significant improvement in performance and an increase of temperature above 24 °C is associated with a statistically significant decrease in performance. This result is in a close agreement with our earlier conclusion reporting the no-effect temperature range being 21-25 °C (Seppänen et al. 2003); however, this new analysis also provides a best estimate of how performance varies with temperature in the 21-24 °C range.

From "slope of the curve" in Figure 1 we further developed curve for the performance in relation to temperature. This curve is shown in Figure 2. It shows the decrement of performance in relation to maximum. For example, at the temperature of 30 °C the performance is only 91.1% of the maximum at 21.75 °C, i.e. the reduction in performance is 8.9%.

Table 1. Studies with performance and temperature in tasks related to office work and the weighting factor of the outcome when developing a relationship between performance and temperature.

Outcome or tasks and weighting factor of the outcome in the analysis ( )	Author and year of the study	Environment of the study
Objectively reported work performance (1)	Federspiel et al. 2004, Heschong 2003, Korhonen et al. 2003, Niemelä et al. 2001, Niemelä et al. 2002, Tham 2004, Tham &Willem 2004	Office environment
Complex tasks (0.5)	Chao et al. 2003, Heschong 2003 Link and Pepler 1970	Office environment Field laboratory Apparel factory
Simple tasks, visual tasks (0.25)	Berglud 1990, Fang 2004, Hedge 2004, Langkilde 1978, Langkilde et al. 1979, Löfberg et al. 1975, Wyon 1996	Laboratory
Vigilance task or manual tasks related to office work (0.15)	Meese et al. 1982 Mortagy and Ramsay 1973; Wyon et al. 1996	Field laboratory Laboratory
Learning (0.15)	Allen et al. 1978, Holmberg and Wyon 1969, Johansson 1975, Pepler and Warner 1968,	Class room

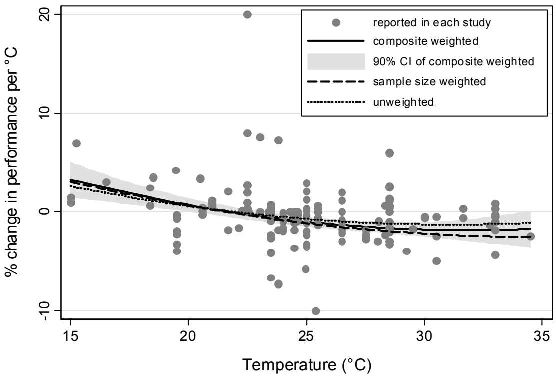

Fig. 1. Percentage change in performance vs. temperature. Positive values indicate improved performance and negative values deteriorated performance with increase in temperature. The graph includes the data points from the studies in Table 1. Weighting factors are explained in the text.

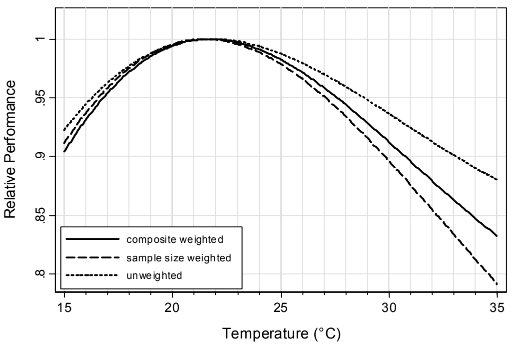

Fig. 2. Normalized performance vs. temperature. Derived from the curve in figure 4. Maximum performance is set equal to 1 at the temperatures where the curves in the figure 1 cross the horizontal axis.

The equation for the curve with composite weighting factors is

$$P = 0.1647524 \cdot T - 0.0058274 \cdot T^2 + 0.0000623 \cdot T^3 - 0.4685328$$

where
P is productivity relative to maximum value
T is room temperature, °C

5 Discussion

The field studies show a consistent decrease in performance in tasks typical of office work when temperature increase above 24-26 °C. The tasks in the reviewed studies are quite simple, and it is not clear how well the data apply to performance in actual office environments. However, as the reviewed studies include different specific tasks, the developed weighted relation may well represent average work in the office and may be applicable in many office environments.

The measurements of performance varied greatly from study to study. The unweighted and sample size weighted regression models are based on the assumption that all measurements reflect underlying productivity equally well. Although the combined weights take into consideration the relevance of different productivity measurements, the assignment of weights is rough and involves subjectivity. Another important assumption is the independence of studies. This assumption is violated in studies performed on the same set of subjects.

6 Conclusion and implications

We have developed a quantitative relationship between work performance and temperatures within, below and above the comfort zone. This relationship has a high level of uncertainty; however, use of this relationship may be preferable to current practice, which ignores productivity. The quantitative relationship between temperature and productivity may vary, depending on other building features and on the characteristics of the building occupants and their type of work. Remedial measures will generally also be more cost effective in buildings that have poorer initial IEQ or more existing adverse health effects.

The data summarised in Figure 1 on the relationships between temperature and productivity decrements include studies of routine-type work and several mental tasks. We were not able to distinguish the effect of the type of work in our review. The model we used averages all studies in actual office work or in tasks performed typically in doing office work. The strongest effect on productivity was reported from phone-service work (Federspiel 2004), and the weakest effect from controlled laboratory experiments with female and male students performing various mental tasks (Pepler and Warner 1968, Langkilde 1978, Langkilde et al. 1979). Data suggest that the effect of the temperature may be stronger in actual work that in short-term laboratory experiments where the motivation may weaken the effect of the temperature. As a first approximation, the model is applicable to all types of office work.

High temperatures, in practice, may be associated with low ventiation rate; however, in the studies referred to in the paper, the ventilation was constant, thus the results indicate only the effect of temperature. Low ventilation combined with high temperature would most probably decrease the productivity further due to the increased prevalence of SBS symptoms and other effects.

7 Acknowledgement

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Productivity with Task and Ambient Lighting System Evaluated by Fatigue and Task Performance

N. Nishihara, M. Nishikawa, M. Haneda and S. Tanabe

Waseda University, 55N701, 3-4-1 Okubo, Shinjuku, Tokyo, Japan
email: nishihara@tanabe.arch.waseda.ac.jp

Summary: *In this study, work place productivity was evaluated by task performance and fatigue. The relationship of fatigue and task performance was studied by using the data of the controllable and uncontrollable illuminance level conditions with Task and Ambient Lighting system. When the subjects could control their task lights, performance of the triple digit multiplication task was significantly higher (p=0.01) and text typing test was tend to be higher (p=0.09) than that when they could not control the task lights. There was significant negative correlation between fatigue level of subjects and their performance of the multiplication task and text typing test.*

Keywords: *Productivity, Fatigue, Performance, Individual control, Task and ambient lighting*
Category: *Subjective experiment*

1 Introduction

It was reported that poor indoor environmental quality leads to office worker's fatigue and measurement of fatigue level may be useful to evaluate the effect of Indoor Environmental Quality on productivity [1], [2]. However, the relationship of fatigue and task performance was not clearly explained.

The objective of this study is to evaluate how much fatigue levels affect task performance. Subjective experiments were conducted with Task and Ambient Lighting (TAL) system, which allows subjects to control of illuminance level individually.

2 Methods

Subjective experiments were conducted in the climatic chamber at Waseda University in Japan. In this study, the relationship of fatigue and task performance was studied by using the data of the controllable and uncontrollable illuminance level conditions with TAL system. The initial settings of illuminance level on the desk without subjects were 700lx with the ambient lighting system (400lx) and the task lighting system (300lx). In the "controllable" condition, subjects were allowed to control the illuminance level on the desk with task lights. In the "uncontrollable" condition, they were not allowed to control it.

Subjects experienced these two conditions in balanced order. Prior to the above-mentioned two conditions, the subjects underwent practice sessions twice under same conditions with "uncontrollable" condition and with only ambient lighting system (700lx). The experimental chamber conditioned at 25°C, 40%RH, and still air.

Air temperature, relative humidity, condensation level of CO_2 in the climatic chamber, illuminance level on the desk and the electrical power consumption of task lights were measured during the exposure. Experimental setup in a climatic chamber is shown in Fig.1. The environmental conditions are shown in Table 1.

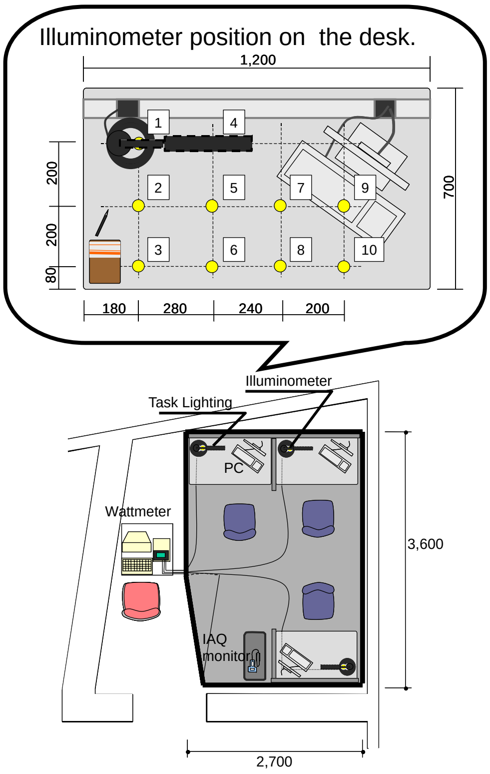


Fig. 1. Experimental setup in a climatic chamber

Twelve male subjects of college-going age participated in the experiments. Anthropometrical data for the subjects are listed in Table 2. They participated in the experiment four times in total at intervals of 1 week. Subjects were exposed in climatic chamber in groups of 3 at a time. Subjects were exposed on the same weekday and the same time of the day in the successive experimental weeks to avoid any influence of weekday/time of the day on the within - subject difference between conditions. All subjects were volunteers and they were paid at a fixed rate for their participation. To investigate the effect of individual control of illuminance level on productivity precisely, it is required to control subjective motivation at the same level as much as possible. However, it is very difficult to neutralize subjective motivation. In this study, in order to increase their motivation to the same level, they were informed that the top 6 performers of the tasks could earn bonus. Therefore, it could be assumed that subjects were highly motivated.

Table 1. Environmental conditions

	Air temp [°C]	Humidity [%RH]	CO_2 [ppm]	Illuminance level [lx]	
				During exposure Position 1	After exposure Position 5
Controllable	25.1 (0.6)	41 (1.5)	645 (78)	526 (102)	696
Uncontrollable	25.1 (0.6)	41 (1.4)	640 (75)	527 (31)	708

Table 2 Anthropometrical data for the subjects.

Sex	No	Age [year]	Height [cm]	Weight [kg]	Body Surface Area[*1] [m^2]	Rohrer Index[*2] [-]
Male	12	22.1 (1.7)	171.3 (7.4)	62.2 (6.9)	1.7 (0.1)	122.6 (7.4)

*1 Calculated by Takahira's Equation :

*2 Rohrer Index = W / $L^3 \times 10^7$ ( ) Standard Deviation

The intensity of general perceptions of the light environment was indicated by the subjects on questionnaires (Acceptability: +1: clearly acceptable, +0: just acceptable, -0: just not acceptable, -1: clearly not acceptable, Comfort sensation: 0: comfortable, -1: slightly uncomfortable, -2: uncomfortable, -3: very uncomfortable, Glare sensation: 0: not uncomfortable, -1: slightly uncomfortable, -2: uncomfortable, -3: very uncomfortable). Subjects filled in National Aeronautics and Space Administration Task Load Index (NASA-TLX) to measure the mental workload [3], [4].

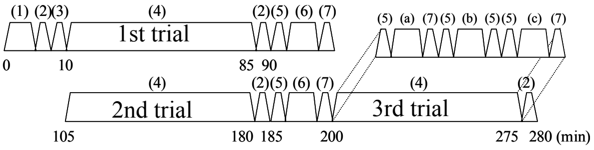
To evaluate fatigue, subjects used the questionnaire for 'Evaluation of Subjective Symptoms of Fatigue', which is recommended by the working group for occupational fatigue of the Japan Society for Occupational Health [5] and is used earlier by Nishihara et al. [6]. It consists of three categories; group I consists of 10 terms about 'drowsiness and dullness', group II consists of 10 terms about 'difficulty in concentration', and group III consists of 10 terms about 'projection of physical disintegration'. The rate of complaints was calculated by equation (1).

General rate of complaints
*= "Total number of a corresponding fatigue symptoms" / "Total number of symptoms on the evaluation sheet" * 100 (%)* ···(1)

Subjects assessed also the self-estimated performance by marking the scales. One of the scales is about suitability of the light environment for tasks (+1: Clearly suitable, +0: Just suitable, -0: Just unsuitable, -1: Clearly unsuitable). The other is the estimation on how subjects thought their productivity at work would be enhanced or interfered by the exposed lighting environment (+50: enhance their productivity, 0: interfere their productivity). All questionnaires were presented to subjects on a computer screen.

During exposures the subjects performed three different typical office tasks being presented to them on a computer screen. They included: 3-digit multiplication on paper, dictionary-thumbing task which ask subjects to look up in a dictionary and type dictionary words on PC, and text typing on PC. Four versions of each task were prepared of approximately the same difficulty. The subjects were presented to each version only once. Performance was studied by analyzing how quickly and how accurately the tasks were performed.

Experimental procedure is shown in Fig.2. Subjects were asked to perform the office simulated tasks for 60 minutes (multiplication task for 20 minutes, dictionary-thumbing task for 20 minutes and text typing test for 20 minutes) three times. In the "controllable" condition, subjects were allowed to control the illuminance level on the desk with task lights to suite each task for 2 minutes before performing tasks.



(1)Questionnaire (2)Voting [Environment, Vigor], Flicker test (3) Voting [Lighting environment, Fatigue], (4) Office simulated tasks, (5) Control in illuminance level [2min.], (6) Resting sedentary [10min.], (7) Voting [Lighting environment, Fatigue, Mental workload, self estimated productivity]

(a) Triple digit multiplication task on paper [20min.]

(b) Reffering to dictionary and input data [20min.]

(c) Text Typing [20min.]

Fig. 2. Experimental procedure

For the analysis, the data during the 2nd trial of office simulated tasks were used to avoid the effect of warming-up and final push. For comparison between controllable and uncontrollable conditions, paired t-test was used. The level of significance was set at $P<0.05$, 2-tail. For the analysis of correlation between fatigue level and the corresponding average value of normalized score of task performance, Pearson's product moment correlation coefficients were calculated.

3 Results

Lighting Environment

The results of acceptability and comfort of the lighting environment are shown in Table 3. Acceptability in controllable conditions was higher than that in uncontrollable conditions. The comfort sensation vote at dictionary-thumbing was significantly higher in controllable condition than that in uncontrollable condition. There was no significant difference in sensation of glare between controllable and uncontrollable conditions. The average values of electrical power consumption of task lights are shown in Table 4.

Table 3 Acceptability and comfort sensation vote

	Acceptability			Comfort		
	Multiplication	Dictionary	Text typing	Multiplication	Dictionary	Text typing
	*p<0.05	** p<0.01	* p<0.05	+p<0.1	* p<0.05	n.s.
Controllable	0.68 (0.32)	0.67 (0.32)	0.63 (0.36)	-0.16 (0.17)	-0.13 (0.13)	-0.18 (0.20)
Uncontrollable	0.45 (0.40)	0.46 (0.33)	0.55 (0.32)	-0.33 (0.32)	-0.23 (0.17)	-0.23 (0.20)

( ) Standard Deviation , n.s.: no significant difference

Table 4 The electrical power consumption of task lights

(W)	Multiplication	Dictionary-thumbing	Text typing	Resting
Controllable	15.9 (3.4)	15.2 (5.3)	13.8 (5.2)	8.4 (7.2)
Uncontrollable	12.4 (0.3)	12.4 (0.2)	12.4 (0.2)	12.4 (0.2)

( ) Standard Deviation

Fatigue

The results of the general rate of fatigue are shown in Fig.3. There was no significant difference in the general rate of fatigue between controllable and uncontrollable conditions.

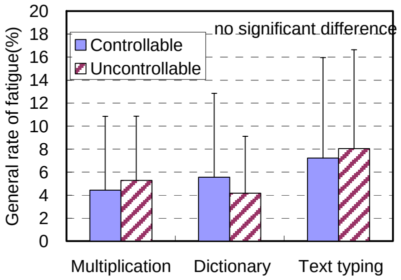


Fig. 3. General rate of fatigue.

Performance of task

When the subjects could not control their task lights, performance of the triple digit multiplication task was significantly lower (p=0.01) and text typing test was tend to be lower (p=0.09) than that when they could control the task lights. There was no significant difference in the performance of the dictionary-thumbing test between controllable and uncontrollable conditions. The results of task performance of multiplication task and text typing are shown in Fig.4.

Self-estimated performance

The results of the self-estimated performance are shown in Fig.5. In the controllable condition, the suitability of light environment for tasks was significantly higher than that in the uncontrollable condition. The light environment with control of the task lights was estimated to enhance their productivity more than that without it.

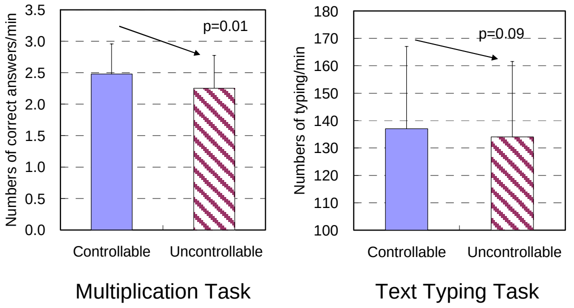
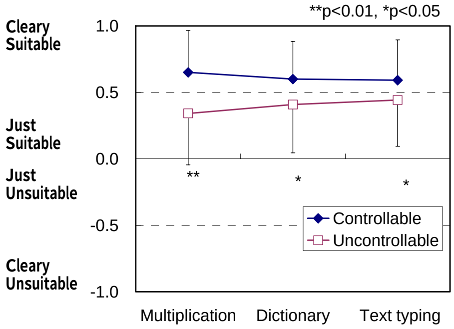
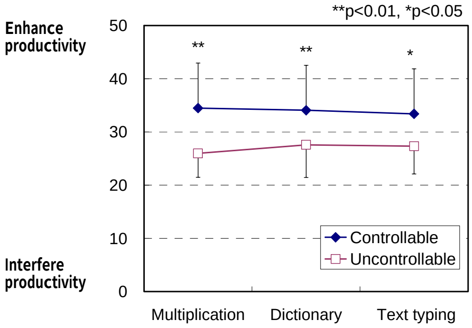


Fig. 4. Task performance



Suitability of light environment for tasks



Influence of Light Environment on Productivity

Fig. 5. Self-estimated performance

Relationship of fatigue and task performance

To evaluate how much fatigue levels affect task performance, the relationship of general rate of fatigue and task performance were examined. The data of the 2nd trial of controllable and uncontrollable conditions were used for the analysis. The task performance for each subject was evaluated by his standardized performance to precisely reflect the performance change of each subject. The standardized performance was calculated from the equation (2).

Standardized performance

$$S_{A,i} = \frac{x_{A,i} - \bar{x}_A}{s_A} \times 10 + 50 \quad ...(2)$$

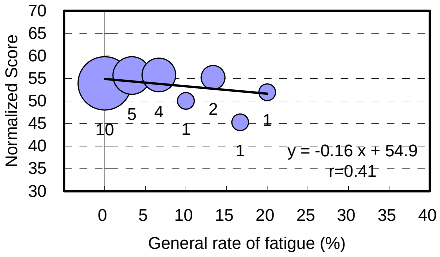
where,

$x_{A,i}$: Task performance during the session i for subject A

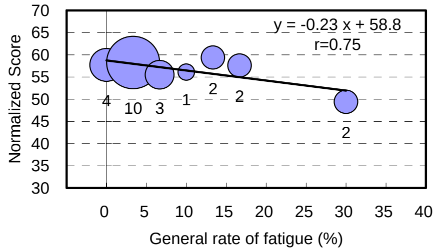
$\bar{x}_A$: Average task performance of the subject A among all sessions

s_A : Standard deviation for task performance of the subject A among all sessions

There was significant negative correlation between fatigue level of subjects and their performance of the multiplication task (r=0.41, p<0.05) and text typing test (r=0.75, p<0.01). The relationship of fatigue level and task performance of three digit multiplication task and text typing test are shown in Fig. 6.



Multiplication Task



Text Typing Task

Fig. 6. Relationship of fatigue level and task performance.

4 Discussions

When the subjects could control their task lights, performance of the triple digit multiplication task and text typing test were higher than that when they could not control the task lights. The self- estimated performances in controllable condition were significantly higher than that in uncontrollable condition. These results suggest that the providing individual control is the one of effective improvement strategies of indoor environment quality and support the previous findings of CIBSE's review [7] and Nishihara and Tanabe [2].

In this study, there was no significant difference in the general rate of fatigue between controllable and uncontrollable conditions, because even in the uncontrollable conditions the light environments were set up to be suitable for tasks and they were relatively accepted by subjects. There was significant negative correlation between fatigue level of subjects and their performance of the multiplication task and text typing task. In the previous studies, it was conjectured that the increase in fatigue would eventually leads to the decrement in performance from the schematic diagram. The results from this experiment should provide the evidences to this presumption and would contribute to its reasoning. Since fatigue is much easier to measure than the performance in real office for most of the time, more studies to link fatigue and performance are desirable for further study in productivity.

5 Conclusions

Subjective experiments were conducted with Task and Ambient Lighting system, which allows office workers to control of illuminance level individually.

1) Acceptability in controllable conditions was higher than that in uncontrollable conditions.
2) The self- estimated performances in controllable condition were significantly higher than that in uncontrollable condition.
3) Performance of the triple digit multiplication task and text typing test were higher in controllable conditions than that in uncontrollable conditions.
4) There was significant negative correlation between fatigue level of subjects and their performance of the multiplication task and text typing task. Measurement of fatigue may be useful to evaluate the effect of indoor environmental quality on office workers' productivity.

Acknowledgements

The authors wish to express appreciations to M Hayakawa, A Tanaka, and S Hyodo for their assistance during the experiment. This study was partially funded by the Grant-in-Aid for Scientific Research (A) of the JSPS (No.14205085).

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The Effect of Traffic Noise on Productivity

M. Haneda[1], S. Tanabe[1] and N. Nishihara[1]

[1]Waseda University, Dept. of Architecture, 3-4-1 Okubo Shinjuku-ku, Tokyo 169-8555
email: haneda@tanabe.arch.waseda.ac.jp http://www.tanabe.arch.waseda.ac.jp

Summary: *Subjective experiment was conducted to investigate the effect of traffic noise on productivity. Multiplication tasks were assigned for one hour, and subjective votes were collected before and after the task. During the experiment, the cerebral blood flows of the subjects were measured. There were no significant difference in performance; however, the fatigue level was higher after subjects worked with traffic noise. The subjects also voted that it required more effort and they felt more frustrated to work with the noise. The cerebral blood flow significantly increased during the task with traffic noise, and the blood flow kept high even after the task ended.*

Keywords: *productivity, subjective experiment, traffic noise, fatigue, cerebral blood flow*
Category: *Subjective experiment*

1 Introduction

Previous studies suggested that mental effort must be increased to maintain performance in the environment with poor indoor quality, which would bring the increase of fatigue and eventually lead to the decrement in performance [1]. The studies on the evaluation methods of productivity using human fatigue and cerebral blood flow have been done on thermal environment [2], on lighting environment [3], on individual air velocity control [4], and on air quality [5]. The objective of this study was to examine the effects on performance, fatigue and cerebral blood flow when simulated office tasks were assigned in a room with traffic noise.

2 Methods

2.1 Experimental design

Subjective experiments were conducted in a multimedia studio where four pairs of speakers were embedded in the surrounding walls. The layout of the studio is shown in Figure 1.

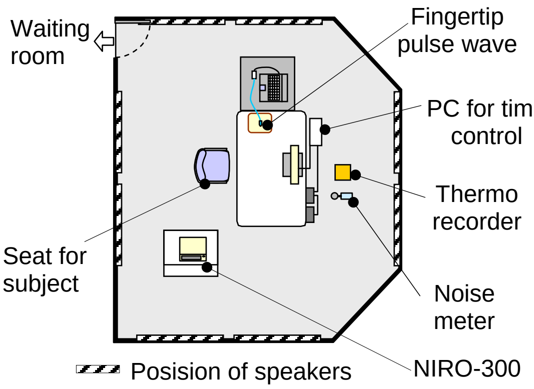

Figure 1. The layout of studio

The experiment was carried out on every Tuesday, Thursday and Friday between November 16th and December 17th, 2004. Twelve male college-aged right-handed subjects participated in this experiment with their age of 20.8±1.7, height of 169.3±6.1cm, and weight of 60.4±8.6kg. To keep the motivation of the subjects at same level, they were informed to be paid bonus depending on their performance. The subjects were exposed on the same day of the week and the same time of the day in the successive experimental weeks to avoid the difference within a subject by day and/or time influence.

2.2 Experimental conditions

Two environmental conditions were set, namely “without noise” and “with noise”. The traffic noise, which was recorded near the heavy traffic street in the city of Tokyo, was played in the studio from the speakers in “with noise” condition.

Davis and Jones have reviewed the studies on the effect of acoustic environment on performance [6]. They categorized the tasks used in the reviewed studies into four groups. In this experiment, of those four groups, multiplication task and short-memorization task were selected. In multiplication task, subjects were to solve triple-digit multiplication problems as many as possible during the task period of sixty minutes on papers (fifteen questions/page). A program to generate signal sound every ten minutes was run by a computer during the multiplication task to check the performance change over time. In short-memorization task, subjects were to see a computer monitor which displayed two Japanese characters at a time for twenty times continuously and write down the pairs of characters on an answer sheet after one minute of break. In the sixty minutes of task period, the process was repeated over twelve times. This task was controlled by the computer. Only the results and analyses of multiplication task are discussed in this paper.

The environmental conditions and the task conditions were combined together to create four experimental conditions. The conditions were balanced for order. Prior to the experiment, the subjects participated in a practice session in one of the experimental conditions.

The environmental conditions measured during the multiplication task are shown in Table 1. The air temperature, relative humidity, and illuminance were kept at same level in both conditions. The sound level of "with noise" was 74dBA, while "without noise" was 42dBA.

Table 1. Environmental conditions

	Air temp. [°C]	Relative humidity [%RH]	Illumi-nance [lx]	Equivalent sound level [dBA]
Without noise	25.3 (0.9)	44 (2)	823 (8)	42 (4)
With noise	25.6 (0.9)	44 (2)	819 (14)	74 (1)

( ) standard deviation

2.3 Measurements

Sensation, acceptance and comfort of the acoustic environment were asked to evaluate the perception of the environment. Sensation of the acoustic environment was measured using a scale with rating of: -3="very noisy", -2="noisy", -1="slightly noisy", 0="neutral", 1="slightly calm", 2="calm" and 3="very calm". Acceptance of the acoustic environment was measured by a scale with rating of: -1="clearly unacceptable", -0="just unacceptable", +0="just acceptable" and +1="clearly acceptable". Comfort was measured with a scale: -3="very uncomfortable", -2="uncomfortable", -1="slightly uncomfortable" and 0="comfortable".

To evaluate the feeling of fatigue, subjects filled in the sheets of "Evaluation of Subjective Symptoms of Fatigue", which was suggested by the working group for occupational fatigue of the Japan Society for Occupational Health. This evaluation method is used in the field of science of labor and ergonomics in Japan. It consists of three categories: group I consists of 10 terms on "drowsiness and dullness", group II consists of 10 terms on "difficulty in concentration", and group III consists of 10 terms on "projection of physical disintegration". Based on Yoshitake's method, the rate of complaints was calculated by Equation (1). By the order of the rate of complaints among three categories, three types of fatigue feeling were suggested [7]: "I>III>II" for general pattern of fatigue, "I>II>III" for typical pattern of fatigue for mental work and overnight duty, and "III>I>II" for typical pattern of physical work. "General rate of complaints" is defined as the rate of complaints about all thirty symptoms.

$$\textit{Rate of complaints}\ [\%] = \frac{\textit{number of selected symptoms of all subjects}}{\textit{number of terms concerned} \times \textit{number of subjects}} \times 100 \quad (1)$$

Mental workload was measured by the Japanese version of NASA-TLX (National Aeronautics and Space Administration Task Load Index). The original version of NASA-TLX [8] was translated into Japanese by Miyake [9]. NASA-TLX consists of six components including: "mental demand", "physical demand", "temporal demand", "performance", "effort", and "frustration level." The subjects vote each component by drawing a mark on corresponding visual analog scale. The endpoints of these scales are: good/poor for "performance" component and low/high for the others.

The near infrared spectrometer (NIRO-300, Hamamatsu Photonics) was used to measure the cerebral blood oxygenation changes during the experiment. Near infrared light was produced by laser diodes and carried to the tissue via optical fibers [10]. The light returned from the tissue to the instrument through another optical fiber by detector. Incident and integrated value of transmitted light intensities were recorded every second. Changes in the concentration of the chromophores oxygenated hemoglobin "ΔO_2Hb" and deoxyhemoglobin "ΔHHb" were calculated by Modified Beer-Lambert equation in μmol/L [11]. The changes in concentration of total hemoglobin "Δtotal Hb" (=$\Delta O_2Hb+\Delta HHb$) were calculated as an index of change rate of cerebral blood flow. Since the instrument measures the changes in concentration, the normalization of each measurement should be considered for comparison. In this experiment, rest in a sedentary position after setting of the probes was scheduled for the process. To compare the state of subjects before and after the task, the time to rest with their eyes closed were provided for two minutes before and after the task. First and last five seconds of measurements were cut off, and the averages of Δtotal Hb before the task (1min.50sec.), during the task (59min.50sec.) and after the task (1min.50sec.) were used for analyses.

2.4 Experimental Procedure

Procedure for this experiment is shown in Figure 2. Duration of the experiment lasted for ninety minutes.

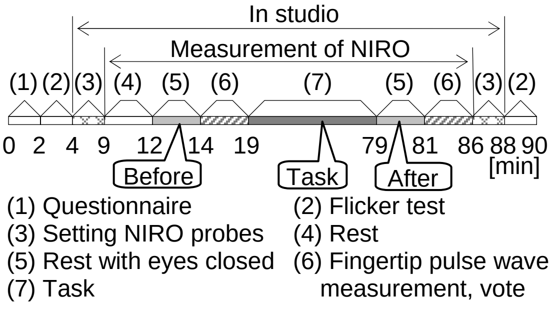

Figure 2. Procedure of subjective experiment

First, subjects answered questionnaire and took Flicker test in a waiting room. After entering the studio, the subjects seated in the chair and the probes of NIRO-300 were set on their right and left forehead. They stayed in a sedentary position for five minutes, and then they closed their eyes and stayed at same position for two minutes. Then, the pulse wave of fingertip was measured and the subjects voted on the perception of the environment, fatigue and vigor. They took the task for sixty minutes. After the task, they stayed with their eyes closed for two minutes again. Then, the pulse wave was measured, and the subjects voted on the perception of the environment, fatigue, vigor and mental workload. The probes were removed from their forehead. Finally, the subjects exited the studio and took the Flicker test in the waiting room.

2.5 Statistical analysis

The comparisons between the environmental conditions were analyzed by paired t-test with the level of significance of $p<0.05$. For performance and Δtotal Hb change over time, the one-way ANOVA was used, and when significant difference of $p<0.05$ was found, Fisher's protected LSD was used for further analysis.

3 Results

3.1 Perception of the environment

Sensation, acceptability, and comfort for the acoustic environment of the conditions reported by the subjects are shown in Table 2. From the results, the environment in "without noise" was evaluated as calm, acceptable, and rather comfortable, while that in "with noise" was evaluated as noisy, unacceptable, and uncomfortable. The two conditions were clearly different by the perception of the subjects (every comparisons between the conditions $p<0.001$).

Table 2. Perception of the environment

	Without noise		With noise	
	Before	After	Before	After
Acoustic sensation	2.19 (0.71)	2.28 (0.69)	-2.31 (0.41)	-2.15 (0.66)
Acceptability	0.56 (0.42)	0.57 (0.38)	-0.50 (0.20)	-0.59 (0.27)
Comfort	-0.28 (0.30)	-0.33 (0.24)	-1.70 (1.35)	-2.11 (0.58)

( ) standard deviation

3.2 Performance

The performance of multiplication task was evaluated by the number of correct answers in a minute. The performance over the task period was 2.19±0.64 in "without noise", while it was 2.13±0.75 in "with noise". There was no significant difference for performance between the conditions.

3.3 Fatigue

The results of "Evaluation of Subjective Symptoms of Fatigue" before and after the task in each condition were shown in Table 3.

Table 3. Fatigue

	Without noise		With noise	
	Before	After	Before	After
General	11.1	16.1	13.6	23.3
Group I	19.2	26.7	19.2	32.5
Group II	5.0	10.0	14.2	26.7
Group III	9.2	11.7	7.5	10.8

The general rate of complaints increased after the tasks, and the increase was larger in "with noise". The order of the categories was I>III>II before and after the task in "without noise". On the other hand, the order was I>II>III before and after the task in "with noise".

3.4 Mental workload

The results of each component of NASA-TLX are shown in Figure 3. The component of "frustration level" and "effort" in "with noise" was significantly higher than in "without noise" ($p<0.03$ and $p<0.02$ respectively).

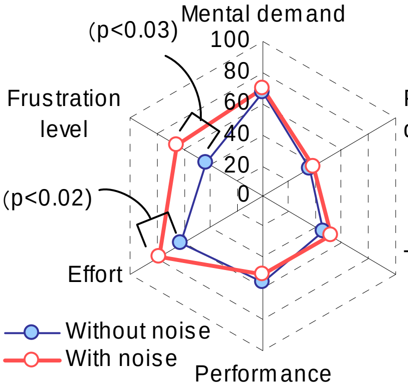

Figure 3. Results on NASA-TLX by components

3.5 Cerebral blood flow

Figure 4 shows the changes in total hemoglobin, which represents the cerebral blood flow, on the right forehead. During the task and after the task, the increase of the blood flow was significantly larger in "with noise" than in "without noise" (both $p<0.02$). By comparing with the state before the task, the changes in the blood flow was significantly larger during the task and also after the task in "with noise" (both $p<0.001$).

Figure 5 shows the changes in total hemoglobin on the left forehead. The blood flow on the left forehead significantly increased in both "without noise" and "with noise" during the task ($p<0.006$ and $p<0.001$ respectively). The blood flow in "with noise" was significantly higher even after the task ended ($p<0.03$), but it was not in "without noise". There were no significant differences between the conditions.

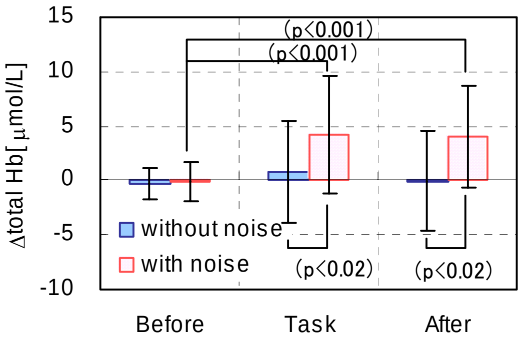

Figure 4. The change in total hemoglobin of right forehead

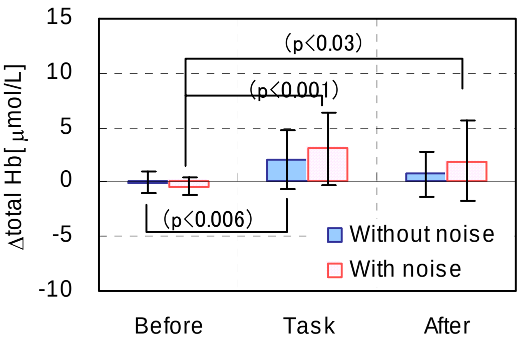

Figure 5. The change in total hemoglobin of left forehead

4 Discussion

The results from this experiment implied that the performance in sixty minutes of multiplication task was not affected due to the difference in exposed acoustic environment, even the difference was clearly perceived by them. As reported by subjects, it may be interpreted that higher degree of effort is required and higher frustration level is suffered to keep the level of performance in the environment with traffic noise. As a consequence, the level of fatigue become higher and the subjects might have been felt mentally tired in that environment. Nishihara and Tanabe [12] discussed in their paper that right-handed person's left brain is activated depending on the difficulty of the arithmetic task. The results of the cerebral blood flow of this experiment showed similar trend on left brain. The result that right brain also required high level of blood flow might be the characteristics for working on arithmetic task in the environment with traffic noise, because it was not observed in the previous studies on thermal [2] and lighting environment [3].

5 Conclusions

To examine the effects on performance, fatigue and cerebral blood flow in traffic noise environment, a subjective experiment was conducted and the following results were obtained.

1. The environment with traffic noise was perceived by the subjects as noisy, unacceptable and uncomfortable.
2. The performance of solving multiplication problems for sixty minutes did not change due to the exposure to traffic noise.
3. The fatigue level was significantly higher after the task in the traffic noise environment, and the subjects experienced the fatigue for mental work instead of general pattern of fatigue as in the environment without traffic noise.
4. Working on arithmetic problems with traffic noise might give more frustration to the occupants and require high level of effort to keep the performance as in normal acoustic environment.
5. The cerebral blood flow on left brain significantly increased during the commitment of task in either with or without traffic noise. Significant increase of the blood flow on right brain with traffic noise was obtained and that might be the characteristic for working on arithmetic task with traffic noise.

Acknowledgements

The authors wish to express appreciations to Mr. M Nishikawa, Mrs. M Hayakawa, Mrs. A Tanaka, and Mr. S Hyodo for their assistance during the experiment. This study was partially funded by the Grant-in-Aid for Scientific Research (A) of the JSPS (No.14205085).

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The Impact of the Room Temperature on the Recollection of Watched Video Program as an Index of Performance

G. Iwashita[1], Y. Hanada[2] and T. Gohara[3]

[1]Musashi Institute of Technology, Tamazutsumi 1-28-1, Setagaya, Tokyo 158-8557, Japan
email: iwashita@sc.musashi-tech.ac.jp
[2]Graduate School, Kagoshima University, Kagoshima, Japan
[3]Former, Lecturer, Kagoshima Prefectural College, Kagoshima, Japan

Summary: *The impact of the room temperature onsubjects' recollection of watched video program was studied in two experimental types, i.e., the experiment under warm condition (29 deg C) and that under cool condition (22 deg C). After watching 30 minutes video program, subjects answered the questionnaire, which asked the contents of the videoprogram. The performance could be measured to check how much subjects remembered the contents. It was found that there was significant difference in the percentage of correct answer in the difficult questions of the above questionnaire between twoexperimental types. The percentage of correct answer under the cool condition was more than that under the warm condition. The evaluation for the indoor environment and subjects' internal condition by subjects under the warm condition was worse than that under the cool condition. Besides the experiments, the subjects' memorization faculty was tested. There was no significant difference in the memorization faculty of subjects between two experimental types.*

Keywords: *Productivity, Recollection test, Memorization faculty, Video program watching*
Category: *Experiment*

1 Introduction

A number of researchers have conducted the studies on the relationship between indoor environmental quality and productivities since Vernon *et al*'s study which investigated the relationship between the monthly output of the laborers of a factory and outside temperature in Britain in 1919. As a results of the Hawthorne experiments, it is generally acknowledged that non-physical factors related staff motivation will affect performance [1]. The purpose of our study is to investigate the effects of room temperature onto the productivity in learning environment such as schools. Then we proposed a new experimental method to investigate the relationship between environmental factors and performance without the above Hawthorne effect. We tried to use the task which checks how much the subjects cannot leak the information. Therefore the subjects replied to the question about the contents of a TV program after viweing it.

2 Methods

2.1 Experimental condition

The experiments were conducted in the university classroom. The classroom had a floor area of 108 m^2 and a volume of 320 m^3. The mechanical ventilation equipment with heat exchanger and the heat pump type air-conditioner were installed in this classroom.

As shown in Table 1, two types of experimental conditions were prepared for this study; type A with room temperature of 29 deg C, and type B with 22 dg C.

Table 1. Experimental types

type	Room temperature	Number of subjects
A	29 deg C	50（12）
B	22 deg C	51（12）

（ ）: number of female subjects

2.2 Subjects

Fifty subjects participated each type of experiment. Subject of experimental type A differed from subject of type B, and there were not overlapping subjects. In this study, subjects were asked to watch a video program for 30 minutes, and asked to answer the questionnaire about the contents of the program after watching it. Then the recollection of the program contents was assigned as the performance of this study. Therefore we had to confirm that there was no significant difference in potential memorization faculty between subjects of experimental type A and those of type B. Memorization faculty test was carried out on the experiment day of each experimental type after the experiment. This memorization faculty test included reconfirmation test of meaningless spelling, reverse reproduction test of a digit number, and reproduction test of meaningful spelling. Table 2 shows the content of this memorization faculty test and Table 3 shows the result of the memorization faculty test. As seen in Table 3, there was found to be no significant difference in memorization faculty between the types of subjects.

Table 2. Content of this memorization faculty test

1	reconfirmation test of meaningless spelling	An experimenter showed 15 meaningless spelling words for 1 minute on screen, and made subjects memorize them. Then, an experimenter presented 30 spelling words on screen and asked the subjects to choose the memorized 15 words out of the 30 words.In these 30 words, 15 new words other than 15 words, which had been presented on screen during memorization period, were also contained.
2	reverse reproduction test of a digit number	Subjects were made to memorize two or more digits, which an experimenter read out. Then, an experimenter asked subjects to write out the number with an opposite direction. If an experimenter read out “1,2,3,4,5,6”, subjects should write out “6,5,4,3,2,1”.
3	reproduction test of meaningful spelling	An experimenter presented 20 meaningful spelling words for 1 minute on screen, and made subjects memorize them. Then, an experimenter asked subjects to write out the memorized 20 words on a reply paper.

Table 3. Result of the memorization faculty test.

Experimental type	A	B
1）reconfirmation test of meaningless spelling （10）	5.5±2.2*	5.5±2.4
2）reverse reproduction test of a digit number （57）	52.6±3.7	52.2±3.8
3）reproduction test of meaningful spelling（20）	13.3±2.4	13.2±2.7

*average±standard deviation （ ）: full mark

2.3 Questionnaire

We carried out the questionnaire survey in order to investigate the subjects’ psychological condition and perceived environmental conditions. Questionnaire items and scales are shown in Table 4. Also subjects evaluated the contsnts of the TV program used in the experiment.

Table 4. Questionnaire items and scales

1	Odor intensity（0：none→5：overpowering）
2	Thermal sensation（+3：hot⇔-3：cold）
3	Acceptability of air（+1：clearly acceptable ⇔-1：clearly unacceptable）
4	Irritation of eye, nose, and throat（0：none→5：overpowering）
5	Air freshness（-3：dirty⇔+3：fresh）
6	Concentration（-3：difficult to concentrate⇔+3：easy to concentrate）
7	Fatiguability（-3：fatigue⇔+3：vigor）
8	Arousal（-3：absentminded⇔+3：head clear）
9	Feeling（-3：feeling bad⇔+3：feeling googd）
10	Sleepiness（0：not sleepy→6：very sleepy）

2.4 Test about the contents of TV program

The main purpose of this experiment was to investigate how much the contents of TV program video were memorized by the subjects in both experimental types, i.e., type A, and type B

We considered the degree of the contents grasp in the test performed after program viewing to be work performance. As a cause that a subject's performance falls, the decrease in the concentration of program viewing can be considered. Then we made the simple questions, which subjects could answer without careful viewing, and the difficult questions, which subjects needed concentrated viewing to answer them. As a TV program, which subjects were asked to view, the nonfiction TV program on recycling and disposal issues of construction sites was used. The running time of the program was 30 minutes.

Table 5. The difficulty of each question in the test of the contents check

No*	Difficulty	Correct answer (%)**
1	Very difficult	49
2	easy	96
3	difficult	84
4	easy	95
5	easy	92
6	easy	99
7	difficult	79
8	difficult	80
9	difficult	79

*:question no.
**: The percentage of the correct answer for the subjects in type A and type B (101 subjects)

There were nine questions in the the test of the contents check carried out after video viewing. The difficulty of each question in the test are shown in Table 5. Subjects chose one from five choices for each question. When they did not remember, they had to choose " I do not remember. " For example, question no.1, no.4, and no.9 out of nine questions were presented in Table 6.

Table 6. Example of the questions about the contents of TV program

No.	Contents of question and choices of answer
1	What % of wooden demolition was illegal abandonment in the TV program?
	(1)20% (2)30% (3)50% (4)75% (5)90% (6) n.r.*
4	What do they building demolition with heavy industrial machines all at once?
	(1) minced demolition (2) whole demolition (3) scrap demolition (4) total demolition (5) bulldozer demolition (6) n.r.
9	What % of garbage was recyclable in the classified demolition spot of the residence using new synthetic building materials?
	(1)90% (2)80% (3)70% (4)50% (5)30% (6)n.r.

* I do not remenber

2.5 Experimental procedure

The experimental procedure is shown in Fig. 1. Subjects were given the guidance for video viewing and had been waited for 30 minutes before the start of the video in the classroom. Subjects were not aware of the purpose of this experiment.

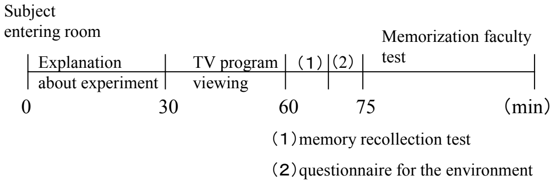

Fig.1.Experimental procedure

3 Results

The average air temperature and the average relative humidity in the classroom are listed in Table 7 for experimental type A and type B.

Table 7. The average air temperature and relative humidity in classroom.

Experimental types	Type A	Type B
Air Temp. (deg C)	28.9±0.5*	21.6±0.8
r.h. (%)	56.1±4.9	39.3±3.5

*: average ± standard deviation

The voted results by subjects in the questionnaire survey for psychological condition and perceived environmental conditions are listed in Table 8. It turned to be a big difference in the thermal sensation between type A and type B. It was found that subjects evaluated the environment of type A worse than that of type B as seen in the assessment for the concentration, fatiguability, arousal, feeling, and sleepiness.

Table 8. Voted values in qurstionnaire survey

	Type A	Type B	s.d.
Odor intensity	1.6±1.1	0.8±0.8	***
Thermal sensation	2.6±0.4	-2.5±0.7	***
Acceptability of air	-0.4±0.4	0.2±0.5	***
Air freshness	-2.1±0.8	-0.1±1.0	***
Concentration	-1.3±1.1	0.0±1.1	***
Fatiguability	-1.2±1.0	-0.4±1.2	***
Arousal	-1.4±0.9	-0.1±1.0	***
Feeling	-1.2±1.3	0.3±1.1	***
Sleepiness	4.0±1.3	3.2±1.5	**

s.d.: significant difference,
***:$p<0.005$ **:$p<0.01$

The replied results of the questions about the Video contents of video are listed in Table 9. The percentage of correct answers of question no.1 was low both in type A and type B, since the contents about question no.1 were shown in the very beginning of the program. Significant differences in the percentage of correct answer between type A and type B were detected for question no.7, no.8, and no.9. In these cases, the percentage of correct answer in type A with higher room temperature was lower than that in type B with cooler temperature.

Table 9. The difficulty of each question in the test of the contents check

No	Type A		Type B		s.d.***
	correct*	n.r.**	correct	n.r.	
1	54	24	43	41	-
2	98	0	94	2	-
3	80	4	88	2	-
4	96	2	94	4	-
5	92	8	92	6	-
6	98	8	100	0	-
7	70	20	88	8	0.05
8	68	28	92	6	0.005
9	68	28	90	6	0.01

*:percentage of corrct answer

**: percentage of voting “I do not remember”

***: significant difference in percentage of correct answer between type A and type B

4 Discussion

For the difficult questions, i.e., question no.7, no.8, and no.9, the percentage of correct answer in type A was lower than that in type B. The percentage of voting “I do not remember” in type A was higher than that in type B also for theses questions. Decrease of arousal level in the warmer environment of type A might have influence on subjects’ concentration and memory.

It was found that there was no effect of thermal difference on the percentage of correct answer for the easy questions, i.e., question no.2-no.6. For these easy questions, the percentage of voting “I do not remember” was also low. In these questions, subjects were asked the episode or important keyword. Therefore they could answer these questions even if they did not concentrate so much during viewing the program.

Wyon *et al.* reanalyzed data from the 1923 report of the New York State Commission on Ventilation [2]. Typewriting efficiency at different temperatures was investigated. Subjects performed considerably more work at 20 degree C than at 24 degree C. In an experiment at different temperatures by Pepler and Warner [3], subjects were thermally most comfortable at 27 degree C, the temperature at which they exerted the least amount of effort and performed the least amount of work. They performed most work at 20 degree C, although most of them felt uncomfortably cold at this temperature.

In our experiment, subjects performed better work at 22 degree C than at 29 degree C. Subjects felt more comfortable at 22 degree C than at 29 degree C. In this study, we investigated how subjects paid attention to the contents of video at different temperatures. The attention could have relation to subjects’ grasp and memory. In this point of view, subjects performed better at cool temperature than warm temperature, since they could have higher sense of arousal at cool temperature. This conclusion may be valid for relatively short period of experimental duration, it is questionable whether this result true for sustained periods of actual learning environment.

The method investigating productivity at different temperatures used in this study, might be useful for avoiding Hawthorne effect.

5 Conclusions

1) It was found that subjects evaluated the environment of type A at 29 degree C worse than that of type B at 22 degree C for the assessment for the concentration, fatiguability, arousal, feeling, and sleepiness.

2) For the difficult questions, the percentage of correct answer in type A was lower than that in type B. Decrease of arousal level in the warmer environment of type A might have influence on the subjects’ concentration and memory.

3) The method investigating productivity at different temperatures used in this study, might be useful for avoiding Hawthorne effect..

Acknowledgements

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Correlates of Self Reported Productivity from Mitigation Studies

L.P. Hulsman[1], J.L. Leyten[1] and A.C. Boerstra[1]

[1]BBA Boerstra Environmental Consultancy, P.O. Box 774, 3000 AT Rotterdam, The Netherlands
email: hl-bba@binnenmilieu.nl http://www.binnenmilieu.nl

Summary: *Results from 10 Dutch mitigation studies (approximately 700 respondents in total) include, apart from an elaborate list of questions about health and comfort responses and building characteristics, data about self reported productivity. The main results are an analysis of the relation of productivity data with health and comfort responses and building characteristics. The general validity of self reported productivity data is discussed on the basis of these results and a literature review. Analysis shows that both negative occupant responses on health and comfort and building characteristics that indicate pollution sources correlate with self reported productivity loss.*

Keywords: *indoor air quality, indoor environment, productivity, mitigation*
Category: *Economic and social costs of IAQ related health effects and benefits of good IAQ*

1 Introduction

Over the years many studies have shown (qualitative and quantitative) relations between improvements in indoor environmental quality (IEQ) and reduced (hidden) operating costs such as medical care cost, reduces sick leave, better performance of work, lower turn over of employees and lower cost of building maintenance due to fewer complaints about comfort or indoor air quality [1]. In practice however the cost-effectiveness of an improved IEQ is ignored when the designing and/or renovating of building and operation systems is concerned. One of the solutions to stimulate integrating IEQ improvements in building design can be to come up with more accurate estimates on the effect of a sub-optimal IEQ in an office building on these (hidden) operating costs, for example on loss of productivity.

So far most quantitative results concerning the effect of IEQ on productivity are based on laboratory studies (for example [2]) or on field-studies in call-centers where productivity can be objectively measured. The quantitative effect of IEQ/health comfort responses on productivity in normal office buildings - where productivity is much harder if not impossible to measure objectively- cannot be derived directly from these studies. This because among other things the laboratory and call centre tasks are not completely representative for every day office tasks and the situation in the laboratory, where there is only a short term relationship with the researcher is different from the long term relation with the employer.

Another approach to estimate productivity effects from the IEQ in office buildings is to ask employees their subjective judgement about this. That this can be a fruitful approach was already shown by Raw and Roys [3] in their reanalysis of existing productivity data. Although they did not give quantitative estimates of the productivity effects, they concluded from the reanalysis that subjectively reported productivity was improved if building related symptoms were 2 or less per person, if the number of workstations per room were 5 or less or if there was occupant control over the environment.

This paper presents an investigation on the relation between self reported productivity (SRP) on the one hand and IEQ on the other. Results from 10 Dutch mitigation studies were analysed.

The general validity of self reported productivity is discussed on the basis of these results and a literature review [4].

2 Method

Results from 10 Dutch mitigation studies were analysed (approximately 700 respondents in total). These studies were part of investigations of IEQ complaints in 10 Dutch office buildings conducted from 2000-2005. The buildings were 2 to 40 years old and the number of respondents varied from 20 to 300 respondents per building. The overall work-tasks of respondents were representative for normal office work and mostly non-repetetive (in total only about 50 respondents were call-center employees or had other repetetive tasks).

The mitigation studies include data about self reported productivity.
Buildings users responded if they did or did not think the building had an effect on their productivity and if they thought this effect was positive or negative. From the 10 mitigation studies three categories of responses were derived. 1) Those that stated a positive SRP effect. 2) Those that stated no SRP effect and 3) those that stated a negative SRP effect from the building on their productivity, see Table 1.
Also quantitative data on SRP was available; respondents were asked to report a percentage from 0 to 100% te represent the quantative negative or

positive effect of the buildings IEQ on their productivity.

Also data on health and comfort responses were available:

- questions about health symptoms, such as headache, lethargy and eye, throat, nose and skin complaints
- an elaborate list of comfort responses, including thermal comfort, indoor air quality, noise and lighting

Building characteristics, such as number of workstations per room, operable windows, type HVAC system and building physics, e.g. the active building mass for free cooling, were available from the building investigations that were previously performed on the 10 buildings. The one aspect all ten buildings had in common was a mechanical ventilation system.

The relations between the different data on SRP and health and comfort complaints and building characteristics were derived. Result of four of the conducted strategies are presented here.

a) Three categories of SRP (positive, no and negative effect) for all 700 respondents.
b) Three categories of SRP (positive, no and negative effect) related to health and comfort complaints for all 700 respondents.
c) Three categories of SRP related to building characteristics for the 10 investigated buildings.
d) Individual quantitative estimates of SRP from all 700 respondents.

The general validity of self reported productivity data is discussed on the basis of the results of these 10 mitigation studies and a literature review [4].

Results

Effect of building on SRP

Tabel 1. Positive, no or negative effect of the building on productivity

	Percentage of respondents
Positive effect	12 %
No effect	37 %
Negative effect	51 %

Half of the respondents report a negative effect on productivity.

SRP and health & comfort complaints

Responses on the three effect categories (positive, no and negative SRP effect) were related health and comfort responses, see figures 1 to 5.

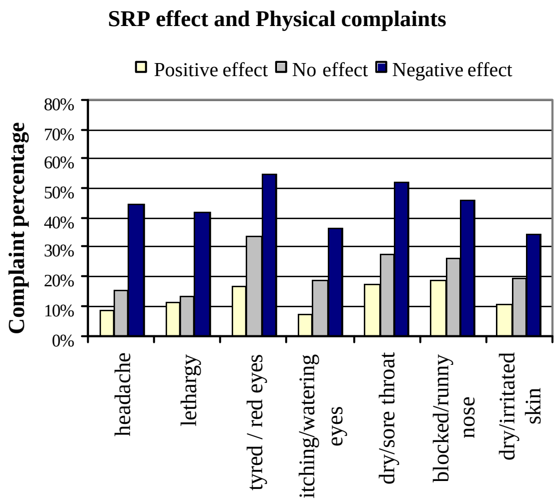

Figure 1.Qualitative self-estimated productivity effect and relation with physical complaints

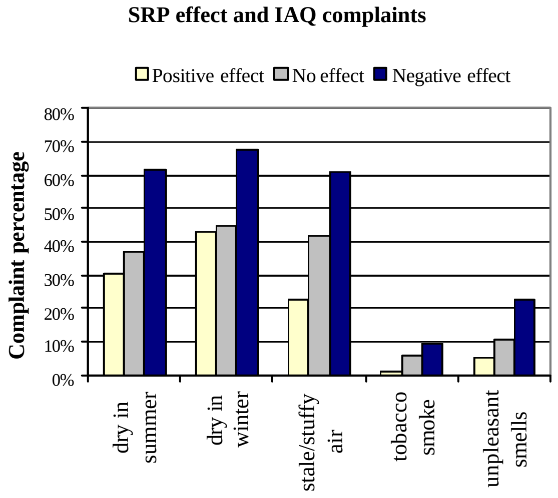

Figure 2.Qualitative self reported productivity effect and relation with IAQ complaints

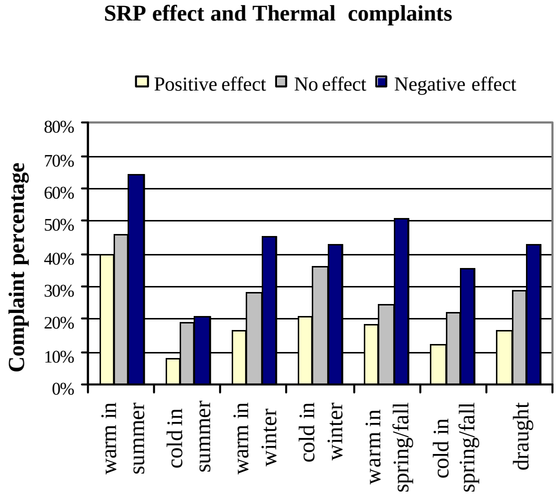

Figure 3. Qualitative self reported productivity effect and relation with thermal complaints

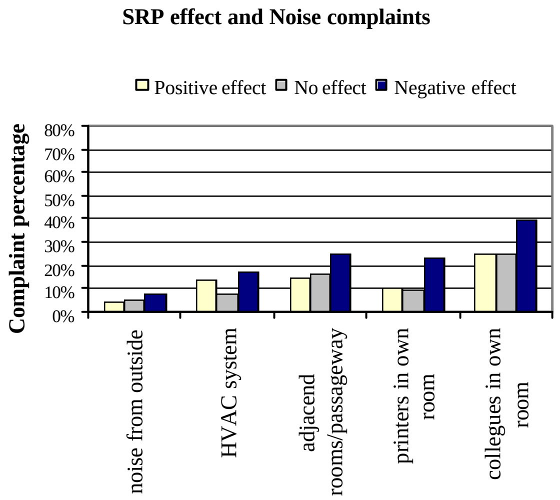

Figure 4. Qualitative self reported productivity effect and relation with noise complaints

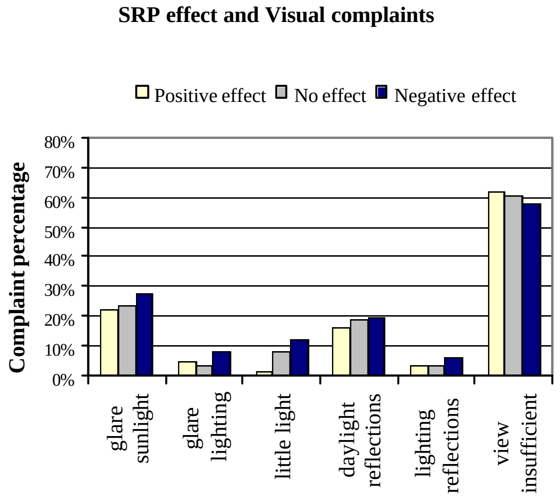

Figure 5. Qualitative self reported productivity effect and relation with visual complaints

These results show that a negative SRP effect on productivity is related to higher complaint rates on health and comfort than positive or no SRP effect. One exception is ‘view insufficient’, on this aspect no clear relation to SRP is found.

With physical complaints (SBS symptoms, such as lethargy) the difference between complaint percentage of positive and negative SRP is larger than with other complaints. Furthermore the clearest effects are found with physical complaints, IAQ complaints and thermal complaints and less clear effects are found with noise complaints and visual complaints.

SRP and building characteristics

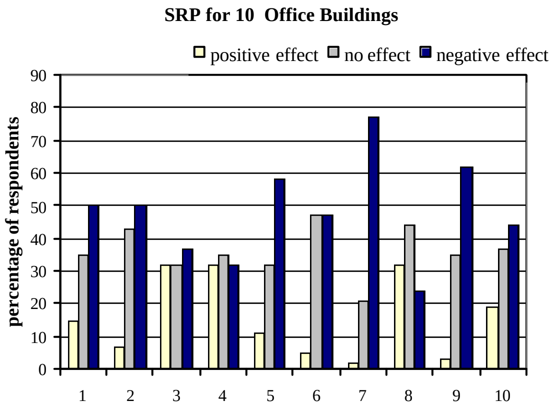

Figure 6. SRP effect of 10 Dutch office buildings

Results from the mitigation studies show that the one building (building 8) without any of the obvious pollution sources such as microbial pollution of HVAC system, internally insulated supply air ducts and recirculation, has the lowest value for negative SRP effect. Other building characteristics showed no distinct relation with the SRP effect, such as type of HVAC system, number of workers per room and building mass. This because the different buildings had similar characteristics; several buildings had rotary heat exchangers, some had humidifiers, many had recirculation of indoor air. On the other hand within buildings different characteristics were present, such as different numbers of persons per room, presence and absence of operable windows. This made it impossible to find correlations between SRP and buildings characteristics.

Quantitative SRP responses

Quantative responses on the size of the positive or negative SRP effect of the building varied from 5 to 80%, with an average of 40% effect on productivity for the 700 respondents. From [4] the maximum productivity effect due to an excellent IEQ in relation to a bad IEQ is 15%, which is much lower than the SRP of the 700 respondents. Because of the extreme differences in the responses on quantative self-estimated productivity and the discrepancy with common knowledge (maximum 15%) no further analyses of these data was carried out.

Discussion

The general validity of self reported productivity is discussed on the basis of the results of this analysis and a literature review [4]. In various publications there have been given different interpretations:

1. self reported productivity is valid in it self and does not need correction
2. self reported productivity is valid, but occupants tend to overestimate its quantity, so a downward correction is needed

3. self reported productivity gives an indication of subjectively experienced effort or fatigue
4. self reported productivity is at most an indication of the general satisfaction with the indoor environment

On the basis of the results from the 10 Dutch mitigation studies an overall conclusion can be drawn: A negative SRP corresponds with higher health and comfort complaint rates.

Concerning the already mentioned interpretations the following conclusions can be drawn:

1. Self reported productivity on the basis of a free estimate between 0 and 100% leads te extreme and not very useful quantitive SRP estimates. For estimates of self reported productivity a more detailed question is neccesary, for instance on the basis of visual analog scales as used in [3] or [5].
2. SRP overestimates the actual productivity effect.
3. Respondents with a negative SRP have higher complaint rates on lethargy/fatigue. So it can be stated that self reported productivity at the least corresponds to productivity as influenced by lethargy/fatigue.
4. Higher complaint rates on health and comfort are related to higher negative SRP effects.

Conclusions

1. Higher health and comfort complaint rates related to IEQ correspond with higher negative self reported productivity effects.
2. Quantitative responses on self reported productivity based on a free estimation of 0 to 100% show extreem discrepancies with results from studies on objectively measured productivity effects. For a more accurate quantative self reported productivity effect a more detailed question is necessary.
3. Since in practice with normal office tasks productivity effects cannot easily be measured but occupants/workers can be asked about their SRP more insight is needed into the relation between SRP and actual productivity effect.
4. Another strategy to estimate actual productivity effects for normal office tasks is to make use of the relationship between perceived air quality (percentage dissatisfied) and objectively measured productivity as reported in [6]. These results imply that every 10% decrease in the percentage dissatisfied with the perceived air quality the performance of office tasks can be improved by 0.8% (The data apply for the air quality level causing 15% to 65% dissatisfaction with air quality).

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Personalized HVAC System in a Sustainable Office Building – Field Measurement of Productivity and Air Change Effectiveness

T. Akimoto[1], M. Sasaki[2], T. Yanai[2], T. Genma[1], H. Amai[3] and S. Tanabe[3]

[1]Kanto-Gakuin University, Kanagawa, Japan
email: akimoto@kanto-gakuin.ac.jp
[2]Nihon Sekkei Inc., Tokyo, Japan
[3]Waseda University, Tokyo, Japan

Summary: *Task/ambient conditioning systems (TAC) are being investigated and are effective air conditioning methods for offices, which can keep steady temperatures, efficiently remove thermal loads, and create a comfortable environment that is pleasant for users. In this study, subjective experiments with a task conditioning system were conducted to investigate thermal comfort and productivity by field measurements. Air change effectiveness of the system was also evaluated using* SF_6 *tracer gas.*

Keywords: *subjective experiments, task conditioning system, productivity, air change effectiveness*
Category: *Occupant perception and work performance*

1 Introduction

In recent years, task/ambient conditioning (TAC) systems are being researched and developed to respond to increases in and localization of indoor heat load and differences in thermal preference among individuals. Moreover, at the 3rd Conference of the Parties to the United Nations Framework Convention on Climate Change, the Kyoto Protocol was adapted; and the temperature inside offices is recommended to be controlled at 28°C in summer as a measure to reduce CO_2 emission in Japan.

In this study, the authors investigated the characteristics of the thermal environment created in an office by a partition-based TAC system, in which pressurized air is blown from the floor through outlets at the floor and near desks, and the effects of the TAC system on the thermal comfort and productivity of workers by monitoring the temperature and air current and conducting experiments including questionnaire surveys. A ventilation test was also performed to investigate the effects of the TAC system on the quality of the air in the respiration zone of workers.

2 Overview of the building monitored

The building in which the experiment was conducted was a new office building of M Company, which was completed in 2004 and has four stories above and one story under the ground and a penthouse. A plan is shown in Figure 1 with points where monitoring was conducted. The office was an open space in which universal layouts could be installed, and there were no pillars. The ceiling height was 4.3 m and the clearance to the beams was 2.84 m in a standard office story. Environment-friendly systems were implemented such as double skin and thermal storage in structure.

An overview of the TAC system used in M Company is shown in Figure 2. A booth layout is shown in Figure 3. Aisles between booths were regarded to be ambient zones, and working spaces surrounded by partitioning panels were defined as task zones. Air outlets in the ambient zones were controlled in units of two persons per outlet, and outlets in the task zones were controlled by each person (25 m^3/h per person). Air blown out from the outlets was supplied from the air conditioning system under the floor. Air flowed from the under-floor chamber through the partitioning panels. The air conditioning was controlled by controlling the temperature of the air and the amount of air current generated by the differences in pressure between the under-floor chamber and the office. The air current in task zones could be controlled by opening and closing shutters. The direction of the air current could also be controlled from 0 to 45 degrees by moving vanes.

3 Monitoring during actual work

To understand the thermal environment at working zones in an office, various physical factors of thermal environment were monitored, such as horizontal temperature and humidity distributions, vertical temperature distribution, airflow speed and radiant temperature. The working environment was evaluated by surveying the amount of clothing of eight workers (six males (Mo1 to Mo6) and two females (Fo1 and Fo2)) on August 1 to 3 (Monday to Wednesday) and asking the workers to declare their comfort and feeling about the working environment and the TAC system. The thermal environment was also monitored using a mobile gauge cart to understand the environment to which the workers were exposed. In M Company, the office temperature was used to be set at 24°C in summers, but was gradually raised since

July 20 to save energy and was controlled to not exceed 28°C during the experiment.

The monitoring conditions are shown in Table 1, and the outdoor conditions on the days of monitoring are shown in Table 2. The conditions of the task air conditioning were outlet apertures of 0% (off), 100% (on), and free control. The workers adjusted the current direction as they liked, which was fixed during the monitoring. The amount of clothing was determined by conducting a questionnaire survey and calculated based on ISO 9920, and was 0.80 clo for males on average and 0.48 clo for females. A difference was observed between workers who wore uniform (0.48 clo) and those who did not.

A representative point for measurement was established in each task zone, at which the vertical temperature distribution, the horizontal temperature and humidity distributions, the temperature and humidity in the booth were continuously monitored. The airflow speed and six direction radiant temperatures in ambient occupied zones and the temperature and humidity at the workers were measured at specified hours. Items to be declared are shown in Table 3. Thermal sensation vote was made to evaluate thermal environment in task zones and the comfort of the zones and air current. Intellectual productivity was evaluated by subjective evaluation. The use of the TAC system was determined by visually inspecting the aperture of the outlets at one-hour intervals.

The relationships between the thermal sensation and comfort sensation of the subjects are shown in Figure 4. Mo5 was not at the desk most of the time and made extreme declarations, and thus his votes was excluded in this study. At the off condition, many declared it was "hot" and "very uncomfortable" and "warm" and "uncomfortable". When the thermal sensation was exceeding "warm", no subjects mentioned the environment was comfortable. At the on and control conditions, many declared "neutral" and "comfortable" to "slightly uncomfortable". At the control condition, the thermal sensation was neutral, and the percentage of people who felt uncomfortable was small. In this experiment, the scores were "comfortable" even at SET* values of 29 to 30°C, showing that the cool feeling of the subjects was enhanced by the TAC system.

The effects on intellectual productivity by the system were investigated by the individual mean scores of all NASA-TLX items (R-TLX) and the mean of all the subjects. There were almost no differences in mental work load among the conditions in this experiment. The asthenopia test showed no differences in vitality mean among the conditions in the male subjects. The female subjected showed high values throughout the day at the on and control conditions, suggesting that females are possibly be more sensitive to the environment than males. In the symptoms test, comparisons among groups showed symptoms of the physical labor type at arriving to the office when the task air conditioning was off, and those of the mental labor and nighttime labor types in the afternoon when the task air conditioning was fully on. Declarations throughout the day showed those of the general type. The total declaration percentage was slightly large in the afternoon at the on condition, but no other differences were observed among the conditions.

4 Air change effectiveness

One of the advantages to use TAC is to provide fresh air to the occupants' breathing zone directly. Clean fresh air could increase work productivity of occupants. The air change effectiveness was evaluated using SF_6 tracer gas. Tracer gas concentration was monitored every second with or without supply air from partition-based outlet. So the impacts of both of the partition-based outlet and the floor outlets were calculated respectively.

The experiment was conducted on October 22 (Saturday) and 23 (Sunday), 2005. As in the environment experiment in summer, the air temperature in ambient zones was set at a general temperature in office, and radiant temperature was assumed to be equal to the air temperature. The method of air conditioning was flowing out pressured air from the floor. Task air conditioning involved blowing out air from outlets on partitions. The efficiency of ventilation was monitored to understand the effects of operating the task air conditioning on the quality of the air in the respiration zones of people in task and ambient zones.

The monitoring conditions were set for different airflow rates at the task and floor outlets, different outlet angles, and different places of gas application. The amount of SF_6 applied was 5 ml/s in all conditions. The monitoring conditions are shown in Table 4. The locations of gas generation and monitoring points are shown in Figure 5 for all conditions. Monitoring was conducted at a typical seat using the steady generation method. A thermal mannequin, which reproduced heat generation from a human body, was placed on the seat. The concentration of the gas was monitored at the respiration zone. The gas concentration was also monitored at six typical points in ambient zones in the office. The temperature and humidity at the task outlet and respiration zone and the vertical temperature distribution at Point (1) in an ambient zone were also monitored. A real-time gas monitor was used to monitor the concentration in the respiration zone. The gas applied was SF_6. The amount of application was controlled using a single gas monitor. The real-time gas monitor collected samples and measured gas concentration at 1-second intervals for several seconds. During the experiment, the air conditioning was operated at steady airflow rate (CAV control), and the VAV control was turned off. The airflow rates at the task and floor outlets were monitored using an airflow meter.

The detailed positions where monitoring was conducted in a booth are shown in Figure 6. In the conditions in which the gas was diffused through the task outlet, the air was blown at angles of 0^o, toward person, and 45^o. In the conditions in which the gas was diffused through the floor outlets, the gas was diffused through two outlets on the floor. The gas concentration was monitored by assuming that the respiration zone was 3 cm beneath the nose from past studies.

Melikov et al.$^{1)}$ conducted a laboratory experiment using a different air terminal device (ATD). They monitored the concentration of SF_6 in inhaled air using a thermal mannequin that breathed and was placed in an ambient environment containing a certain concentration of SF_6 and supplying outdoor air through task outlets (ATD). The personal exposure effectiveness ε_P was calculated using Equation (1) and the contribution of the air from ATD to the respiration zone.

$$\varepsilon_P = \frac{c_{I,0} - c_I}{c_{I,0} - c_{PV}} \qquad (1)$$

$C_{1,0}$: Concentration in inhaled air without personalized ventilation [ppm]

C_1: Concentration in inhaled air [ppm]

C_{PV}: Concentration in the air of personalized ventilation [ppm]

In our experiment, ε_P was calculated by assuming $C_{1,0} = 0$, C_1 = mean concentration in the respiration zone, and C_{PV} = concentration in supplied air using Equation (2) to determine the percentage of air from the task outlet reaching the respiration zone. The concentration in supplied air was calculated from the amount ventilated and generated. The mean concentration for each condition was determined as the mean of three minutes from four minutes before termination of application to one minute before the termination.

$$\varepsilon_P = \frac{\text{Mean concentration in respiration zone } [ppm]}{\text{Concentration in supplied air } [ppm]} \qquad (2)$$

The results of monitoring are shown in Table 5 for all conditions of applying the gas through task and floor outlets together with the temperature and humidity values monitored at the outlets and respiration zone. A comparison with the results of Melikov et al. is shown in Figure 7.

In T_1 (fully open, toward person), the mean concentration was 113 ppm, and ε_P, which shows the ratio of airflow from the task outlet reaching the respiration zone, was 0.38. In T_5 and T_7 (fully open, toward person), the values were 0.41 and 0.36, respectively. In T_4, T_6, and T_10 (semi open, toward person), the values were 0.14, 0.18 and 0.16, respectively. These were similar to the values calculated by Melikov et al. for a task air conditioning system that blew out air from the front and tested in a laboratory. In T_2 (fully open, 0^o), almost no air from the task outlet reached the respiration zone, and ε_P was 0.02. In T_3 (fully open, 45^o), the value was 0.12, showing that about 10% of the air reached the respiration zone. Appropriate adjustment of airflow direction from TAC was shown to be effective in supplying fresh air to the occupant of the seat. In conditions in which the gas was supplied from the floor outlets, almost no SF_6 was detected in the respiration zone. Just little amounts of air from the floor outlets reached the respiration zone, and the majority was diffused to ambient zones and ventilated, little affecting the air in the respiration zone.

5 Conclusions

At the on and control conditions, using TAC, many workers declared "neutral" and "comfortable" to "slightly uncomfortable". At the control condition, the thermal sensation was neutral, and the percentage of people who felt uncomfortable was small. The scores were "comfortable" even at SET* values of 29 to 30°C, showing that the cool feeling of the subjects was enhanced by the TAC system. The ventilation experiment showed that fresh air could be efficiently supplied to workers by appropriately adjusting the direction of TAC outlets. Just little amounts of air from the floor outlets reached the respiration zone, little affecting the air in the respiration zone.

Acknowledgements

A part of this study was financially supported by 'Grant-in-Aid for Scientific Research (17560538, 2005)' of Japan Society for the Promotion of Science (JSPS).

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[1] Arsen K. Melikov, Radim Cermak, Milan Majer: Personalized Ventilation :evaluation of different air terminal devices, Energy and Buildings, pp. 829-836, 2002.

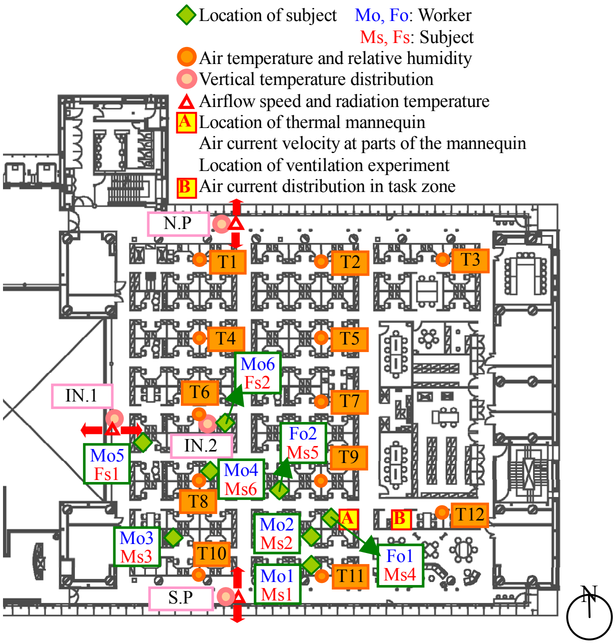


Figure 1 Plan and points of monitoring (second floor of M Company)

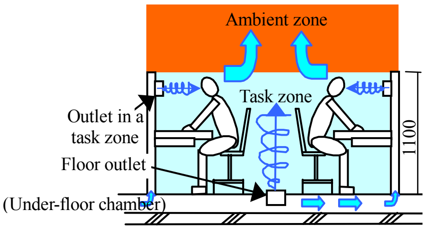


Figure 2 Overview of the TAC system of M Company

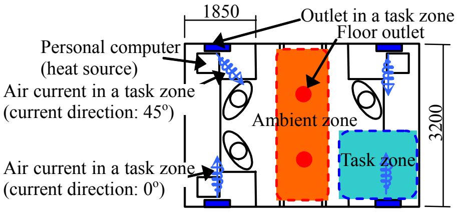


Figure 3 Booth layout

Table 1 Monitoring conditions

Condition	off	on	control
Month and day	August 1 (Monday)	August 2 (Tuesday)	August 3 (Wednesday)
Air conditioning setting	28°C		
Relative humidity	50%RH		
Indoor air current	Calm current		
Air conditioning method	Diffusion from the floor, drawn off from the ceiling		
Amount of clothing	Male: 0.80 clo, female: 0.48 clo		

Table 2 Outdoor conditions of the days

	Mean air temperature [°C]	Maximum air temperature [°C]	Minimum air temperature [°C]	Relative humidity [%]	Mean airflow speed [m/s]	Weather
August 1 (Monday)	30.4	33.2	26.9	72	3.1	Fair with occasional rain
August 2 (Tuesday)	29.9	33.3	27.3	75	2.9	Cloudy with occasional rain
August 3 (Wednesday)	30.8	33.4	27.6	74	3.0	Fair with occasional cloud

Table 3 Items to be declared

Period / Item	At arriving at the office	During work	At leaving the office
Clothing	○	–	–
Questionnaire B	○	–	–
Thermal environment	○	○	○
Symptoms test	○	○	○
Asthenopia test	○	○	○
Vitality	○	○	○
NASA- TLX	–	–	○

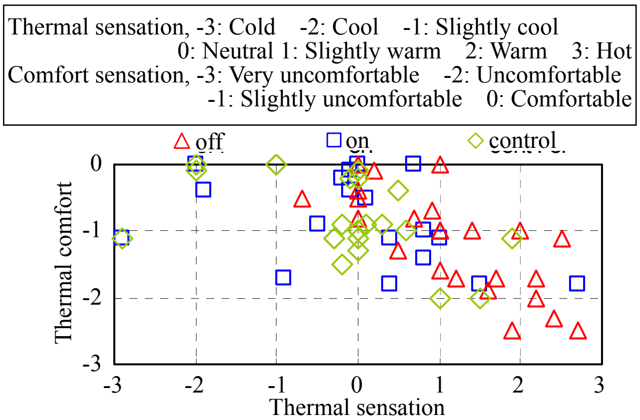


Figure 4 Thermal sensation and comfort sensation

Table 4 Experimental conditions

Condition	Location of application	Outlet	Air current direction	Airflow rate at the floor outlet	Airflow rate at the task outlet
T_1	Task outlet	Fully open	Toward person	107	40
T_2			0°		
T_3			45°		
T_4		Semi open	Toward person		20
T_5		Fully open	Toward person	87	33
T_6		Semi open			16
T_7		Fully open	Toward person	73	29
T_8			0°		
T_9			45°		
T_10		Semi open	Toward person		15
F_1	Floor outlet	Fully open	Toward person	107	40
F_2		Entirely closed			5
F_3		Entirely closed (taped)			0
F_4		Fully open		87	33
F_5		Entirely closed			16
F_6		Fully open		73	29
F_7		Entirely closed			0

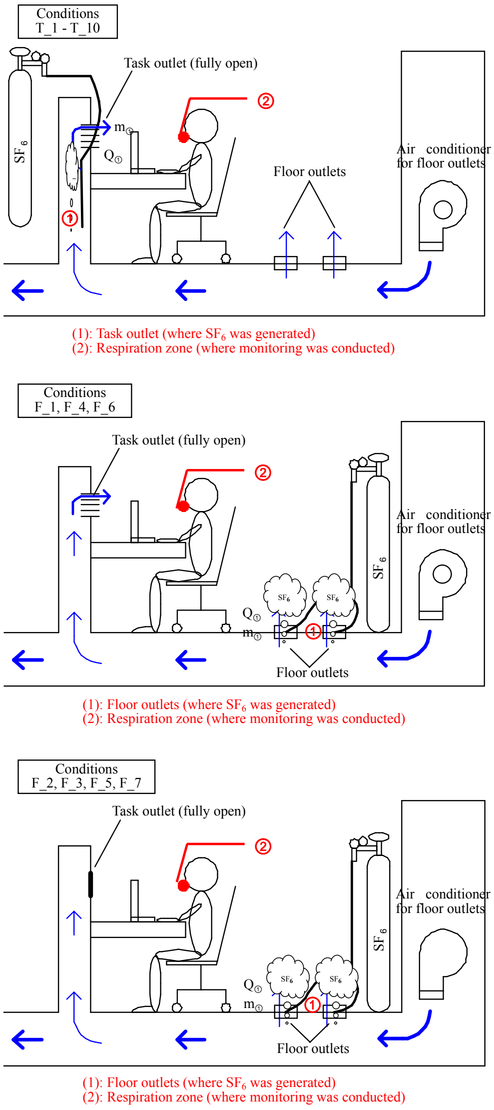


Figure 5 Location of gas generation and monitoring points

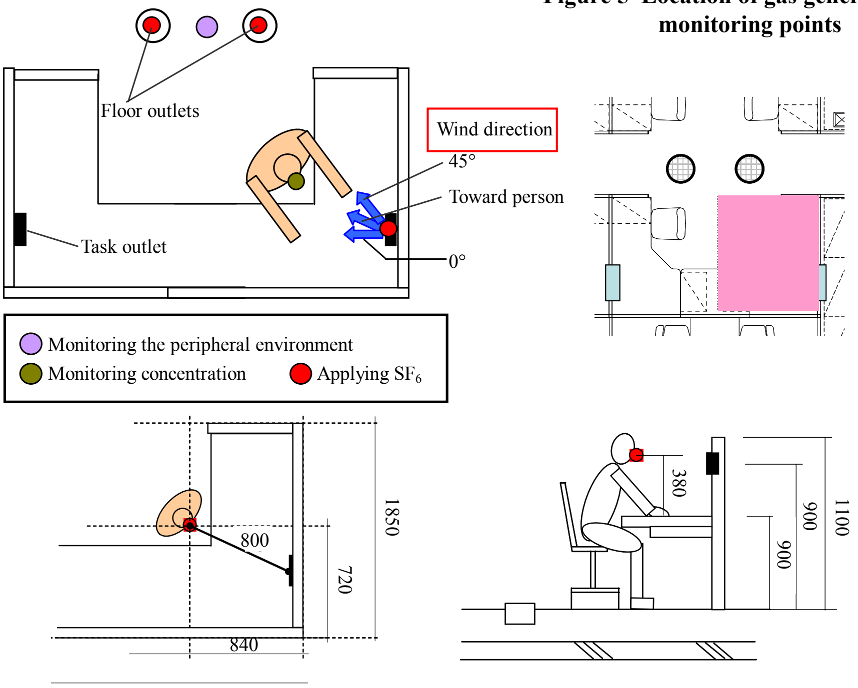


Figure 6 Points of monitoring in a booth

Table 5 Results of monitoring for all conditions of applying the gas through task and floor outlets and the temperature and humidity values monitored at the outlets and respiration zone

🟨 Monitored on October 22 🟦 Monitored on October 23

Condition	Concentration in supplied air [ppm]	Mean concentration [ppm]	Temperature at outlet [^oC]	Humidity at outlet [%]	Temperature at respiration zone [^oC]	Humidity at respiration zone [%]	Ambient temperature [^oC]	ε p
T_1	298	113	21.3	66	23.4	54	23.4	0.38
T_2	298	7	21.2	67	25.8	47	23.4	0.02
T_3	298	36	21.2	66	24.2	51	23.3	0.12
T_4	590	(80)	22.9	44	26.0	33	23.4	0.14
T_5	355	146	22.4	44	24.5	35	23.6	0.41
T_6	737	135	23.1	44	24.9	36	23.6	0.18
T_7	404	147	22.8	36	25.1	30	23.9	0.36
T_8	404	(76)	23.0	37	27.1	28	24.1	0.19
T_9	404	(60)	23.6	36	26.6	29	24.4	0.15
T_10	786	(126)	23.3	39	25.7	31	23.7	0.16
F_1	55	0	22.0	63	24.0	52	24.1	0.00
F_2	55	0	22.9	59	25.7	47	23.6	0.00
F_3	55	0	-	-	26.0	46	23.6	0.00
F_4	68	0	22.3	46	24.3	36	23.6	0.00
F_5	68	6	-	-	26.4	33	23.5	0.09
F_6	80	4	22.7	37	25.0	30	23.7	0.05
F_7	80	5	-	-	26.9	28	23.8	0.06

ε_P : personal exposure effectiveness

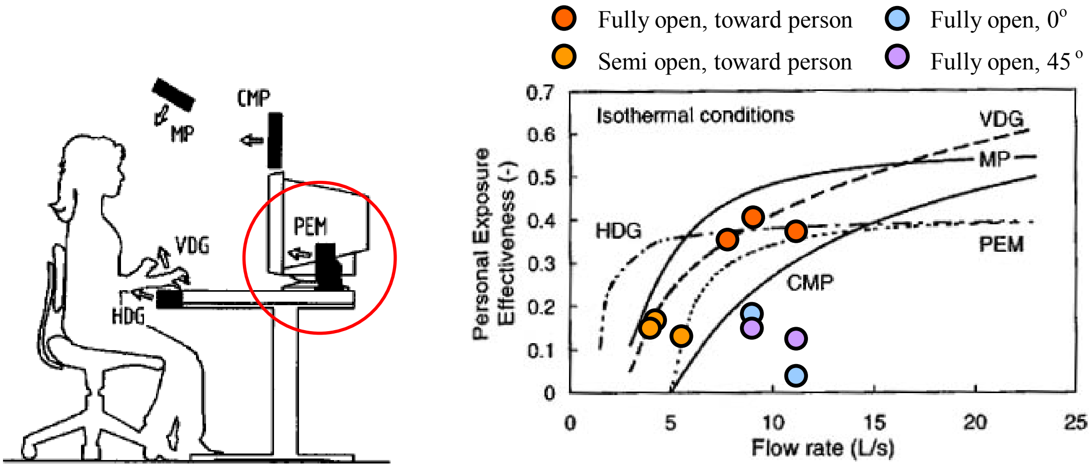


Figure 7 Comparison with the results of Melikov et al.

Study on the Productivity in Classroom (Part 1)
Field Survey on Effects of Air Quality/Thermal Environment on Learning Performance

S. Murakami[1], T. Kaneko[1], K. Ito[2], and H. Fukao[3]

[1] Keio University, 3-14-1, Hiyoshi, Kohoku-ku, Yokohama, Japan
email: murakami@sd.keio.ac.jp http://www.murakami.sd.keio.ac.jp
[2] Tokyo Polytechnic University, 1583 Atsugi, Kanagawa, Japan
[3] Taisei Corporations, 344-1 Nase, Totsuka-ku, Yokohama, Japan

Summary: *Many research papers have been published on the potential effects of indoor environmental quality of in classrooms and offices on productivity. This paper (Part 1) gives an outline of the series of this study and reports the results of field measurements focusing on the effect of the air quality and thermal environments on learning efficiency, with differences in ventilation rate. It also evaluates the consistency between objective and subjective evaluations of learning efficiency.*

Keywords: *Productivity, Learning Performance, Field intervention Survey*
Category: *Human responses to IAQ*

1. Introduction

A series of these studies evaluate the effects of changes in the air quality and thermal environments on learning performance in classroom. These studies involve field intervention surveys in actual classrooms with students, and realistic simulation experiments in climate chamber using student subjects very closely simulating the same conditions as in the actual classroom. In this study, we attempted to evaluate the consistency of the field measurements and climate chamber experiments, which were difficult to compare precisely, using the same learning performance evaluation methods. This paper (Part 1) reports the results of field intervention survay and the next paper (Part 2) report on the results of realistic simulation experiments in climate chamber.

2. Summary of Study on Improving Learning Performance

A series of studies, including (Part 1) and (Part 2), evaluated the effects of the indoor environmental quality on learning performance from various perspectives, using as the subject a college that provides lectures nationwide to prepare students to take certification examinations of 1st class authorized architect. The college provides a uniform teaching environment nationwide by using DVD-based video image lectures. They also conduct standardized examinations (quiz) to measure the level of understanding after each lecture.

Generally, the teaching level of lecturer has a significant effect on learning performance. Since lectures are held in different classrooms and by different lecturers, it is very difficult to compare the effects of the indoor environmental quality on learning performance. The college chosen for this study provides standardized lectures nationwide, using the same DVD-based contents, and checks learning achievements by conducting standardized quizzes (test). This provides a reproducible learning environment and allows cross-environmental evaluation of the field measurements. Also, the use of DVD-based lectures allows the classroom environment used in the field measurements to be precisely replicated in the laboratory.

Based on the above characteristics, we evaluated the effect of the indoor environmental quality on learning performance, using the approaches of field intervention surveys and laboratory experiments. We adopted standardized quizzes used in the actual classroom to evaluate learning performance objectively. This allowed us to use a method standardized for all college buildings and classrooms in evaluating learning performance in the field measurements and to compare learning performance among classrooms with different indoor environments. Use of a standardized method of evaluating learning performance based on standardized quizzes in the field measurements and laboratory experiments allowed us to evaluate the effect of the indoor environment on learning performance from various perspectives.

2.1 Field Intervention Surveys

Before carrying out the field intervention survey on learning performance, the ventilation rate, and background levels of illumination and sound were measured to clarify of the indoor environmental quality, particularly the physical environmental parameters of the classroom to be surveyed. After preliminary measurement of the indoor environmental quality, the learning performance was measured for students in two classrooms with different indoor environments. Since field intervention surveys reflect the subjects' psychology, they have the advantage that the Hawthorne effect does not easily appear. In this paper (Part 1), the results of these field intervention surveys are reported.

2.2 Realistic Simulation Experiments in the Laboratory

Laboratory experiments in the climate chamber were conducted, simulating the classroom environment and lecture system of the college chosen for the field intervention surveys. The details and results of experiments in the laboratory will be reported in the subsequent paper (Part 2).

3. Methods of Field Intervention Surveys on Learning Performance

Field intervention surveys were conducted to evaluate the effect of changes in the air quality and thermal environments on learning performance, using classrooms at the college. Two evaluations methods – an objective evaluation based on quiz scores and a subjective evaluation based on a questionnaire on psychological factors – were used, and their consistency was evaluated as well. Figure 1 shows an appearance of the classroom where the field surveys were being carried out.

Field intervention surveys were carried out from January to April 2005 at the Ikebukuro campus of Nikken Gakuin College in Japan. An Air Handling Units are installed for temperature control in the ceiling of each classroom. Outdoor air is introduced in through the air intakes around the edge of the floor, and is delivered through the hallway into each classroom through the under-cut of the door. Each room has a ventilating fan, which, when operating, creates a negative pressure in the room and introduces outdoor air into the classroom through the hallway. The outdoor air flow rate introduced into each classroom is controlled by turning on or off the ventilating fan in each classroom.

Field intervention surveys were made by changing particularly the ventilation rate, focusing on the effect of indoor air quality (IAQ) on learning performance. The ventilating fan was turned off completely for low ventilation rate and was turned on constantly for high ventilation rate. The subjects of the lectures were roughly divided into two: a Theoretical Subject (in the field of building structure) and Memorization Subjects (in the fields of architectural planning and building construction). Learning performance was evaluated for each of the Theoretical and Memorization Subjects and compared under indoor environments with the case of high and low ventilation rate.

Measurements were made using lectures that were given on the same day and that were of the same duration to take into account the circadian rhythm of the subject students.

Field intervention survey began at 9 AM when the lecture began, according to the normal lecture procedure. After the 180-minute lecture ended (12 noon), the subjects took a 30-minute quiz, and then filled out the self-assessment form (Questionnaire). Three five-minute breaks were provided during the 180-minute lecture.

S= 141.7 m^2 (10.7×13.3m)

h= 2.4 m

ventilating fan;
4 places in classroom

Undercut of door;
4 places in classroom
(0.2×0.6m)

Figure 1 Appearance of the Classroom

Table 1 Classroom Environmental Conditions

Vent. Rate (outdoor air)	Lecture contents	Number of Subjects	Temp.&Rh
High (3.5 h^{-1})	Theoretical Subjects	41	24.2(°C),22(%)
Low (0.4 h^{-1})		41	27.1(°C),35(%)
Low (0.4 h^{-1})	Memorization Subjects I	50	27.3(°C),44(%)
High (3.5 h^{-1})		50	25.2(°C),43(%)
High (3.5 h^{-1})	Memorization Subjects II	57	24.5(°C),42(%)
Low (0.4 h^{-1})		57	28.1(°C),63(%)

The trial subjects were students taking a course for the qualifying examination for first-class architects. Those students were highly motivated because nearly all of them were to take a qualifying examination slated for June. The total number of subjects was about 70, most of whom were workers in their twenties to forties. Since the students need to attend all of the lectures, based on the curriculum provided by the college, the subject groups in individual measurement cases were almost the same. Table 1 shows classroom environmental conditions and measurement cases.

3.1 Measurement of the Physical Environmental Factors in the Classroom

Carbon dioxide concentrations and dust concentrations were monitored continuously during the measurement. A photoacoustic multi-gas monitor (INNOVA) was used to measure the carbon dioxide concentration, and a light- scattering digital dust monitor to measure the dust concentration.

The air change rate, chemical pollutants concentration (VOCs and carbonyl compounds), and fungus concentration (airborne fungi and settling fungi) were measured when students were not present. SF6 was used as a tracer gas for step-down method to measure the air change rate, and a multi-gas monitor was used to measure concentrations. The air conditioner was operated at 25°C during the measurements. VOCs were collected by active sampling on a Tenax TA, and were analyzed by GC/MS after thermal desorption. Carbonyl compounds were collected by active sampling on a SepPak-DNPH, and were analyzed by HPLC after solvent desorption. Settling fungi were collected by passive sampling on a 90-mm sterilized Petri dish with a PDA culture medium placed in the middle of the floor. Airborne fungi were collected by active sampling on the PDA medium. Both settling and airborne fungi were cultured in the incubator at 28°C after sampling. Fungus growth (number of colonies, CFU) on the surface of the PDA medium on the seventh day was monitored.

Table 2 Questions of Standardized Quizzes for the Objective Evaluation (in the fields of architectural planning)

Question 10; Which is the **most improper one** among the following descriptions concerning various wiring methods used for the office construction?

(1) The free-access floor wiring method makes the floor a double floor, and it is a method of using between those as wiring space, and there is an effect of reducing the design load of the floor.
(2) The floor on the standard floor was made to the free-access floor of 6cm in height, and to correspond to the change in the layout of the office, considered in the office building.
(3) Under the carpet wiring method is a method to construct a thin cable directly in the above the floor level, and special floor finish is needed. However, it is possible to correspond to the change easily.
(4) It wires a necessary place, and the bus baton wiring method is large the maximum, permissible current, and in the method to accommodate and to protect the conductor in this, is suitable for a mass power supply.
(5) In general, the conductor used for the bus baton wiring method is copper or, aluminum.

Table 3 Part of Self-Assessment Form for the Subjective Evaluation

Question 5; **Air Environment** (Contamination and smell of air)

(1) Are you satisfied with a current air environment? ☐.
1.) Desatisfied 2.) Slightly Desatisfied 3.) Medium 4.) Slightly Satisfied 5.) Satisfied
(2) What influence does today's air environment give to the level of the lecture contents understanding? ☐.
1.) Disimproved 2.) Slightly Disimproved 3.) No Influence 4.) Slightly Improved 5.) Improved

Question 8; **Understanding level** of lecture contents

(5) Convert at the time (in minutes) lost due to factors in various indoor environment in the classroom today.
☐.min

Air temperature, air velocity, relative humidity and mean radiant temperature were measured during the period of the field intervention survey. Air temperature and humidity were continuously measured by a digital temperature/humidity meter, and the mean radiant temperature was continuously measured by a globe thermometer. Air velocity was measured by an anemometer. All data was stored once every minute. For sound and illumination levels, indoor equivalent sound levels were measured with a noise meter, and desktop illumination levels were measured with a digital illuminometer.

3.2 Evaluation of Learning Performance

1) Evaluation of Objective Learning Performance

Objective learning Performance was evaluated according to scores in standardized quizzes to measure the level of understanding of lectures. The purpose of the lectures was to prepare students to take the qualifying examination for first-class authorized architects. Each standardized quizzes consisted of 20 questions, each of which was answered by choosing one out of five options. Table 2 shows questions in a typical standardized quiz. To compare scores in quizzes on different lecture content, a correction was analyzed to the scores based on data on the average scores in the examinations conducted by Nikken Gakuin College in 2004FY, and the difficulty levels of all examinations were standardized.

2) Evaluation of Subjective Learning Performance

In addition to the objective evaluation using quiz scores, a subjective evaluation of learning performance was carried out using a questionnaire as self-assessment form. The items to answer on the form were: (1) the effect of the classroom environment on the level of understanding of the lecture content (5-point scale); (2) time (in minutes) lost due to factors in the indoor environment; (3) factors limiting the understanding of the lecture content (choosing top three out of eight factors: 1. thermal environment; 2. air environment; 3. illumination levels; 4. sound levels; 5. spatial environment; 6. human relationships; 7. lecture content; 8. motivation), and (4) improvement rate (%) in the level of understanding of lecture contents with improvements in the above environmental factors (=1 to 5 in (3)). Table 3 shows part of the self-assessment form for the subjective evaluation.

The significance level was set at 5% and a corresponding t-test was used to compare quiz results with varying environmental conditions. The Wilcoxon matched-pairs signed rank test was used as a corresponding rank scale in comparing the results of self-assessment with varying environmental conditions.

4. Results

4.1 Physical Environment

Figure 2 shows the results of ventilation rate per person. The outdoor air flow rate was 1190 [m^3/h] (= 3.5 at air change rate [h^{-1}]) in the high ventilation case and 136 [m^3/h] (=0.4 [h^{-1}]) in the low ventilation case. Dust concentrations did not change when the ventilation rate was changed. The carbon dioxide concentration became constant at around 1000 [ppm] in the high ventilation case. In the low ventilation case, the indoor CO2 concentration gradually increased due to respiratory CO2 emissions and eventually exceeded 5000 [ppm].

Measurement of VOC concentrations show a formaldehyde concentration of below 10 [$\mu g/m^3$] and an acetaldehyde concentration of below 12 [$\mu g/m^3$], thus meeting the guideline values for indoor concentrations set by WHO. Airborne and settled fungi levels were 10.0 [cfu/m^3] and 1.6 [cfu/m^2], respectively. Almost no indoor fungi were observed because it was the winter season.

Figure 2 also shows the results of PMV calculations. PMV was calculated based on a metabolic rate of 1.0 [met] and the amount of clothing typical for the classroom of 1.0 [clo], which was determined based on monitoring. PMV was about 0.8 [-] and PPD was about 17 [%] for low ventilation rate case, while they were about -0.1 and about 5[%] for high ventilation rate case.

Since the air-conditioning system in the classrooms was a constant flow rate type, the thermal condition changed with the change in the ventilation rate (outdoor air flow rate), resulting in different thermal environments for high and low ventilation rate case.

The desktop illumination level was 817 [lx], and the equivalent noise level was 46.9 [dB].

4.2 Evaluation of Learning Performance

Figure 3 shows the results of evaluating the objective learning performance based on the standardized quizzes. For the Theoretical Subject in the field of building structure, a significant improvement of 4.7 points ($p<0.03$) resulted with the change in environmental conditions from low to high ventilation. This is a 5.4[%] improvement in learning performance when expressed as a percentage of the score for low ventilation. For Memorization Subject I in the fields of planning and construction, a significant improvement of 6.4 points ($p<0.002$) resulted with the change in environmental conditions from low to high ventilation. This is an 8.7[%] improvement in learning performance. For Memorization Subject II in the field of planning, a significant improvement of 4.6 points ($p<0.0007$) resulted with the change in environmental conditions from low to high ventilation. This is a 5.8[%] improvement in learning performance.

Figure 4(1) shows the results of self-assessment of the “time lost due to the indoor environment.” For the Theoretical Subject, a significant decrease of 6.0 minutes ($p<0.004$) in “time lost due to the indoor environment” resulted with the change in environmental conditions from low to high ventilation. The effective lecture time which was defined to express the change in learning performance as a percentage was calculated by subtracting the “time lost due to the indoor environment” in the self-assessment form from the overall lecture time (180 minutes). The improvement is a 4.0[%] in learning efficiency (converted to time) when expressed as a percentage of the effective lecture time for low ventilation. For Memorization Subject I, a significant decrease of 3.8 minutes ($p<0.04$) in the “time lost due to the indoor environment” resulted with the change in environmental conditions from low to high ventilation. This is a 2.2[%] improvement in the effective lecture time. For Memorization Subject II, a significant decrease of 4.7 minutes ($p<0.02$) in the “time lost” resulted with the change in environmental conditions from low to high ventilation. This is a 2.8[%] improvement in the effective lecture time.

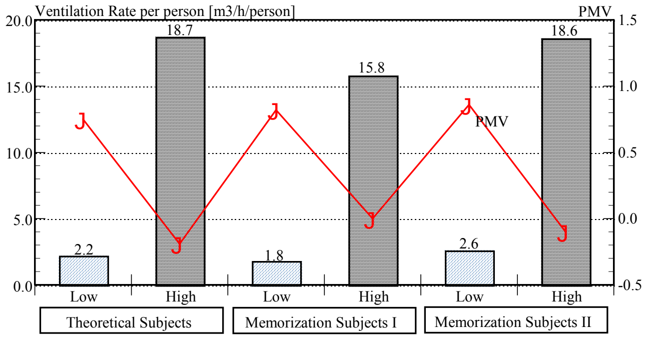


Figure 2 Ventilation rate and PMV

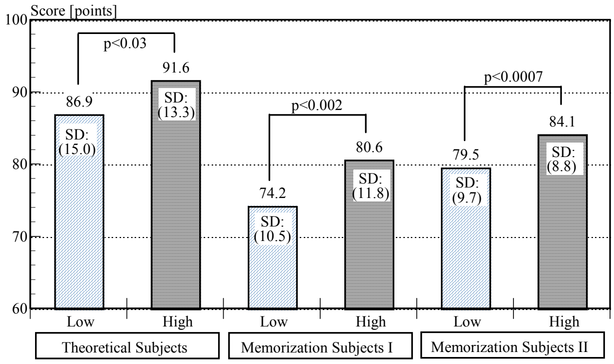
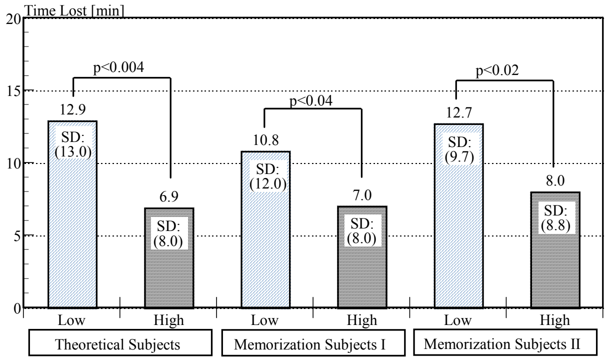
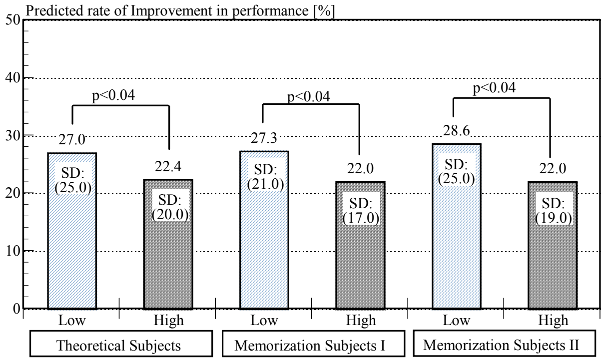


Figure 3 Results of Objective Evaluation



(1) “Time lost due to the indoor environment.”



(2) “Predicted rate of improvement in learning performance with an improvement in the environment.”

Figure 4 Results of Subjective Evaluation

Figure 4(2) shows the results of self-assessment of the “predicted rate of improvement in learning performance with an improvement in the environment.” The subjects were requested to report the learning performance improvement rates that they expected if the indoor environment was improved. In this measurement, for the Theoretical Subject, a significant decrease of 4.6[%] (p<0.04) in the expected improvement rate resulted with the change in environmental conditions from low to high ventilation. This means that the learning performance improved by 4.6[%] (p<0.04) on changing the environmental conditions. Similarly, for Memorization Subject I, a significant decrease of 5.3[%](p<0.04) in the expected improvement rate resulted with the change in environmental conditions from low to high ventilation. In other words, the learning efficiency increased by 5.3[%] (p<0.04). For Memorization Subject II, a significant decrease of 6.6[%] (p<0.04) in the expected improvement rate resulted with the change in environmental conditions from low to high ventilation. In other words, the learning efficiency improved by 6.6[%] (p<0.04).

Table 4 shows the results of a self-assessment of the percentage of dissatisfied of indoor environment. For the Theoretical Subject and Memorization Subject II, a significant improvement in the percentage of dissatisfied of thermal environment resulted with the change in environmental conditions from low to high ventilation.

4.3 Evaluation of Consistency between the Objective and Subjective Evaluation of Learning Performance

Figure 5 shows learning performance improvement rates [%] (from low to high ventilation rate) for the quiz-based objective evaluation and self- assessment form-based subjective evaluation for the Theoretical Subject and Memorization Subjects I and II. The measurements show that the subjective evaluation tends to underestimate the learning performance compared to the objective evaluation. A comparison between the evaluation based on the “expected improvement rate” and the evaluation based on the “effective lecture time” shows that the evaluation based on the expected improvement rate agrees more closely with the objective evaluation.

5. Evaluation of the Learning Performance by Score

The subjects were put into two groups: a higher score group and a lower score group to analyze the effect of air and thermal conditions and motivation on learning performance. Subjects in the higher score and lower score groups were defined as those with above-average and below-average scores in the quiz for low ventilation case, respectively.

Figure 6(1) shows the results for the objective learning performance (based on the standardized quiz) by score for Theoretical Subject. For the higher score group, no significant difference in the quiz results was identified with changes in the environmental conditions. For the lower score group, a significant improvement of 11.2 points (17.9[%]) resulted with a change in the air environment from low to high ventilation (p<0.009).

Table 4 Percentage of Dissatisfied

	Air env. Dissatisfied [%]		Thermal env. Dissatisfied [%]	
Ventilation	Low	High	Low	High
Theoretical Subjects	7.9%	11.3%	50.0%	29.6%
	n.s.		p<0.003	
Memorization Subjects I	18.1%	8.0%	44.6%	33.0%
	n.s.		n.s.	
Memorization Subjects II	11.3%	9.3%	59.7%	34.9%
	n.s.		p<0.0005	

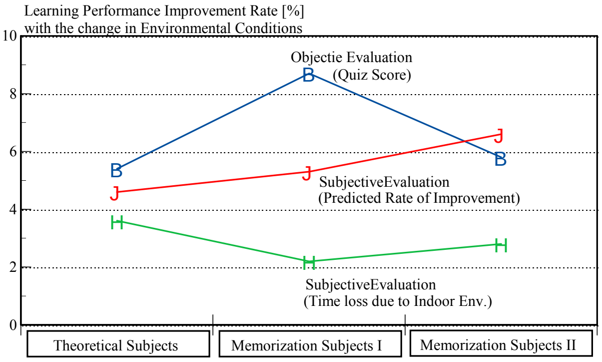
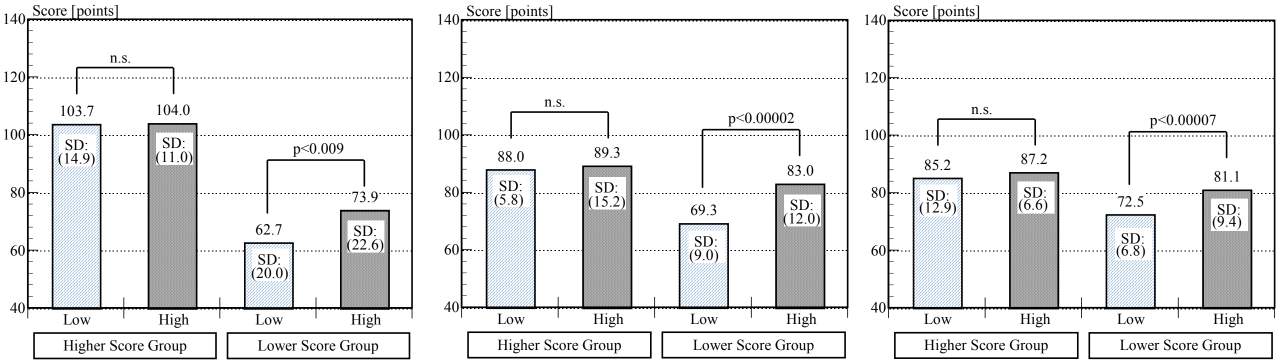


Figure 5 Learning performance improvement rates [%]

Figure 6(2) shows the results for the objective learning efficiency (based on the standardized examination) by score for Memorization Subject I. For the higher score group, no significant difference in the experimental results was identified with changes in the environmental conditions. For the lower score group, a significant improvement of 13.7 points (19.8[%]) resulted with a change in the air environment from low to high ventilation (p<0.00002).

Figure 6(3) shows the results for the objective learning efficiency (based on the standardized examination) by score for Memorization Subject II. For the higher score group, no significant difference in the experimental results was identified with changes in the environmental conditions. For the lower score group, a significant improvement of 8.6 points (12.9[%]) resulted with a change in the air environment from low to high ventilation (p<0.00007).

As shown above, no significant difference in learning efficiency was identified between the set environments for the higher score group for any of the Theoretical Subject, Memorization Subject I or Memorization Subject II, and the learning efficiency improved significantly with the change in the air environment, i.e., an increase in ventilation, for the lower score group (p<0.009). Thus, the lower score group was



(1) Theoretical Subject (2) Memorization Subject I (3) Memorization Subject II

Figure 6 Results for the objective learning performance by Score group

more susceptible to changes in the indoor environment.

6. Discussion

Figure 7 shows the relationship between the results of objective evaluation (quiz score) and the air environmental factors. In this section, statistical analyses were carried out for the data of Memorization Subjects. The logarithmic relationship was observed between quiz score of objective evaluation and ventilation rate per person [m^3/h/person]. The linear relation was observed between quiz score of objective evaluation and percentage of dissatisfied of air environment of subjective evaluation.

7. Conclusions and Implications

(1) The change in environmental conditions from low to high ventilation significantly improved the objective learning efficiency by 4.7 points (5.4[%]) for the Theoretical Subject ($p<0.03$), by 6.4 points (8.7[%]) for Memorization Subject I ($p<0.002$), and by 4.6 points (5.8[%]) for Memorization Subject II ($p<0.0007$).

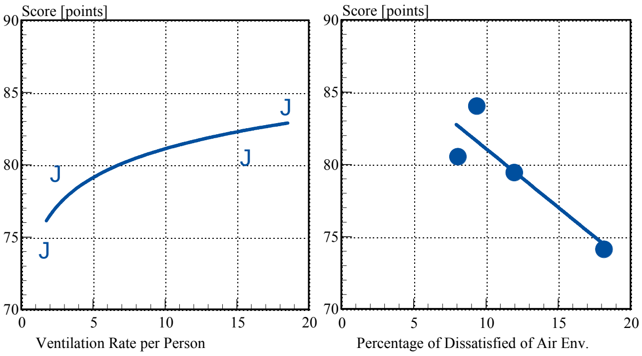
(2) The change in environmental conditions from low to high ventilation significantly improved the subjective learning efficiency.

(3) The subjectively reported “effective lecture time” significantly improved by 6.8 minutes (4.0%) for the Theoretical Subject ($p<0.004$), by 3.8 minutes (2.2[%]) for Memorization Subject I ($p<0.04$), and by 4.7 minutes (2.8[%]) for Memorization Subject II ($p<0.002$).

(4) The subjectively reported “expected improvement rate” improved by 4.6[%] for the Theoretical Subject ($p<0.01$), by 5.3% for Memorization Subject I ($p<0.05$), and by 6.6% for Memorization Subject II ($p<0.04$).

Notes

Pre-screening was conducted on the following factors that were expected to have a significant effect on learning performance, using self-assessment form data: (1) physical condition [%], (2) previous learning experience [%], and (3) level of interest in lecture (five-point scale). Only highly reliable subject data was selected. In the screening process, subject data that was not available for the environmental comparison between Theoretical Subject and Memorization Subjects I and II was also discarded.



(1) Quiz score vs Vent. rate (2) Quiz score vs Dissatisfied

Figure 7 Objective Evaluation vs Air Environment

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Indoor Pollutants, Microbial Concentrations And Thermal Conditions Influence Student Performance

S.R.Jurado

Air Conditioning R3M, 1626 João Carrato Street, TrêsLagoas, MS. 79600130–Brazil
email: r3marcondicionado@yahoo.com.br

Summary: *The investigation included thirty classrooms, air-conditioned (n=12) and naturally ventilated (n=18), at eleven different schools for comparison of indoor air quality. Environmental parameters were monitored in indoor and outdoor schools. A total of 674 pupils aged 10-12 filled in a questionnaire on building-related symptoms and they also make a test for checking the academic performance at both types of classrooms. Rooms with natural ventilation tended to have higher fungal concentration than air-conditioned rooms. The indoor average PM10 concentrations exceeded the Brazilian standards in six naturally ventilated classrooms. Indoor CO2 concentrations often exceeded 1000 ppm in ten air-conditioned rooms. The relative air humidity and indoor temperature for the majority of rooms with air-conditioning were within acceptable ranges, except classrooms with natural ventilation. Indoor exposures by children to dust, fungi, carbon dioxide, pets and tobacco were found to be associated with respiratory problems, headache, problems concentration, fatigue and lethargy. In the air-conditioned schools, pupils had better academic performance than that of naturally ventilated schools.*

Keywords: *Indoor air pollution, biocontaminants, schools, student performance.*
Category: *Measurement and Monitoring IAQ*

1. Introduction

Public concern about adverse effects of indoor air has increased in recent decades, beginning with episodes during the 1970 sin which occupants of residences and commercial and institutional buildings reported health problems associated with their buildings[1]. Among the commonly reported complaints in these episodes have been eye and upper respiratory tract irritation, headache, fatigue, and lethargy, and breathing difficulties or asthma. Wider recognition of this problem has also produced concern that health problems from poor indoor environments may reduce the performance of occupants in buildings, with potentially substantial adverse effects on work force productivity[2,3]. Buildings factors or pollution in buildings most frequently and consistently associated with respiratory health effects are the presence of moisture[4], mold[5,6], and microbiological pollutants[7]; animal and other biological allergens[8,9]; and combustion products, including nitrogen dioxide and carbon dioxide[10]. Other risks factors for respiratory health effects include: moisture or dirt in heating, ventilation and air conditioning (HVAC) systems[11]; low ventilation rates[12,13]; formaldehyde[14,15]; chemicals in cleaning products[16]; and outdoor pollutants or vehicle exhaust[17]. Air quality at schools is of special concern since children are susceptible to poor air quality because they breathe higher volumes of air relative to their body weights and their tissues and organs are actively growing[15]. Good air quality in classrooms favour children's learning ability, teacher and staff's productivity[18]. Investigations of air quality at classrooms help to characterize pollutants levels and implement corrective measures if necessary. Indoor air quality problems can result in increased absences because of respiratory infections, allergic diseases from biological contaminants, or adverse reactions to chemicals used in schools. There is evidence that many schools in the United States and Europe have significant and serious indoor environmental problems[14], however, this is the first study about indoor air quality in the Brazilian schools. The objectives of this paper are to characterize air pollution level at eleven schools in Brazil, to compare the measured concentrations between naturally ventilated and air conditioned classrooms, and to suggest ways to reduce pollutant levels in classrooms.

2. Methodology Site description and the study population

The study was conducted between August and November 2005. Air samples were collected from eleven elementary schools classified in: seven with natural ventilation / NV (AGlisted) and four with air conditioning /AC (HLlisted) in the Brazil, in the States of Mato Grosso do Sul and São Paulo, including the cities of Três Lagoas, Ilha Solteira and Araçatuba. (Table2). Therefore, thirty classrooms were studied (n=18, naturally ventilated rooms by opening the windows; n=12, air conditioned rooms).The schools were located in residential areas. Two or three classrooms from each school were studied.

Particular attention was put on selecting rooms showing similar geometrical features: all rooms selected for the tests were rectangular and show one external wall, one side in contact with a corridor, and the two other sides in contact with adjacent rooms. Fixed characteristics of the buildings (construction materials, ventilation systems) and observations of the general cleanliness were obtained from each school. Signs of moisture, water damage or fungal growth on building materials were assessed visually.

A total of 674 children between 10-12 years of age were recruited as volunteers from schools to answer a questionnaire of building-related symptoms and a test containing questions about arithmetic and sentence comprehension. Each participant was informed that all personal data were confidential, and the principals of the pupils gave permission for their participation. Study participants were asked to report on a number of building-related symptoms, experienced within the preceding 4 weeks, including irritation of eyes, nose and throat; headache; concentration problems; fatigue; lethargy and absenteeism due to respiratory disease. Response categories for these symptoms were 'no' or 'yes'. The questionnaire also included questions about parents smoking habits (daily exposure to tobacco), presence of pets at home and thermal sensation of students at classrooms with natural ventilation and air conditioning. The thermal sensation of people was performed according to International Standard of Thermal Comfort [19] as follows: too hot: +3; hot: +2; mild hot: +1; well, nor hot neither cold: 0; mild cold: -1; cold: -2; too cold: -3. For this relation, the people who vote +3, +2, -3 and -2 on the seven-point perception scale were considered thermically dissatisfied. The people who vote +1 and -1 were not considered as dissatisfied.

Environmental parameters and Occupancy parameters

Parameters of interest and pollutants were indoor and outdoor carbon dioxide (CO_2), temperature, relative humidity (RH), air speed, viable fungi, and indoor particulate matter with diameter less than 10 μm (PM_{10}) or airbone dust. Sampling equipments were placed at 1.5 m above ground level at both and outdoor locations. CO_2 concentrations were measured using a non-dispersive infrared sensor (TESTO DIGITAL 535). Temperature and relative humidity were measured using TESTO DIGITAL 605-H1. For measuring wind speed was utilized TESTO DIGITAL 405-V1. Cultural fungi were sampled using Andersen sampler, MAS-100 model (MERCK) operating at fixed volume of 250 liters and Saboraund agar in 90 mm disposable Petri dishes. After incubation, colonies were counted with the aid of a stereoscopic microscope. The number of colony-forming units (ufc) of fungi in each sample was calculates as cfu/m^3. Colony counts were adjusted using Andersen's positive hole correction factors [20]. Airborne particles (PM_{10}) were measured by GILIAN^{TM} (model BDX II). The levels of all measured parameters were comparable for the two ventilations systems (naturally ventilated and air-conditioned rooms). The number of the occupants also was monitored (Table 1).

Statistics

The comparison all parameters and pollutants in the naturally ventilated and air-conditioned classrooms were performed using non-parametric Mann-Whitney test. The outcomes of interest, indoor fungal concentration; indoor dust; indoor CO_2 levels; pets at home and daily exposure to tobacco were tested for a linear correlation with all buildings-related symptoms (Pearson *r*). $P < 0.05$ was taken as statistically significant.

3. Results

CO_2 measurements

Carbon dioxide (CO_2) concentrations can be considered as an indicator of ventilation rate. The CO_2 monitoring showed that concentrations vary from classroom to classroom and change according to ventilation type, window operation and occupation rate. The highest CO_2 concentrations (frequently exceeding 1000 ppm) occurred in the classrooms with air-conditioning due to poor air renovation (Table 2). Measured CO_2 levels in the rooms with natural ventilation were within specified Brazilian guidelines. The mean CO_2 concentrations in outdoors were around 362 ppm, they ranged from 268 to 701 ppm. Measurements of indoor CO_2 were significantly and negatively correlated with UR.

Biological measurements

Rooms with natural ventilation tended to have higher fungal concentration than air-conditioned rooms (672.7 *vs.* 466.9, respectively, $p<0.05$) (Table 2). Windows being open for part of the day, increased outdoor temperature and outdoor fungal concentrations can be related to increase indoor fungal concentration in the naturally ventilated rooms. Mean outdoor fungal concentration was around 715 ufc/m^3 (values from 236 to 1384 ufc/m^3). Indoor biocontamination was assessed using indoor/outdoor (I/O) fungi concentrations ratio. I/O ratios above 1.5 reveal indoor air pollution due to insufficient ventilation, inappropriate clean-up practices or outdoor contamination. The naturally ventilated classrooms showed I/O > 1.5 in three, equal to 1.5 in three, < 1.5 in twelve rooms. All air-conditioned rooms had I/O below 1.5. I/O ratio had statistical significance between naturally ventilated and air-conditioned rooms (Table 2). Indoor fungal concentration was positively associated with room temperature (p=0,03). The naturally ventilated schools built before 1990 had the highest indoor fungal concentrations compared with temporary schools, which had the lowest.

Thermal comfort parameters

The comfort parameters of relative air humidity and indoor temperature for the majority of rooms with air-conditioning were within acceptable ranges, except classrooms with natural ventilation, which ten had relative air humidity above 65% and all temperature superior to 26°C (Table 2). Outdoor RH varied between 53.8% and 79.9%. Indoor RH recommended by national guidelines should be 40 to 65%. Average outdoor temperature ranged from 27.0 to 34.4°C. Indoor temperature suggested by Brazilian standards should be 23 to 26°C in summer and 20 to 22°C in winter. The indoor wind speed was within Brazilian standards in both types of ventilation (Table 2). The outdoor wind speed varied 0.02 to 0.20 m/s. In respect to thermal sensation, 60.95% and 17.63% were thermally dissatisfied, 22.07% and 31.55% not dissatisfied at classrooms with natural ventilation and air-conditioning, respectively. The ISO 7730 suggest for an environmental to be thermal acceptable, a percentage of dissatisfied people should be lower than 10%.

Particulate matter or airbone dust

The airbone dust concentrations were significantly higher inside naturally ventilated rooms than air-conditioned rooms (602.3 *vs* 3.17 μg/m^3) (Table 2). The former had values ranging from 1.12 to 1818.2μg/m^3 (recommended Brazilian values are ≤ 80 μg/m^3). This suggests that dust within naturally ventilated rooms was of environmental origin. In the air-conditioned rooms, there was lower penetration of outdoor dust.

Building-related symptoms and academic performance

Almost 65% student participants had pets at home and more 18% of schoolchildren reported daily exposure of tobacco. There were not significant differences of building-related symptoms between occupants of the naturally ventilated and air-conditioned classrooms (Table 3). With respect to absenteeism, there also was not significant difference between students of classrooms with natural ventilation and air-conditioning (Table 4). More 50% of students had some type of general or specific symptoms (Table 3) when it happens, these are considered building-related symptoms (formerly ‘sick building syndrome’- SBS). The daily exposure by students to tobacco was positively correlated with eye, nasal and throat irritations, headache and difficulties in concentration. Pets at home were significantly associated with absenteeism and all specific and general symptoms. The pupils of air-conditioned rooms had statistically significant marks with comparable to students of naturally ventilated classrooms (7.17±0.10 *vs* 8.32±0.11). The academic performance was negatively and significantly associated with higher room temperatures.

Table 4 shows the univariated associations of airbone fungi concentrations with a number of building-related symptoms. All symptoms were positively associated with the level of airbone fungi expressed as the number of cfu: eye irritation, nasal irritation, throat irritation, headache, concentration problems, fatigue and lethargy. However, association significant was noted for fatigue and lethargy in the naturally ventilated rooms. A significant positive trend was found between CO$_2$ levels and throat irritation and headache in both types of ventilation systems. The highest CO$_2$ levels were significantly and positively associated with concentration problems and fatigue. The particulate matter concentrations were positively associated with specific and general SBS-symptoms. For air-conditioned rooms, none significant association with the building-related symptoms was observed, whereas, significant correlation was noted for eye irritation and headache in the pupils of the rooms with natural ventilation.

Table 1. Main features of the rooms selected.

	Construction materials	*Building age*	*Area (m^2)*	*N° of students*
A1	Brick	Ages of 70	48.0	32
A2	Brick	Ages of 70	48.0	24
B1	Brick	> 2000	49.0	31
B2	Brick	> 2000	49.0	25
B3	Brick	> 2000	49.0	21
C1	Concrete	Ages of 90	48.0	22
C2	Concrete	Ages of 90	48.0	23
D1	Brick	Ages of 70	48.0	28
D2	Brick	Ages of 70	54.0	27
E1	Brick	Ages of 80	56.0	19
E2	Brick	Ages of 80	54.0	16
E3	Brick	Ages of 80	56.0	11
F1	Brick	> 2000	49.0	34
F2	Brick	> 2000	49.0	28
F3	Brick	> 2000	58.0	33
G1	Brick	Ages of 70	49.0	19
G2	Brick	Ages of 70	49.0	18
G3	Brick	Ages of 70	49.0	19
H1	Brick	> 2000	61.0	21
H2	Brick	> 2000	52.0	26
H3	Brick	> 2000	56.0	29
I1	Brick	Ages of 70	54.0	32
I2	Brick	Ages of 70	54.0	27
I3	Brick	Ages of 70	54.0	23
J1	Brick	Ages of 70	24.0	10
J2	Brick	Ages of 70	24.0	8
J3	Brick	Ages of 70	48.0	9
L1	Concrete	Ages of 90	41.0	25

L2	Concrete	Ages of 90	39.0	20
L3	Concrete	Ages of 90	39.0	14

Table 2. Mean concentration and variation between classrooms for measured indoor air pollutants, room temperature, wind speed and relative humidity.

	NV		*AC*	
Pollutant/ Parameter	*Mean*	*Min-max*	*Mean*	*Min-max*
CO_2 (ppm)	467.6	321-704	1858.3*	727-3024
Room temp. (°C)	31.6	28.2-35.7	27.6*	25.2-32.1
Relative humidity (%)	65.6	50.7-83.5	53.3*	44.6-64.5
Wind speed (m/s)	0.13	0.04-0.25	0.11	0.02-0.26
Airbone dust ($\mu g/m^3$)	602.3	1.12-1818.2	3.17	0.6-7.0
Viable fungi (cfu/m^3)	672.7	320-1348	466.9*	96-956
I/O	1.27	0.23-3.34	0.50*	0.15-0.75

*p<0.05

Table 3. Symptoms, absenteeism and perception of indoor climate among the students at both ventilation systems.

Type	*Students of naturally ventilated rooms (n=430)*	*Students of air-conditioning rooms (n=244)*
Specific symptoms		
Eye irritation (%)	27.77	23.03
Nasal irritation (%)	23.96	19.03
Throat irritation (%)	12.87	12.71
General symptoms		
Headache (%)	23.61	21.41
Difficulties in concentration (%)	13.80	13.55
Fatigue (%)	21.76	21.68
Lethargy (%)	24.61	22.49
Absenteeism (%)	8.60	5.73
Perception of Indoor Climate		
Too hot (%)	27.00	4.10
Hot (%)	33.95	6.15
Mild hot (%)	19.77	10.65
Well, nor hot neither cold (%)	16.98	50.82
Mild cold (%)	2.30	20.90
Cold (%)	0	6.97
Too cold (%)	0	0.41

Table 4. Building-related symptoms according to level of airbone fungi, carbon dioxide and particulate matter (PM) at naturally ventilated and air-conditioned rooms.

	Fungi		*CO_2*		*PM*	
	NV	*AC*	*NV*	*AC*	*NV*	*AC*
Specific symptoms						
Eye irritation	0.2	0.2	0.4	0.5	$0.5^{\dagger}$	0.4
Nasal irritation	0.3	0.5	0.3	0.5	0.1	0.2
Throat irritation	0.1	0.3	$0.5^{\dagger}$	$0.7^{\#}$	0.4	0.5
General symptoms						
Headache	0.2	0.4	$0.5^{\dagger}$	0.8*	$0.5^{\dagger}$	0.5
Difficulties in concentration	0.3	0.5	0.01	1.0*	0.2	0.5
Fatigue	$0.4^{\dagger}$	0.5	0.2	0.9*	0.3	0.4
Lethargy	$0.4^{\dagger}$	0.1	0.3	0.4	0.3	0.5

*P < 0,001; $^{\#}$P < 0,01; †P< 0,05

4. Discussion

In this study, the pupils of air-conditioning classrooms had better academic performance than that of naturally ventilated rooms, in spite of the higher CO_2 levels in the formers rooms. There is good evidence that moderate changes in room temperature, even within the comfort zone, affect children's abilities to perform mental tasks requiring concentration, such as addition, multiplication, and sentence comprehension. Overall, warmer temperatures tend to reduce performance, while colder temperatures reduce dexterity and speed [21].

Thirty percent of naturally ventilated classrooms showed higher airbone dust concentrations because of construction materials, inappropriate clean-up pratices and kitchens near rooms. The combustion activities as cooking and smoking can produce PM indoors [22]. Higher particulate matter concentrations in these rooms were also due to outdoor sources of PM that may infiltrate indoors. Indoor PM concentrations are typically equal to or higher than concurrently measured outdoor levels, depending on the sources and activities that are present indoors.

Many outdoor pollutants enter readily into the air indoors, and as the children spend the great majority of their time in the schools, it is likely that described symptoms by they largely reflect effects from indoor exposures. Dust in the schools was positively associated with the building-related symptoms; however, significant correlation was found for eye irritation and headache in the naturally ventilated rooms. Also, dust in schools has been associated with statistically significant increases in allergic sensitization and prevalence of asthmatic symptoms [14].

The naturally ventilated rooms showed higher airbone fungi concentrations than air-conditioned ones due to, probably, outdoors fungi infiltration. Higher temperature and relative humidity also can be increased airbone fungi levels indoors in these rooms.

We noted that air-conditioning in the schools is associated with lower absentee rates and improved performance. The air-conditioning systems are designed to control temperature and humidity (a positive effect), however, they may also become contaminated with biological pollutants (a negative effect) if they are not judiciously maintained. A review of building investigation reports also suggests significant benefits to health and performance from good HVAC systems maintenance. Presumably, these benefits result because properly maintained HVAC systems can provide consistently good thermal and ventilation control while also reducing the risk of biological contamination [21].

Another study demonstrated that home air-conditioning was associated with lower penetration of outdoor particles, and the association between PM10 and hospital admissions was lower in cities with a higher prevalence of air-conditioning [23].

In total, in 10 out 12 air-conditioned rooms had concentration of CO_2 above 1000 ppm, exceeding the Brazilian standard due to inadequate ventilation. Increase the rate of ventilation could also remove the accumulated CO_2; for example, the use of ceiling fans, exhaust fans could increase the exchange of indoor air with the outdoor, but further investigations is necessary because increased ventilation could also increase the indoor concentration of outdoor generated pollutants. We did not observe association between levels CO_2 and decrease academic performed. However, the highest levels CO_2 were positively and significantly associated with concentration problems and headache. Subsequent studies are necessary for comparing the academic performance in air-conditioned rooms with CO_2 above 1000 ppm and CO_2 within standards, however, others environmental parameters may be within guidelines.

The ventilation in the schools was generally reasonable, but the contamination of cat and dog allergens and daily exposure by schoolchildren to tobacco at home was considerable and building-related symptoms were common. Thus, homes and schools are critical exposure microenvironments for children.

A study confirmed that the most important particle source in homes was smoking and second, cooking [24]. The environmental tobacco smoke results in lung cancer deaths, heart disease deaths and asthma episodes in children [22]. Animal allergens, for instance, that of cat and dog are transported on people’s clothes and hair to the school [25].

Indoor exposure by children to dust, fungi, carbon dioxide, pets and tobacco were found to be associated with eye, nose, and throat irritation; headache, problems concentration, fatigue and lethargy.

Overall inadequacies in the indoor air quality of Brazilian schools not yet been systematically characterized. Nevertheless, the well-documented conditions of inadequate ventilation and indoor pollutants in many schools merit public concern and additional research.

5. Conclusions

Our results suggests that poor environments in schools, due primarily to effects of indoor pollutants, adversely influence the health, performance, and attendance of students.

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The Risk Screening for Indoor Air Pollution Chemicals in Japan

K. Azuma[1], I. Uchiyama[2] and K. Ikeda[1]

[1] National Institute of Public Health, 2-3-6 Minami, Wako, Saitama, 351-0197, Japan
e-mail: azuma@kcn.ne.jp http://www.niph.go.jp
[2] Kyoto University, Yoshida Honmachi Sakyo-ku, Kyoto, 606-8501, Japan

Summary: *Thousands of chemicals have been identified in indoor environment. However, priority rating of those chemicals based on the health risk level was not effective attempted in Japan. We developed a risk screening scheme for indoor air pollution chemicals and analyzed current status on the risk levels of indoor chemicals identified in past 10 years in Japan. Those chemicals were classified three categories based on the health risk level. Our results showed that the risk levels of 93 chemicals were characterized, and 7 chemicals, e.g., formaldehyde, acrolein or benzo(a)pyrene and so forth were classified the highest risk category.*

Keywords: *Indoor Air pollution, Indoor Air Quality, Health Risk, Risk Assessment, Risk Screening, Japan*
Category: *Risk assessment in relation to indoor exposures*

1 Introduction

In recent years, public health problem caused by indoor air pollutants has been drawing strong public concern in Japan. Governmental agencies have taken effective measures to solve the problem, for instance, “Guidelines for indoor air quality” of 13 chemicals, e.g., formaldehyde, toluene and so forth. Thousands of chemicals have been identified in indoor environment. The exiting regulations do not cover enough ranges those chemicals. Especially, priority rating of those chemicals based on the health risk level was not effective attempted in Japan [1]. We developed a risk screening scheme for indoor air pollution chemicals and analyzed current status on the risk levels of indoor chemicals identified in Japan.

2 Methods

Exposure assessment

We searched for the field survey studies of indoor concentrations in residential environment in Japan. The search period was 10 years after January 1995. The JST Online Information System (JOIS) by Japan Science and Technology Agency (JST), the database of MHLW grants system and the studies of governmental agencies were searched. The source studies which provided the best available estimates of typical concentrations in non-industrial indoor environments were selected. As the results, 19 studies were selected [2]-[20]. The selections were based on the following criteria; 1) large scale survey, e.g., nationwide or prefectural wide; 2) random sampling (not specific population, e.g.,

Table 1 The documents or reports for hazard assessment

No.	Documents or reports
(1)	MHLW, Japan: Indoor Air Pollution, Summary on the discussions of the meetings, progress report, Vol. 1 (2000), Vol. 2 (2000), Vol. 3 (2001), Vol. 4 (2002)
(2)	Ministry of Environment, Japan: Environmental risk assessment of chemicals, Vol. 1 (2002), Vol. 2 (2003), Vol. 3 (2004)
(3)	Agency for Toxic Substances and Disease Registry (ATSDR): Toxicological Profile Information Sheet
(4)	U.S. National Toxicology Program, Center for the evaluation of risks of human reproduction (CERHR): NTP-CERHR expert panel report
(5)	International Programm on Chemical Safety: Concise International Chemical Assessment Documents (CICAD), No. 1-66
(6)	European Chemicals Bureau (ECB): European Union Risk Assessment Report
(7)	International Programm on Chemical Safety: Environmental Health Criteria (EHC), No. 1-231
(8)	U.S. Environmental Protection Agency, Office of Pollution Prevention & Toxics (OPPT): Chemical Fact Sheets
(9)	U.S. Environmental Protection Agency (EPA): Pesticide Tolerance Reassessment & Reregistration Documents
(10)	U.S. Environemtal Protection Agency (EPA): Integrated Risk Information System (IRIS)
(11)	Organisation for Economic Co-operation and Development (OECD): Screening Information Data Set (SIDS)
(12)	California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (OEHHA): Chronic Reference Exposure Levels
(13)	WHO Headquarters (2000) Guidelines for Air Quality
(14)	WHO Europe (2000) Air Quality Guidelines for Europe 2nd edition., WHO Regional Publication, Europeans Series, No. 91, Copenhagen

allergic subjects); 3) description of arithmetic average or 95th percentile of indoor air concentration;

Hazard assessment

For the chemicals identified in the exposure assessment, estimated human no observed adverse effect levels (NOAELs) or unit risks (URs) were determined. We searched for the documents or reports released by international or governmental agencies to obtain the reliable observed effect level for hazard assessment. The available documents or reports were shown in Table 1.

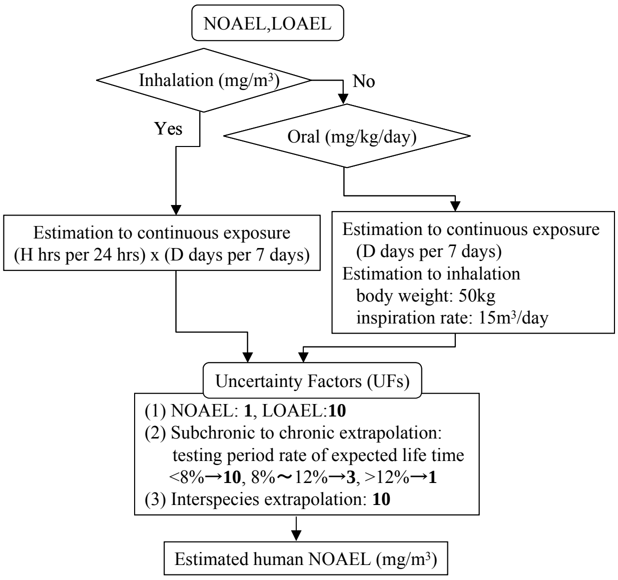

Fig. 1 Estimating scheme for the non-cancer effects

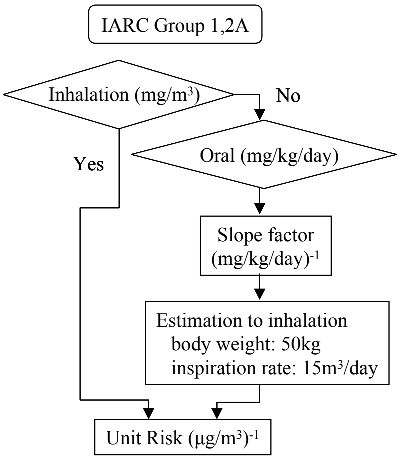

Fig. 2 Estimating scheme for the cancer effects

Estimating schemes for the non-cancer effects and the cancer effects were shown in Fig. 1 and Fig. 2, respectively. Subchronic or chronic no observed adverse effect level (NOAEL) or the low observed adverse effect level (LOAEL) based on systemic, developmental, reproductive, neurological immunological or lymphoreticular endpoints, were estimated from these documents or reports as non-cancer effects. Priority rating the NOAEL or LOAEL was based on the following criteria; 1) Priority is given to human studies over animal studies; 2) Priority is given to NOAEL over LOAEL, if NOAEL > LOAEL, LOALE is selected; 3) Most sensitive endpoint is selected; 4) Longer-term exposure study is selected. Finally, the estimated human NOAEL was determined from the scheme of Fig.1. The unit risk (UR) of the chemicals that were classified carcinogenic to humans (Group1) or probably carcinogenic to humans (Group2A) in the evaluation of carcinogenicity by International Agency for Research on Cancer (IARC) were determined from the scheme of Fig. 2.

Risk characterization

The margin of exposure (MOE) or the carcinogenic excess risk was calculated from formula (1) or formula (2), respectively. The risk was classified from criteria of Table 2. Category A suggests classification should be decreased health risks immediately, category B suggests classification should be recommended further detailed research, or category C suggests classification should not be taken an action immediately. 95th percentile was the preferred indicator of typical indoor concentrations for risk characterization because it provides an indicator of high-end exposure but is not greatly affected by outliers as with the maximum. When the 95th percentile was not available from source studies for exposure assessment, arithmetic average was used as other indicators. The integrated risk category was determined from most severe category of MOE or carcinogenic excess risk.

$$\mathrm{MOE} = \frac{\text{Estimated human NOAEL}}{\text{Indoor concentration}} \tag{1}$$

$$\text{Carcinogenic excess risk} = \text{Indoor concentration} \times \mathrm{UR} \tag{2}$$

Table 2 The risk characterization criteria

MOE	Carcinogenic excess risk	Category
< 10	≧ 10^{-5}	A（action）
≧ 10,< 100	≧ 10^{-6},< 10^{-5}	B（surveillance）
≧ 100	< 10^{-6}	C（inaction）

3 Results and Discussion

Indoor air concentrations of 159 chemicals were identified from the source studies in Japan. Of 159 chemicals, estimated human NOAELs of 92 chemicals and URs of 5 chemicals were determined. 51 out of 92 estimated human NOAELs and all chemicals of URs were determined from the studies of inhalation exposure. As a whole, MOEs or carcinogenic excess risks were determined in 93 chemicals. The estimated human NOAELs in our study were shown in Table 3. The carcinogenic excess risks were shown in Table 4. Table 3 was showed the only chemicals which MOEs were below 1000 in the risk screening results in Table 5.

Table 3 Estimated human NOAELs

Compound	Indicator	Exposure route	Ovserved effect level *	Species	Health endpoint	Uncertainty factor	Estimated human NOAEL mg/m^3	Sources
Formaldehyde	NOAEL	Inhalation	0.09	Humans	Hyperplasia of the nasal mucosa, nasal and	1	0.021	(12)
Acrolein	LOAEL	Inhalation	0.92	Rats	Histopathological changes of the nasal mucosa	1000	0.00016	(2)
Naphthalene	LOAEL	Inhalation	10.00	Mice	Respiratory effects	100	0.018	(12)
1,4-Dichlorobenzene	NOAEL	Inhalation	120.00	Rats	Histopathological changes of the nasal mucosa	10	2.143	(1)
Acetaldehyde	NOEL	Inhalation	275.00	Rats	Degeneration of olfactory epithelium	100	0.491	(1),(2),(10)
2-Butoxyethanol	NOAEL	Inhalation	2.92	Humans	Changes in blood parameters	10	0.069	(3)
Carbon tetrachloride	NOAEL	Inhalation	6.10	Rats	Changes in the liver morphology	30	0.042	(7)
Xylene	LOAEL	Inhalation	91.00	Humans	Central nervous system effects	30	0.722	(2)
d-Limonene	NOEL	Oral	*10.00*	Rats	Increased liver weight	30	0.794	(5)
Benzene	NOAEL	Inhalation	1.70	Humans	Changes in blood parameters	3	0.135	(12)
Toluene	LOAEL	Inhalation	332.00	Humans	Central nervous system effects	30	2.635	(1),(2),(14)
1,2,4-Trimethylbenzene	LOEL	Inhalation	494.33	Rats	Decreased maternal and pup body weight	100	0.883	(8)
1,2-Dichloropropane	LOAEL	Inhalation	69.30	Rats	Hyperplasia of the nasal mucosa	300	0.041	(2)
Chlordane	NOAEL	Inhalation	0.10	Rats	Liver lesions, changes in serum chemistry	30	0.00079	(3)
ε-Caprolactam	NOAEL	Inhalation	24.00	Rats	Respiratory effects	30	0.143	(2)
Nonanal	NOAEL	Oral	*12.40*	Rats	Toxicological effects	30	1.378	(1)
1,3,5-Trimethylbenzene	LOEL	Inhalation	494.33	Rats	Decreased maternal and pup body weight	100	0.883	(8)
1,2,3-Trimethylbenzene	LOEL	Inhalation	494.33	Rats	Decreased maternal and pup body weight	100	0.883	(8)
n-Hexane	LOAEL	Inhalation	204.00	Humans	Multiple neurological lesions	30	1.619	(2),(3)
Tetrachloroethylene	LOAEL	Inhalation	15.00	Humans	Central nervous system effects	10	0.357	(3)
Ethylbenzene	NOAEL	Inhalation	327.47	Rats	Hyperplasia of pituitary gland	10	5.848	(11),(12)
Stylene	LOAEL	Inhalation	64.26	Humans	Neuropsychological deficits	10	1.530	(12)
Methylene chloride	LOAEL	Inhalation	140.00	Humans	Elevated carboxyhemoglobin levels	10	3.333	(12)
Decanal	NOAEL	Oral	*12.40*	Rats	Toxicological effects	30	1.378	(1)
Chloroform	NOAEL	Inhalation	24.00	Mice	Kidney lesions	10	0.429	(2)
Fenthion	NOAEL	Oral	*0.02*	Monkeys	Cholinesterase inhibition	100	0.00067	(9)
Trichloroethylene	LOAEL	Inhalation	170.00	Humans	Neurotoxicological effects, eye irritation	30	1.349	(12)
Butanal	NOAEL	Inhalation	151.00	Rats	Respiratory effects	30	0.899	(11)
n-Decane	NOAEL	Oral	*100.00*	Rats	Increased liver weight	30	11.111	(1)
Methyl acetate	NOAEL	Inhalation	1057.00	Rats	Degeneration of olfactory mucosa,liver lesions	100	1.888	(6)
n-Nonane	NOAEL	Oral	*100.00*	Rats	Increased liver weight	30	11.111	(1)
Chlorpyrifos	LOAEL	Oral	*0.30*	Rats	Cholinesterase inhibition	100	0.010	(1),(9)
2-Butoxyethoxyethanol	NOAEL	Inhalation	94.00	Rats	Liver effects	30	0.560	(6)
Octanal	NOAEL	Oral	*12.40*	Rats	Toxicological effects	30	1.378	(1)
n-Undecane	NOAEL	Oral	*100.00*	Rats	Increased liver weight	30	11.111	(1)
Fenitrothion	NOAEL	Oral	*0.13*	Dogs	Cholinesterase inhibition	100	0.0042	(9)

* Inhalation（mg/m^3）、*Oral*（mg/kg/day）

Table 4 URs

Compound	Species	Exposure route	Health endpoint	UR (μg/m^3)$^{-1}$	Sources
Benzene	Humans	Inhalation	Leukemia	2.9x10^{-5}	(12)
Benzo(a)pyrene	Humans	Inhalation	Lung cancer	8.7x10^{-2}	(13),(14)
Formaldehyde	Rats	Inhalation	Squamous cell carcinomas of the nasal cavity	1.3x10^{-5}	(10)
Tetrachloroethylene	Mice	Inhalation	Hepatocellular adenoma and carcinoma	5.9x10^{-6}	(12)
Trichloroethylene	Mice	Inhalation	Hepatocellular adenoma and carcinoma、lung adenocarcinoma and malignant lymphoma	2.0x10^{-6}	(12)

We determined the estimated human NOAEL based on the scheme shown in Fig. 1 developed in our study. Especially, in the scheme, when observed effect levels of inhalation exposure were not identified, estimated human NOAELs via inhalation exposure were converted from observed effect levels of oral exposure studies, reference human body weight of 50 kg and reference human respiration rate/day of 15 m^3 in Japanese people.

Pharmacokinetic data on chemical metabolism, effective dose at target site, or species differences between laboratory test animals and humans are considered in dose-response assessments when they are available. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment guidelines [21] assume that in the absence of evidence to the contrary, the chemicals that cause cancer after exposure by ingestion will also cause cancer after exposure by inhalation, and vice versa. Based on the guidelines, we also assume that the chemicals that cause adverse health effects after exposure by ingestion will also cause the health effects at same target site after intake to body by inhalation exposure. As the results, estimated human NOAELs or URs of more chemicals were determined under the developed schemes.

Ranges of the MOE in the chemicals which values of average concentrations are below 100 and the carcinogenic excess risk were shown in Fig. 3 and Fig. 4, respectively. The ranges were included overall MOE calculated by arithmetic averages of indoor air concentrations in source studies. The risk screening results of the only chemicals which MOEs were below 1000, were shown in Table 5. The I/O means the ratio of indoor air concentration to outdoor air concentration.

Table 5 Risk screening results

Compound	Measuring period	Estimated human NOAEL mg/cm^3	Indoor Air									Outdoor Air
			Indoor air concentration μg/m^3			MOE		Unit risk (μg/m^3)$^{-1}$	Carcinogenic excess risk		Risk	Risk
			Average	I/O	95percentile	Average	95percentile		Average	95percentile		
Formaldehyde	1997-2004	0.021	46.910	6.5		0.5 A		$1.3\text{x}10^{-5}$	$6.1\text{x}10^{-4}$ A		A	A
Acrolein	2000-2003	0.00016	0.267	3.0		0.6 A					A	A
Naphthalene	2001-2003	0.018	2.078	14.3	8.896	8.6 A	2.0 A				A	B
1,4-Dichlorobenzene	1997-2003	2.143	114.149	49.2	318.989	18.8 B	6.7 A				A	C
Acetaldehyde	2000-2004	0.491	25.140	6.8		19.5 B					B	C
2-Butoxyethanol	2001-2003	0.069	2.891	90.3	5.897	24.0 B	11.8 B				B	C
Carbon tetrachloride	1997-2003	0.042	1.542	2.2	1.132	27.5 B	37.4 B				B	B
Xylene	1997-2004	0.722	24.888	3.9	60.831	29.0 B	11.9 B				B	B
d-Limonene	1997-2003	0.794	27.164	58.5	60.339	29.2 B	13.2 B				B	C
Benzene	1997-2003	0.135	4.554	1.7	7.125	29.7 B	19.0 B	$2.9\text{x}10^{-5}$	$1.3\text{x}10^{-4}$ A	$2.1\text{x}10^{-4}$ A	A	A
Toluene	1997-2004	2.635	80.443	3.8	140.432	32.8 B	18.8 B				B	B
1,2,4-Trimethylbenzene	1997-2003	0.883	15.325	7.1	28.694	57.6 B	30.8 B				B	C
1,2-Dichloropropane	1997-2003	0.041	0.444	3.8	0.639	92.9 B	64.6 B				B	C
Chlordane	1999-2002	0.00079	0.0062	24.8		128.0 C					C	C
ε-Caprolactam	2001-2003	0.143	0.889	59.0	0.609	160.7 C	234.6 C				C	C
Nonanal	1997-2003	1.378	7.925	7.5		173.9 C					C	C
1,3,5-Trimethylbenzene	1997-2003	0.883	4.710	4.6	6.561	187.4 C	134.5 C				C	C
1,2,3-Trimethylbenzene	1997-2003	0.883	3.616	5.4	8.197	244.1 C	107.7 C				C	C
n-Hexane	1997-2003	1.619	6.619	2.3	13.076	244.6 C	123.8 C				C	C
Tetrachloroethylene	1997-2003	0.357	1.367	2.9	2.843	261.2 C	125.6 C	$5.9\text{x}10^{-6}$	$8.1\text{x}10^{-6}$ B	$1.7\text{x}10^{-5}$ A	A	A
Ethylbenzene	1997-2004	5.848	17.977	3.5	35.139	325.3 C	166.4 C				C	C
Stylene	1997-2004	1.530	4.683	13.3	13.069	326.7 C	117.1 C				C	C
Methylene chloride	1997-2003	3.333	9.842	5.0	21.659	338.7 C	153.9 C				C	C
Decanal	1997-2003	1.378	3.975	6.9		346.6 C					C	C
Chloroform	1997-2003	0.429	1.147	2.6	1.654	373.6 C	259.1 C				C	C
Fenthion	1999	0.00067	0.0017	n.a.		398.7 C					C	n.a
Trichloroethylene	1997-2003	1.349	3.045	3.9	4.104	443.1 C	328.8 C	$2.0\text{x}10^{-6}$	$6.1\text{x}10^{-6}$ B	$8.2\text{x}10^{-6}$ B	B	B
Butanal	2000-2003	0.899	1.900	5.4		473.1 C					C	C
n-Decane	1997-2003	11.111	18.763	9.8	61.455	592.2 C	180.8 C				C	C
Methyl acetate	2001-2003	1.888	2.938	115.1	17.089	642.6 C	110.5 C				C	C
n-Nonane	1997-2003	11.111	16.245	13.2	45.771	684.0 C	242.8 C				C	C
Chlorpyrifos	1999-2002	0.010	0.014	5.0	0.123	690.8 C	81.0 B				B	C
2-Butoxyethoxyethanol	2001-2003	0.560	0.692	1.9	4.435	809.1 C	126.2 C				C	B
Octanal	2001-2003	1.378	1.500	2.0		918.5 C					C	C
n-Undecane	1997-2003	11.111	12.071	11.3	32.610	920.5 C	340.7 C				C	C
Fenitrothion	1999-2001	0.0042	0.004	n.a.		942.9 C					C	n.a
Benzo(a)pyrene	1999-2002		0.001	0.9				$8.7\text{x}10^{-2}$	$5.0\text{x}10^{-5}$ A		A	A

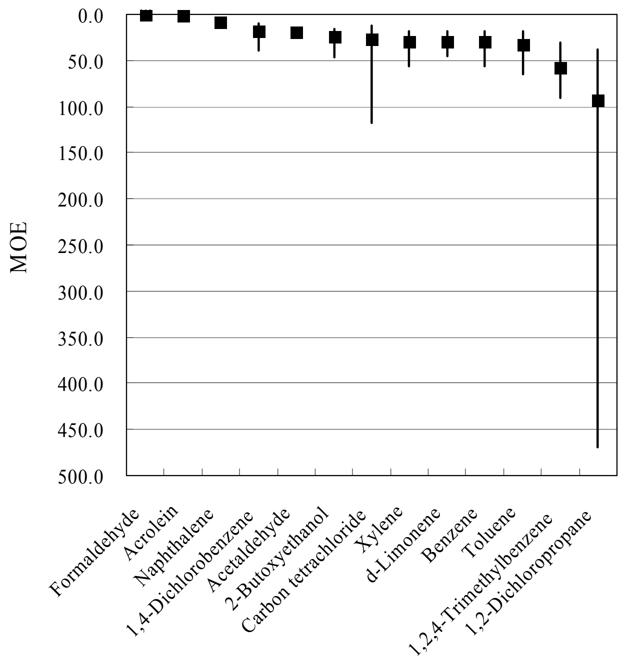

Fig. 3 Ranges of the MOE

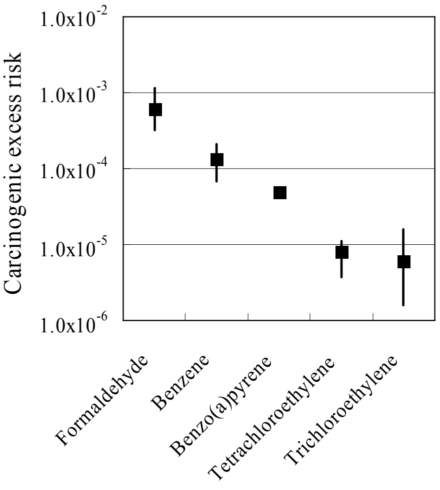

Fig. 4 Ranges of carcinogenic excess risk

7 chemicals were classified in category A and 10 chemicals were classified in category B. Both MOE and carcinogenic excess risk of formaldehyde were highest in this study. The regulations enforced by Japanese governmental agencies had been a significant reduction in the indoor air concentrations of formaldehyde, down 55% from 2000 to 2003 [8][11]. However, the range of risk by formaldehyde in indoor air has been remaining high levels as shown in Fig. 3 and Fig. 4. More regulatory action for reduction of formaldehyde concentrations in indoor air would therefore be needed.

The chemicals of risk category A in both indoor and outdoor air were formaldehyde, acrolein, benzene, tetrachloroethylene and benzo(a)pyrene. These chemicals were designated priority targets, specific chemicals and so forth in the Air Pollution Control Law in Japan. However, the risks by these chemicals also have been remaining high levels. Hence, further detailed research and regulatory action would be needed. Especially, formaldehyde, acrolein, benzene and tetrachloroethylene have emission sources in indoor from I/O values as shown in Table 5. Further detailed research for indoor emission sources of these chemicals would be needed.

The outdoor air concentrations were measured at verandas or under eaves in source studies. In case of chemicals having strong emission sources in indoors, the outdoor air concentrations measured those places are liable to be higher than ambient air concentrations. In those cases, therefore, the risks of outdoor air might be overestimated in ambient air regulations. Those risk evaluation would be remaining issue to be researched.

1,4-Dichlorobenzene and naphthalene were classified category A and had high I/O ratios. The emission sources of these chemicals in indoor are mainly repellents. The exposures by these chemicals depend on lifestyle of occupants. The recommendations of use, handling, storage or risk information should therefore be provided for public people.

British Department of Health [22] and Chinese State Environmental Protection Administration [23] established indoor air guideline of benzene and benzo(a)pyrene. German Federal Environmental Agency [24] established the guideline of naphthalene. These chemicals also should be focused attention as high risk indoor air pollution chemicals in Japan.

4 Conclusion

We developed a risk screening scheme for indoor air pollution chemicals and analyzed current status on the risk levels of those chemicals in Japan. As the results, the risk levels of 93 indoor air pollution chemicals were characterized in this study. We also found the priority chemicals, which were 7 chemicals of category A should be decreased health risks immediately and 10 chemicals of category B should be recommended further detailed research.

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Health Hazards in the Home Environment
A Risk Assessment Methodology

D Ormandy[1]

[1]Safe and Healthy Housing Research Unit, Law School, University of Warwick, Coventry, CV4 7AL, UK.
email: david.ormandy@warwick.ac.uk http://www2.warwick.ac.uk/fac/soc/law/research/centres/shhru/

Summary: *A methodology for the assessment of potential threats to health in the home environment has been developed in England. The system takes account of the likelihood of exposure to a health hazard and the degree of incapacity of the possible outcomes, and allows the comparison of the dangers from a wide range of hazards, including hygrothermal conditions and indoor air quality. The methodology has been subject to extensive testing and has now been introduced as the national prescribed method for assessing conditions in existing housing. The methodology is capable of adaptation for a range of situations.*

Keywords: *Energy efficiency, Indoor Air Quality, Hazards, Health, Home environment, Risk assessment.*
Category: *Risk Assessment*

1 Introduction

A risk assessment methodology has been developed that grades the severity of the estimated threat to health and safety from defects and deficiencies in housing. It provides a means for comparing hazards in different dwellings, and for comparing widely differing hazards. In England, this system has been adopted as the statutorily prescribed method for assessing housing conditions as the first stage in determining whether enforcement action should be taken. However, it may be that the original development and the principles could be adapted and developed for assessing threats from conditions in the housing environment, for profiling conditions from housing survey data, and perhaps other uses.

The chance to develop the system, the Housing Health and Safety Rating System (HHSRS), arose through an opportunity to review the statutory minimum standard for housing and the principles behind it. This influenced the approach and the development of the HHSRS.

1.1 Background to the English Housing Standards

There has always been some health based justification behind the English housing standards, although by the 1990s this had become obscured. The early 19th century English movement for a recognition of the association between ill health and the physical environment created pressure for some form of state intervention to ensure perceived causes of disease were eliminated. This movement promoted what became known as the ‘Sanitary Idea’, built on a notion that smells were linked with disease, that diseases were spread by miasma. The theory went, remove the sources of smells – the rubbish, the raw sewage – and make provision for fresh air and light, and the incidence of diseases would be reduced.

In 1868 Parliament placed duties on local authorities to identify and deal with dwellings that were ‘in a Condition or State dangerous to Health so as to be unfit for Human Habitation’ [1]. However, it wasn’t until 1919 that there was an attempt to define what was meant by the term unfit, or fit, for human habitation. It was then that the Ministry of Health proposed a definition [2], recommending that a house should be regarded as unfit if it was not (i) free from serious dampness; (ii) satisfactorily lighted and ventilated; (iii) properly drained and provided with adequate sanitary conveniences and with a sink and suitable arrangements for the disposal of waste water; (iv) in good general repair, and had not (v) a satisfactory water supply; (vi) adequate washing accommodation; (vii) adequate facilities for preparing and cooking food; (viii) a well ventilated store.

Even the idea of a common national definition wasn’t adopted until some 35 years later when a statutory standard was introduced by the Housing Repairs and Rents Act 1954 [3]. This stated that a dwelling would be deemed unfit if it was so far defective in one or more of eight requirements as to be not reasonably suitable for occupation. These requirements were really only general headings of matters to be taken into account, and was more limited than the 1919 recommendations. It included repair, dampness, water supply, sanitary conveniences and cooking facilities. However, there was no reference to washing accommodation, and it limited the requirement for lighting to ‘natural’ lighting.

With only two minor changes – the removal of the requirement for food storage facilities, and the additional of a requirement dealing with internal arrangement [4] – this remained the national standard for the next 36 years. It was replaced in 1990 [5] by a the new Fitness Standard that was really just an up-dated version, although it did introduce for the first time requirements for the provision of artificial lighting, for heating, for hot water, and for personal washing facilities.

1.2 The Link between Housing Conditions and Health

The original concept of what was the minimum necessary for a dwelling to be fit for its purpose – that of providing a safe and healthy shelter for the occupiers – could be said to be grounded in some notion of a link between conditions and health, albeit the Sanitary Idea. However, the phrasing of the statutory standards were building focussed, the emphasis being on what was necessary to achieve the result. And although it was claimed that the approach of the new Fitness Standard introduced in 1990 was to be different, the language of the Standard itself remained the same. While the guidance [6] alluded to the health basis underlying the requirements, the appraisal of the dwelling was primarily an assessment of the structure and amenities of the dwelling – the assessment of defects and deficiencies.

1.3 Research, Research, and More Research

In 1993 Warwick Law School was commissioned to investigate the way that local authorities interpreted and applied the new Fitness Standard [7]. That study found that while there appeared to be a relatively uniform understanding and application of the Standard, there was scope for some amendments and clarifications. As well as suggesting some improvements to the Guidance on certain requirements [8], the report identified matters that should be covered by a standard aimed at protecting health and safety. These included –

- internal arrangement, or dangerous design features;
- thermal insulation;
- sound insulation;
- threats to health or safety from the immediate locality;
- fire precautions and means of escape in case of fire; and
- radon.

Other research was been carried out, by the Building Research Establishment (BRE), primarily reviewing the evidence of the relationship between building design and condition and the health and safety of users [9]. This review also involved checking the extent to which legal controls gave protection users, including controls applicable to existing dwellings [10].

In this research, the BRE provided a comprehensive review of the evidence and used a simple risk assessment approach to rank threats to health and safety. The reports showed that the many of the most serious potential hazards that could be found in dwellings were not covered by the statutory standards, complementing and confirming the conclusions of the *Monitoring the New Fitness Standard* report [7].

Following these two studies, Warwick Law School was commissioned to carry out further work with three prime aims. First, to identify and review all the legal provisions controlling minimum standards in existing housing with particular reference to such matters as anomalies, overlaps; and gaps. Second, to investigate options to cover the omitted hazards highlighted by the previous studies. And finally, working with the BRE, to investigate whether a risk assessment approach could be devised for housing conditions.

The report from this study proposed two options to deal with the anomalies and weaknesses identified [11]. Either minor amendments to the existing standard, or, and more fundamental, the development of a completely different approach that would allow the grading of conditions based on the severity of the threats to health and/or safety. Adopting the more radical proposal, in July 1998, the Minister for Housing announced that a Rating System would be developed and commissioned Warwick Law School, working initially with the BRE, to do so.

2 The Development of a Hazard Rating System

The principle underlying the development work was that a dwelling, including the structure, associated outbuildings, garden, yard or other amenity space, and means of access, should provide a safe and healthy environment for the occupants and any visitors. However, it is impossible to satisfy this ideal as some hazards are necessary and even desirable – such as electricity, gas, stairs, windows, and cooking facilities. These necessary and unavoidable hazards should be as safe as possible.

The intention was to develop a system that –

(a) took into account both the frequency of a hazardous occurrence and the potential severity of the outcome;

(b) recognised that there are a range of possible outcomes that could result from a hazardous occurrence; and

(c) allowed comparison of the widely differing hazards that could be found in dwellings.

Taking account of both the frequency or likelihood of a hazardous occurrence and the severity of the outcome gives a truer indication of the importance of a hazard. For example, a relatively infrequent occurrence which results in a very severe or fatal outcome may be more significant than a occurrence which happens frequently but causes a relatively minor outcome.

Physiological Requirements
Damp and mould growth etc
Excessive cold
Excessive heat
Asbestos etc
Biocides
CO and fuel combustion productions
Lead
Radiation
Uncombusted fuel gas
Volatile organic compounds

Psychological Requirements
Crowding and Space
Entry by intruders
Lighting
Noise

Protection Against Infection
Domestic hygiene, pests and refuse
Food safety
Personal hygiene, sanitation and drainage
Water supply

Protection Against Accidents
Falls associated with baths etc
Falling on level surfaces
Falling on stairs etc
Falling between levels
Electrical hazards
Fire
Flames, hot surfaces etc
Collision and entrapment
Explosions
Position and operability of amenities etc
Structural collapse and falling elements

Figure 1 – Potential Housing Hazards adopted for the HHSRS

Class I

This covers the most extreme harm outcomes. It includes –

Death from any cause; Lung cancer; Mesothelioma and other malignant lung tumours; Permanent paralysis below the neck; Regular severe pneumonia; Permanent loss of consciousness; 80% burn injuries.

Class II

This Class includes severe conditions, including –

Cardio-respiratory disease; Asthma; Non-malignant respiratory diseases; Lead poisoning; Anaphylactic shock; Crytosporidiosis; Legionnaires disease; Myocardial infarction; Mild stroke; Chronic confusion; Regular severe fever; Loss of a hand or foot; Serious fractures; Serious burns; Loss of consciousness for days.

Class III

This Class includes serious conditions such as –

Eye disorders; Rhinitis; Hypertension; Sleep disturbance; Neuro-pyschological impairment; Sick building syndrome; Regular and persistent dermatitis, including contact dermatitis; Allergy; Gastro-enteritis; Diarrhoea; Vomiting; Chronic severe stress; Mild heart attack; Malignant but treatable skin cancer; Loss of a finger; Fractured skull and severe concussion; Serious puncture wounds to head or body; Severe burns to hands; Serious strain or sprain injuries; Regular and severe migraine.

Class IV

This Class includes moderate harm outcomes which are still significant enough to warrant medical attention. Examples are –

Pleural plaques; Occasional severe discomfort; Benign tumours; Occasional mild pneumonia; Broken finger; Slight concussion; Moderate cuts to face or body; Severe bruising to body; Regular serious coughs or colds.

Figure 2 – Examples of the Classes of Harm adopted for the HHSRS

Any hazardous occurrence could result in one of a range of outcomes. For example, below a window there may be soft earth on one side and spiked railings on the other; so, from a fall out of that window, there would be a 50% chance of bruising and a 50% chance of serious puncture wounds.

Housing hazards differ widely in their effect on health, in the potential to cause death, and in the nature of exposure. For some there needs to be a period of exposure before there is any apparent effect on health, such as excess cold and damp. For others, the outcome can be relatively quick, such as for falls. And while some have the potential to cause death, such as asbestos, for other, such as noise, death is very unlikely. A simple and obvious means to allow comparison of the risk from all housing hazards would be to devise a system that generated a numerical score to reflect that risk.

2.1 Identifying Housing Hazards

The first stage was to identify all the potential hazards that could be found in dwellings. Building on the work by the BRE [9], a review was carried out of reported research to collect and collate evidence of the relationship between housing and the health and safety of users. From this a list of potential hazards was drawn-up. However, for the purposes of this development, the list was limited to those hazards attributable to a greater or lesser extent to the housing design and conditions, but excluded any attributable solely to human behaviour, household equipment, furnishings and furniture (see Figure 1).

This review provided details of the potential impact of each hazard, including the nature and severity of the health outcome. It also gave information on dwelling features and defects that may mitigate or increase the risk for each hazard.

2.2 Range of Outcomes

The health outcomes from the identified housing hazards could be physical injury, physical or mental illness, or other health conditions. Other work by the BRE proposed a classification and weighting system for different health outcomes reflecting the degree of incapacity suffered [12]. This work proposed seven Classes, however, only the top four were serious enough for the victim to seek medical attention and so likely to be recorded. These top four Classes were adopted for the Rating System (see Figure 2).

Subsequent, as part of updating and refining work (with the London School of Hygiene and Tropical Medicine), the list of health outcomes for the four HHSRS Classes was extended and some re-classified [13].

2.3 Producing a numerical score

Several approaches were investigated to produce a simple formula that combined the likelihood, the spread of possible outcomes and the weightings for the Classes of Harm. After trials, a relatively simple formula was adopted. This formula generates a single Hazard Score as the sum of the products of the weightings for each Class of Harm which could result from the particular hazard, multiplied by the likelihood of an occurrence, and multiplied by the set of percentages showing the spread of Harms (see Figure 3). To make the final numbers more manageable, the original weighting given to the Classes of Harm in the BRE's work [12] were increased in proportion.

3 Hazards in the English Housing Stock

Both to test the effectiveness of the formula and to produce detailed information on the impact on health in the English Housing stock, data on housing characteristics and condition were matched with data on health and injuries that could be related to housing.

Details on accidental (unintentional) home injuries were obtained from data collected through the Home Accident Surveillance System (HASS) [13]. As well as details of the victim, this data included information on the site of the accident, whether any dwelling feature(s) was implicated, and the nature and seriousness of the injury caused. Information on other health conditions was obtained from Hospital Episode Statistics (HES) [14], which gave details of inpatient admissions. These datasets were supplemented by mortality data from the Office of National Statistics [15], Home Office Fire Statistics, and General Practice Research Database.

A Housing and Population Database was created from a range of datasets to give details on housing characteristics, including house types and age. This database also contained information on household characteristics. The datasets used included the 1996 English House Condition Survey [16] the census, and commercial datasets such as ACORN [17].

Both the health, accident and housing datasets included postcodes, which in the England contain an average of 14 dwellings. Because of the low number of dwellings, there is a high degree of homogeny of housing in each postcode. Using the postcodes, the data on mortality and morbidity was matched with the Housing and Population Database and then analysed [18].

Using the HHSRS Formula, the analyses of the matched databases produced national average Hazard Scores for each of the 29 hazards. For each hazard it was possible to generate the national average likelihood and spread of harm outcomes for –

a) up to eight dwelling types (four age bands of houses, and four age bands of flats or dwellings in multi-occupied houses); and

b) four age groups of victims, so highlighting if one age group (if any) was more vulnerable to that hazard than the others.

	Class of Harm Weighting		**Likelihood**		**Spread of Harm (%)**		
I	10,000	X	$\frac{1}{L}$	X	O_1	=	S_1
II	1,000	X	$\frac{1}{L}$	X	O_2	=	S_2
III	300	X	$\frac{1}{L}$	X	O_3	=	S_3
IV	10	X	$\frac{1}{L}$	X	O_4	=	S_4
					Hazard Score	=	$(S_1 + S_2 + S_3 + S_4)$

Where –

L = the Likelihood of an occurrence
O = the Outcome expressed as a percentage for each Class of Harm
S = the row product for each Class of Harm.

Figure 3 – The HHSRS Hazard Score Formula

These results provided a hazard profile for the English housing stock, allowing hazards to be ranked by order of the risk (both the likelihood and severity of outcomes) [19].

3.1 Current uses of the HHSRS

Eight years after the concept of a health and safety based grading system for housing conditions was first suggested, the HHSRS was introduced as the statutorily prescribed method for assessing housing conditions in England for the purposes of Part 1 of the Housing Act 2004 on 6th April 2006 [20].

Assessing the condition of existing houses cannot be based on a strict quantifiable approach. The variations in design, construction and maintenance mean that a qualitative approach is more appropriate, involving a high degree of judgment, preferably informed professional judgment.

Since 1954, the statutory housing standards have involved two stages – first a judgment as to whether there was a failure of any of the requirements, and second, whether that failure made the dwelling not reasonably suitable for occupation. So although the first stage was building focussed, the second required some judgment of the potential effect on occupation. The HHSRS places the emphasis firmly on the potential effects of defects. Using the national averages as bench-marks, the stages involved are now – first whether the conditions mean that there is a greater than average risk from any hazard, second an assessment of how much more likely is a hazardous occurrence is more likely, and third, an assessment as to whether the outcomes will be more serious than the average. Trials using the HHSRS assessment during the development showed that this approach was more informed and logical. It also resulted in more consistent and justifiable results than the previous approach. This was convincing enough for the UK government to introduce the HHSRS in the legislation.

The HHSRS is also used in the English House Condition Survey. This is used to monitor housing conditions in England and to inform national housing policies.

4 Discussion

In part, this is a story about how research directly contributed to a change in national policy and, ultimately, a change in legislation. This started with the review of the 1990 Fitness Standard, centring on the interpretation of a legal standard and its application. The positive reaction to that work led to involvement in the examination of the underlying basis for such a standard; ie, the health and safety justification for the requirements. This in turn led to a wider review of housing standards and the opportunity to recommend a shift in the approach, a shift away from a pass/fail model to risk assessment system. It also allowed a complete revision of the underlying principles, finally moving from the Victorian Sanitary Idea to a modern evidence and risk assessment based health and safety approach. The result is that housing assessment is focussed on the use or intended use of the structure – to provide a safe and healthy home.

The HHSRS is evidence-based and is health and safety focussed. Reported research linking conditions in the housing environment to health were used as the basis for identifying potential housing and to provide details for the hazard profiles. Comparison of the prevalence of hazards to provide national benchmarks were provided from the statistical analyses of matched housing and health databases. While the assessment is qualitative, relying on informed professional judgment, it should be based on the evidence obtained from an inspection of the premises. This evidence underpins the decisions for any enforcement action.

The HHSRS was developed for particular purposes. However, the underlying principles, the collected evidence on the relationship between housing conditions and health, could inform other work.

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THE INFLUENCE OF ULTRAFINE PARTICLES AND OCCUPANCY FACTORS ON THE RISK FROM RADON IN SOME IRISH DWELLINGS

James McLaughlin and Colin Hogg

Radon and Human Exposure Group, School of Physics,
University College Dublin, Ireland.
james.mclaughlin@ucd.ie

Summary: *A description is given of investigations into the temporal variations of ultrafine aerosol particles in 33 dwellings in Ireland and their influence on lung cancer risk from exposure to indoor airborne radon progeny. In order to determine the variation of radon progeny dose contributions to individuals within households a questionnaire was used to determine indoor occupancy factors and activity profiles for the 126 people residing in the investigated dwellings. It was estimated that dose variations within households as high as a factor of 3 could occur. This indicates that the common practice of assigning the same dose and risk to all members of a household may seriously underestimate the risk at the level of the individual.*

Keywords: *Ultrafine aerosols, dwelling occupancy, radon risk.*
Category: IAQ & Air Exposure.

1 Introduction

Associations between both short term and chronic exposure to airborne particles and respiratory diseases are well documented [1]. Sensitive groups such as the elderly and asthmatics are at particular risk to increased morbidity and mortality from such exposures. The mechanisms involved in these health risks appear to be complex and in most cases are still largely unknown. While traditionally in air pollution studies coarse mode (> 2 μm) airborne particles have received much attention there is increasing evidence that much smaller particles in the ultrafine and fine modes (approx. range 10 nanometers to ~ 2 μm) may play a more important role in causing respiratory disease that heretofore realized. These particles can penetrate and deposit more efficiently in the lower respiratory tract (bronchial, bronchiolar and alveolar regions) than coarse mode particles [2]. In the indoor environment such particles may be produced from many sources such as cooking, heaters, smoking and other human activities. They may also be present due to infiltration from outdoor sources. In Ireland, while airborne particles are monitored in some indoor workplaces very little attention has been paid so far to the non-occupational exposure of the general population to airborne particles in their dwellings. This paper describes the results of a study of 126 people resident in 33 individual, single-family unit dwellings, in which exposures to ultrafine particles were measured and assessed. In addition to measurements of the ultrafine airborne particles in the dwelling long term measurements (minimum duration of 3 months) of radon gas concentrations were made in the selected dwellings. It should be noted that the radiation dose and associated lung cancer risk from radon gas itself is actually quite small compared to that arising from the deposition of its associated short-lived alpha-particle progeny, deposited in the lung. These progeny may be present in both the unattached state of the aerosol attached state. The portioning of the radon progeny between these two states is largely a function of the ambient aerosol characteristics, with the effect of ultrafine particles being dominant. In terms of radiation dose to lung tissue, the unattached state, which deposits in the bronchial region, has a higher dose impact than the attached radon progeny. In the absence of airborne particle data the dose from the radon progeny is usually estimated on the crude assumption of an equilibrium factor F= 0.4 existing between radon and its progeny in the air [3] In the present study, as described below, the simultaneous measurement of both radon and airborne particles in the dwellings makes it possible to more accurately estimate the temporal variation of the radiation dose and associated risk to the exposed occupants of the dwelling

2 Measurements:

For each dwelling within the cohort, ultrafine/fine airborne particle concentrations, in the approximate size range 20nm to 1μm, were measured using a portable condensation nucleus counter (CNC) (Model: TSI P-Trak 8525). The objective was to investigate the temporal variation of the airborne particle concentration during a typical 24-hour period. The CNC was programmed to sample the air for 2-3 minutes every 15 minutes, yielding 96 measurements over the 24-hour period. The airborne particles were measured within the 'room of maximum occupancy', which may be defined as the room within the dwelling that the family/occupants spend most time together, typically a living or sitting room.

Mean radon gas concentrations, in both the principal bedroom and the 'room of maximum occupancy' for each dwelling was measured over a minimum period of three months using standard SSI diffusion type passive alpha track CR-39 radon detectors.

In addition to these measurements, the lifestyle characteristics of the occupants were determined using a specially designed questionnaire. The questionnaire was used to determine the characteristics of (a) the dwelling, i.e. ventilation, surface to volume ratio, heating, etc (b) the occupants i.e. age, sex, etc (c) the occupancy pattern of the occupants resident in the dwelling over a typical 24-hour period, (d) the cooking habits of the occupants and (e) the smoking characteristics of any resident smoker.

The airborne particles and radon concentration data along with questionnaire information was used to model the behaviour of radon gas and its short-lived progeny in the indoor environment of each dwelling. A modified Jacobi Room Model [4], designed for modelling the behaviour of radon and its progeny was used to estimate the variations of the equilibrium factor, exposure in Working Levels (WL) and the Potential Alpha Energy Concentration (PAEC) within a dwelling over a 24-hour period (WL and PAEC are standard quantities for expressing radon progeny concentrations). Of necessity, certain assumptions were used in the modelling process. It was, for example, assumed the measured quantities such as aerosol concentrations and radon were representative of typical conditions in each dwelling. The natural ventilation rates of the dwelling was assumed to be 0.7 ach^{-1} during the nighttime and daytime unoccupied hours and $1.2ach^{-1}$ when the dwellings were occupied during the day. The surface to volume ratio of rooms in a dwelling was assigned the typical value of $5m^{-1}$ for use in the Jacobi Room Model. This is a parameter of importance in the model in the partitioning of radon progeny between airborne and surface deposited states.

Dose & Risk Estimation:

Using a modified Jacobi Room Model, together with radon gas, aerosol and room characteristics the temporal variation of the Potential Alpha Energy Concentration (PAEC) was determined. From this, radon progeny exposure in Working Level Months (WLM) was calculated for every 15-minute interval over a typical 24-hour period for each dwelling. The WLM is a standard unit of radon progeny exposure and is defined as the exposure to radon progeny of energy 2.05 x 10^{-5} J m^{-3}, for 170 hours.

In a dwelling the contribution to the total annual radiation effective dose due to exposure of individual members of the household to airborne short-lived radon progeny is strongly influenced the temporal occupancy pattern of the dwelling by each individual.

From the questionnaire data, the indoor occupancy pattern of each occupant was used to infer the duration of time spent at the following levels of exercise

- Light activity
- Sleeping
- Sitting

and the corresponding breathing rate was assigned based on the occupants age and sex. [2].

For each WLM exposure, per 15-minute interval, the effective dose, in mSv, was determined. In Table 3 of [5], the dose conversion factor (DCF) for homes was estimated to range from 4.2 to 8.0 mSv WLM^{-1}, with assumed aerosol characteristics and a nasal breathing rate of 0.75 m^3/h. A mean DCF, of 6.1 mSv was used in this study.

It is reasonable to assume the dose increases linearly with the average breathing rate. [6] For each occupant the DCF was adjusted for the assigned breathing rate for the occupant's level of activity. [2]

Thus, for each occupant within the cohort, the temporal variation of the effective dose received from radon progeny within the dwelling for a typical day is calculated. This is used to estimate the annual effective dose (in mSv) for the occupant.

To estimate the probability of developing lung cancer, a dose to risk conversion factor of 0.05 Sv^{-1} was used for each occupant within the cohort [7].

Results & Discussion:

Ultrafine Particles:

The measured concentration for the dwellings ranged from 200 to 500,000 particles /cm^3 (the upper limit of detection of the CNC). Table 1 shows a summary of the data separated into the 20 non-smoking dwellings and 13 smoking dwellings.

Dwellings	**Non-Smoking (pt/cc)**	**Smoking (pt/cc)**
Min	200	200
Mean	16,500	42,700
Median	6,900	25,250
Max	485,500	500,000

Table 1. Summary of the ultrafine particle concentrations for the 33 dwellings in the cohort.

Figure 1 and Figure 2 show the temporal variation of the ultrafine particle concentration for a non-smoking and smoking dwelling respectively. Cooking causes the main peaks in Figure 1. whereas in Figure 2, smoking is the dominant source of airborne particles. In comparing these two figures it should be noted that the concentration scales are different for each figure.

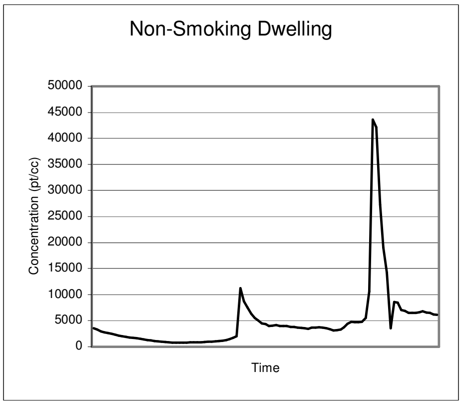

Figure 1. Ultrafine particle concentrations for a non-smoking dwelling.

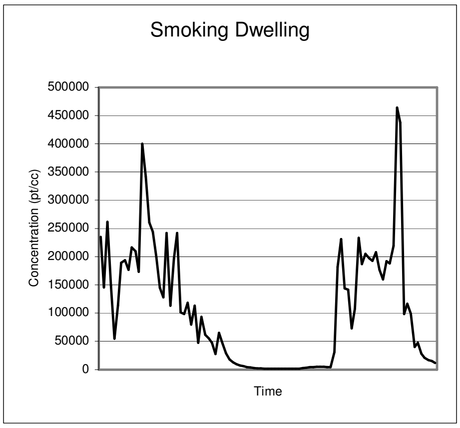

Figure 2. Ultrafine particle concentrations for a smoking dwelling.

Radon Gas Concentrations:

The measured radon concentrations found in the 33 individual dwellings ranged from 20 Bq/m^3 to 246 Bq/m^3. The minimum and maximum concentrations for the 'room of maximum occupancy' was 29 Bq/m^3 and 241 Bq/m^3 respectively with a mean of 81.57 Bq/m^3 and for the bedroom, the range was from 22 Bq/m^3 to 246 Bq/m^3, with a mean of 69 Bq/m^3. This is not considered a large range, as in Irish dwellings the mean value is almost 89 Bq/m^3 and there are 8.8% of dwellings over 200 Bq/m^3. [8]

Indoor Occupancy Factors:

The indoor dwelling occupancy factors (IOF) of the individuals within the cohort were found to range from 0.42 to 0.92, with a mean IOF of 0.60, which is 25% lower than the assumed IOF of 0.8 used by the International Commission on Radiological Protection.[3]

Dose:

For the 126 individuals in the study the average annual effective dose from the inhalation of radon progeny ranged from 0.13 mSv to 1.84 mSv with an average of 0.57 mSv and a standard deviation of 0.38 mSv. Here the cohort can be conviently divided into three subgroups, which comprise the following: (a) stay-at-home parent/ young child (b) out of home worker and (c) school going child. Doses from exposures to radon progeny outside the home and in other locations are not considered here. Here the emphasis is on doses within the home.

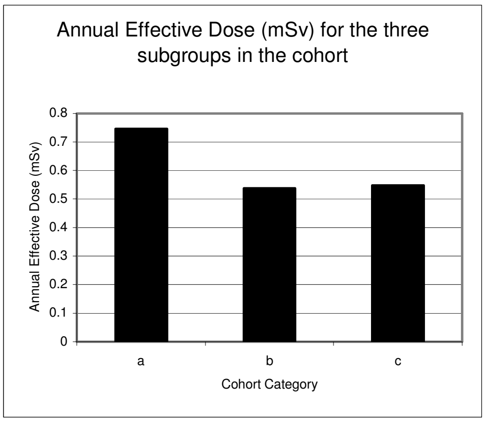

Figure 3. The average annual dose received by the three subgroups in the cohort.

On average, the estimated annual dose received at home by a stay-at-home parent/young child is 0.75mSv, with an out of home worker and school child receiving almost the same dose, 0.54mSv and 0.55mSv per year respectively. Thus, on average, the stay-at-home parent/young child, receives an annual dose of about 37% greater than the out of home worker and school going child.

In certain houses, the relative daily dose received by occupants can differ as mush as a factor of 3 see Figure 4 below. In this example, the stay-at-home parent receives 3.2 times the daily effective dose from radon progeny from inside the dwelling only to that of the school going child and 1.83 times the daily dose of the out of home worker. It must be noted that in this paper, the indoor occupancy pattern of all the occupants in the cohort is assumed to be constant, however this not unreasonable simplification overlooks the change of occupancy patterns at weekends and seasonal fluctuations.

Risk:

To estimate the percentage chance of developing lung cancer, the standard dose to risk conversion factor of 0.05 Sv^{-1} is used.

The results above show that on average, the stay-at-home parent/young child, receives a risk of about 37% greater than other members of the family.

Conclusion:

The results of this small study indicate that the approach of using the ultrafine particle concentration for modelling the behaviour of radon and its short-lived progeny within dwellings and integrating the indoor occupancy patterns of the occupants will improve the accuracy of the radon dose and risk estimates for the general Irish population. While in absolute terms, radon levels in the selected dwellings were not considered to be high, a similar pattern of relative exposure and dose between stay at home and out of home members of the families will be present also in the case of high radon dwellings.

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Tobacco smoke as a risk factor for asthma severity in children

M. Morais-Almeida, A. Gaspar, S. Marinho, S. Piedade, A. Romeira, J. Rosado-Pinto

Immunoallergy Department, D. Estefânia Hospital, Rua Jacinta Marto, 1169-045 Lisbon, Portugal
Email: mmoraisalmeida@netcabo.pt

Summary: *The considerable impact of asthma over the last decades, especially in children, associating a significant and rising prevalence to an increase in severity and health costs, has led to multiple well designed epidemiological studies, involving significant population-based samples, carried out to investigate causes and to evaluate risk factors. These studies have provided invaluable information, allowing us to design and implement preventive programs aimed at reducing the burden of this disease. Environmental tobacco smoke exposure adversely affects asthmatic children in several ways, including increase in total IgE and specific IgE antibody responses, eosinophilia, decrease in lung function, increase in bronchial hyperreactivity, and increase in number of attacks and emergency room visits. Our data, including Portuguese children with asthma, has also confirmed these findings.*

Key-words: *asthma; children; tobacco smoke exposure; prevention; risk factors*
Category: *Indoor air quality, building-related diseases and human response / Indoor climate*

1. Introduction

The development and phenotypic expression of allergic diseases depends on a complex interaction between genetic and several environmental factors, such as exposure to food and inhalant allergens and also to non-specific adjuvant factors (e.g. tobacco smoke, air pollution and infections).[1] The first year of life seems to be a particularly vulnerable period and there is evidence that sensitisation is related to the level of allergen exposure during early life. At present, atopic heredity seems to be the best predictor as regards the development of allergic disease at birth.[2] Early sensitisation, either to aeroallergens or to foods, atopic dermatitis and allergic rhinitis, are predictors for later development of allergic lower airway disease. Various environmental pollutants that may enhance the risk of sensitisation include tobacco smoke, NO_2, SO_2, ozone, and diesel particles. Amongst these, and in an indoor perspective, passive smoking is by far the best-established risk factor, particularly during early childhood.[3] The indoor environment plays a probably larger role in the development of allergic diseases than outdoor air pollution, and it is usually considered one of the *major* risk factors responsible for the increase in asthma prevalence. It is also recognised as an asthma trigger, both in children and adults.[3]

Expanding the concept of environmental influences, the mother is not only a source of genetic information, but also a true "environmental factor", as there is a very close continuous immune interaction between her and the offspring.[3] The intrauterine environment, and exposure to tobacco smoke during pregnancy, may play a significant role, with subsequent respiratory effects on the infant. Maternal exposure to allergens during pregnancy is also an important factor due to mother-fetus immune interactions.[4,5]

Outdoor pollution acts by enhancing bronchial responsiveness, allergic sensitisation and by exacerbating existing respiratory diseases;[6] its effect is probably less important in infants and small children who live indoor most of the time. Infections seem to have a complex mechanism of action: some respiratory viruses act by inducing asthma or allergic sensitisation, whereas other infections (viral, bacterial and parasitic infestations) may have a protective effect. Exposure to tobacco smoke, particularly maternal smoking, has been reported by several studies as one of the most important risk factors for childhood asthma.[4,5]

Bronchial asthma represents a major health problem. Several worldwide studies have provided compelling evidence that its prevalence, as well as its severity, have been increasing over the last decades, particularly in children. This has led to a high rate of school absenteeism, emergency room visits and hospital admissions,[7,8] asthma being the leading cause of hospital admissions in children with chronic disease. Parallel to a decrease in the global number of admissions at paediatric age, several studies showed an increase in the number of admissions – and particularly readmissions – due to asthma.[9,10] Although the reasons for this finding are yet to be determined, this suggests that the increase in asthma severity might be more important than the increase in incidence.[8,10]

We aim to present an overview of the findings relating tobacco smoke exposure with asthma and its severity, including a review of our own data.

2. ETS and asthma severity

There are few studies evaluating the risk factors for hospital admissions due to asthma in children; amongst these, the significant risk factors identified were: age under 4 years, male gender, black race, low socio-economic status, absence of specialised medical care, prior asthma hospitalisation, environmental tobacco smoke exposure and sensitisation to indoor allergens.[7-13]

Over the last 15 years, we performed three studies on the risk factors for asthma in children, especially focusing on the relation between exposure to environmental tobacco smoke (ETS) – a preventable pollution exposure – and paediatric asthma severity. The first survey (A), included a sample of 1045 schoolchildren randomly selected from the general population, aged 9 to 11 years (mean age: 9.8 years);[14] the second survey (B), included a cohort of 308 pre-school asthmatic children, followed prospectively for 8 years since 1993 (mean age at the time of the last assessment: 11.1 years);[15] the third study (C) included a sample of 124 inpatient asthmatic children (admitted due to severe asthma exacerbations) and a control group of children (n=124), matched for age, gender and socio-economic status, observed in a first appointment in our out-patient clinic (mean age: 4.1 years).[16]

Using multiple logistic regression analysis, ETS was identified as an independent risk factor for asthma and for asthma severity in all of the above mentioned studies: A. ETS during the first year of life (mother) and diagnosis of asthma ever (OR 1.4, 95%CI 1.0-2.0, p=0.04) and current ETS (mother) and active asthma severity (OR 2.0, 95%CI 1.0-3.9, p=0.04); B. Current ETS (mother) and active asthma severity (OR 2.4, 95%CI 1.2-4.7, p=0.016); C. Current ETS (parents) and asthma severity, quantified as hospitalization risk (OR 6.6, 95%CI 2.5-17.8, p=0.002). In this last study (C), we have also identified as significant and independent risk factors for hospital admission: prior asthma hospitalisation (and particularly during the previous 12 months), allergic sensitisation, maternal asthma and onset of symptoms before 12 months of age. As it was found by other authors, day-care or nursery attendance and large family size were identified as protective factors.[16]

3. ETS and its effect on the airways of asthmatic patients

It is well known that ETS adversely affects asthmatic children in several ways, including increase in total IgE and specific IgE antibody responses, eosinophilia, decrease in lung function, increase in bronchial hyperreactivity, and increase in number of asthma attacks and emergency room visits.[11,12,14-18] Chilmonczyk et al,[17] in a retrospective study including 199 asthmatic children, found a relationship between tobacco smoke exposure and asthma morbidity through the measurement of urine cotinine levels. Other authors have also tried to correlate passive smoking to asthma morbidity. Azizi et al,[11] in a study performed in Kuala Lumpur with 158 hospitalised children, reported a relative risk of 1.9 for passive smoking. Macarthur et al,[12] also identified passive tobacco smoke exposure as a risk factor for readmission to hospital due to asthma.

The mechanisms by which passive smoking is associated with an increase in the severity of childhood asthma are still unclear. A possible mechanism could be a direct effect on the bronchial mucosa by triggering an inflammatory process, since tobacco smoke has two main effects on the respiratory tract: 1) induction of inflammation, and 2) mutagenic/carcinogenic effects.[19] It could also enhance allergic sensitisation by the disruption of the bronchial epithelium, increasing the permeability to allergens. Another hypothesis could be that this epithelium disruption may promote the appearance of respiratory infections, known common triggers of asthma exacerbations. It has been demonstrated that cigarette smoking affects the immune system. Impairment of alveolar mononuclear cell function may contribute to the higher rate of respiratory infections observed in individuals exposed to tobacco smoke (either active or passively); however, the increased susceptibility of smokers to infections of other origin (e.g. wound-related) implies that the effects of tobacco smoke are not restricted to the respiratory immune competent cells. Cigarette smokers with no chronic obstructive pulmonary disease exhibit impaired NK cytotoxic activity in peripheral blood and unbalanced systemic production of pro- and anti-inflammatory cytokines.[20]

Epidemiologic studies have suggested that ETS increases the prevalence and severity of allergic diseases, such as asthma and even atopic dermatitis.[21] It was demonstrated that, even in healthy non-atopic children, exposure to ETS causes changes in cellular infiltrates which partly resemble those seen in the nasal mucosa of allergic children.[22] In a murine model that included generation of and exposure to environmental tobacco smoke followed by aerosolised allergen challenge, Seymour et al showed that "second-hand smoke" up-regulates the allergic response to inhaled allergens.[23] Rumold et al[24] found that, in mice, ETS can induce allergic sensitisation to a normally harmless antigen, and that may explain why second-hand smoke is a major risk factor for the development of allergy in children.[25]

Despite all the knowledge regarding the effects of ETS on the expression of allergic diseases, there is a paucity of information on the immunological effects of maternal smoking on the fetus. Noakes et al compared, for the first time, cord blood mononuclear cell cytokine responses to ovalbumin or house dust mite and mitogens in neonates whose mothers smoked throughout pregnancy, with a control group of neonates never exposed to maternal smoke. They concluded that maternal cigarette smoking can modify aspects of fetal immune function and highlighted the need for further studies on this area.[26]

4. ETS and asthma outcome

Inhaled corticosteroids are the most effective treatment currently available for chronic asthma, and international asthma guidelines emphasize the importance of the early introduction of inhaled corticosteroids as first line treatment for those with persistent disease. Most patients with mild to severe asthma respond to inhaled corticosteroids – as confirmed by improved asthma symptoms and lung function, as well as reduced bronchial hyperreactivity and eosinophilic inflammation – although a small percentage of patients with asthma have been shown to be steroid resistant.[1] Therefore, although inhaled corticosteroids have an established role in the treatment of asthma, studies have mostly concentrated on non-smokers and little is known about the possible effects of cigarette smoke on the therapeutic efficacy of these drugs in asthma. Nevertheless, in a study undertaken by Chlamers et al,[27] in order to investigate the effect of active cigarette smoking on the response to treatment with inhaled corticosteroids in patients with mild asthma, the authors demonstrated that active cigarette smoking impairs the efficacy of short-term inhaled steroid treatment in mild asthma. This finding, reproduced by other authors using oral steroids,[28] has important implications for the management of asthmatic patients who smoke, as well as that of children exposed to this pollutant. The mechanism underlying the lack of response to inhaled corticosteroids in smoking asthmatics is not known. As stated previously, cigarette smoke has the potential to cause harm to the airways in a number of ways, including direct toxicity and proinflammatory activity, but cigarette smoking might also alter the molecular mode of action of steroids.[27]

Recently, Meyers et al performed a genome-wide linkage screen for asthma and bronchial hyperresponsiveness, determining the influence of ETS exposure during childhood on the results of genetic linkage studies to investigate gene-environment interactions (for chromosomes 3p and 5q). The results of their study demonstrate that the influence of some susceptibility genes for a common disease such as asthma might not be apparent unless there is a concomitant appropriate exposure to certain environmental stimuli, such as passive exposure to cigarette smoke. The authors concluded that this approach might be useful in the identification of asthma susceptibility genes.[29]

The importance of tobacco smoke exposure lies in the fact that it is potentially avoidable. In a prospective study including 807 asthmatic children, Murray et al[30] found a reduction in the severity of asthma and an improvement in functional respiratory parameters associated with a reduction in smoke exposure. This study allows us to stress the importance of the implementation of preventive anti-smoking campaigns, aiming especially at the parents of asthmatic children. The identification of risk factors for asthma severity – related to hospital admission rates – allows the design and establishment of preventive strategies, particularly directed to high-risk children, with emphasis on medication planning and on the establishment of education programs, including avoidance of environmental tobacco smoke and aeroallergen exposure.

5. Conclusions

As it was demonstrated for ETS, other significant indoor pollutants/irritants are associated with the occurrence and severity of allergic respiratory symptoms, especially current asthma symptoms: wood smoke pollution related to cooking,[31] new surface materials in the home (linoleum flooring, synthetic carpeting, particleboard, wall coverings, furniture, paint),[32,33] building quality,[34] and formaldehyde.[35]

With this review, we showed that ETS, a very particular and common indoor pollutant, is a highly significant risk factor for severity of paediatric asthma in Portugal, as it was also demonstrated in other countries. Given the documented health risks to the mother and infant and the significant number of women who continue to smoke in the postpartum period, it is imperative that health care providers continue to assess smoking status and provide smoking-cessation counselling at every consultation.

We expect that these data, is enough to provide evidence of the importance of education and prevention programmes on tobacco smoke control – focusing on both adults and children – even for the most sceptical. The results of these programs can have a very positive impact in the health and quality of life of asthmatic patients, as well as the ability of reducing the considerable burden of this disease.

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Impact on Exposure of Pollutants Released in the Indoor Environment

Miranda Loh[1], D.H. Bennett[1,2]

[1]Harvard School of Public Health, 401 Park Drive, Boston, MA, 02215, USA
email: mloh@hsph.harvard.edu
[2]University of California, One Shields Ave, TB 169, Davis, CA 95616, USA

Summary: *This study examines the influence of the indoor environment on exposure to a suite of air pollutants, designated by the United States Environmental Protection Agency (EPA) as hazardous air pollutants (HAP's). The EPA found that several of these compounds were responsible for a large percentage of overall excess cancer risk in the population. However, their analysis only examined outdoor concentrations. To fully quantify human exposure, we need to include the indoor environment, where we spend about 80% of our total time. We assemble data from several monitoring and modeling studies to better understand the average levels of total personal exposure, and to determine the relative contribution of exposure resulting from indoor versus outdoor origin. For many HAP's, indoor concentrations are higher than outdoor concentrations, due to the presence of indoor sources combined with infiltration from outdoor air. We find that many of HAPs examined have a significant proportion of exposure coming from the indoor environment.*

Keywords: *Hazardous Air Pollutants (HAPs) , indoor exposure, risk*
Category*: Risk assessment in relation to indoor exposures*

1 Introduction

As part of an effort to complete a risk comparison between a suite of hazardous air pollutants (HAP's), we developed a model to determine personal exposures to several HAPs and estimate the contribution from the indoor environment based on data from several field studies. The US Environmental Protection Agency (EPA) used modeled outdoor HAP's concentrations to estimate health risks across the continental United States, and found that several volatile organic compounds (VOC's), particularly 1,3-butadiene, formaldehyde, and benzene had concentrations over cancer benchmark levels in 90% of all census tracts, and that almost half of total estimated lifetime cancer cases could be attributable to VOC's [1], with the remainder attributable to polycyclic aromatic compounds (PAH's). The actual risks from HAP's are most likely higher than that found in the EPA study, since personal exposures are generally higher than outdoor concentrations. A significant fraction of personal exposure comes from indoors, particularly homes. In this analysis, we compare risks for several HAP's, based on personal exposure, and estimate the contribution from the indoor environment.

2 Methods

Personal inhalation exposure to VOC's and PAH's was calculated using a stochastic model. A person's total exposure is the sum of exposure in each microenvironment he/she visits. Thus, for each microenvironment, distributions of pollutant concentrations were weighted by a distribution of the fraction of time a person was expected to spend in that microenvironment. We used Crystal Ball (standard v.7.1.2, Decisioneering) software for Microsoft Excel to run 10,000 simulations resulting in a distribution of daily average exposure in each microenvironment, as well as personal exposure for each compound. Time distributions were based on data from the National Human Activity Patterns Survey (NHAPS), a cross-sectional survey of the time people spend in different places conducted in the US [18].

For VOC's, the microenvironments included home, commuting, dining, shopping, outdoor, and work. Compounds included aldehydes, hydrocarbons, and several chlorinated compounds. The PAH's were divided into two groups based on the EPA's weight-of-evidence classification for carcinogenic effects and on the amount of available data from field studies. Group 1 (benzo[a]anthracene, benzo[b] fluoranthene, benzo[a]pyrene, chrysene, dibenzo[a,h]anthracene, indeno[1,2,3-cd]pyrene) are labeled B2, with sufficient animal evidence of carcinogenicity, but inadequate human evidence. Group 2 (anthracene, benzo[g,h,i]perylene, phenanthrene, pyrene, fluoranthene) are classified as C or D with limited information on potential carcinogenicity. Concentrations of each PAH were summed to provide an overall group concentration. Naphthalene is included separately since concentrations are at least an order of magnitude higher than other PAHs. Not all PAH congeners have equal risks for cancer, and are weighted by a relative toxicity value with respect to benzo(a)pyrene in risk analyses. In this analysis, we examine both the unweighted and risk-weighted exposures.

Concentration distributions were developed by assessing and combining data from various studies in each microenvironment [2-17]. We gave priority to studies conducted in the US post-1995, to reflect more recent product composition and industrial and mobile source emissions. We compared the reported parameters, the percent of detectable values, and the limit of detection per study. Studies were not included in the final distribution if the mean was greater than the 90th percentile (indicating a highly skewed distribution), or more than 50% of the values were under the detection limit and the detection limit was deemed to be high compared with those of other studies. For the final input distributions, we combined studies by categorizing them geographically and weighting each city/geographic region equally. We fitted lognormal distributions to the reported parameters (either mean and standard deviation or 50th and 90th percentiles) using Crystal Ball.

The concentration distributions are considered a baseline for a hypothetical general US population, and do not include specific subpopulations that may have differential exposures, except in one case. Because some studies showed that for 1,4-dichlorobenzene, certain subpopulations had much higher exposures at home, we included an alternative high home concentration distribution [2, 7].

For PAH's, less data was available for non-home microenvironments, so we substituted outdoor distributions for non-home microenvironments. For the commuting microenvironment, we used concentrations from two European studies measuring particulate PAH's at roadsides, while the other congeners were assigned outdoor concentrations [19, 20].

In addition to determining the average percent of exposure occurring in the indoor environment, we determined the fraction of that exposure resulting from indoor sources. For homes, we divided the indoor concentration by the indoor/outdoor (I/O) ratio to get the outdoor contribution, which was then subtracted from the indoor concentration to obtain the indoor contribution.

Not all studies include data indicating the relative portion from indoor vs. outdoor sources. Therefore, we extrapolated data from studies that do explicitly report the contribution from the indoors to all studies. For VOC's we constructed a distribution of indoor/outdoor ratios from two studies [7, 8]. For the PAH's, we estimated distributions from one study conducted in three US cities [14].

For VOCs in offices, we use the reported indoor-outdoor difference as a metric of indoor contribution, and we preferred to use a measure reported by the study authors [15]. For shopping and dining microenvironments, we also used the indoor-outdoor difference; however, in this case, as an outdoor surrogate, we used transportation means from that same study [16, 17].

3 Results and Discussion

Modeled personal exposures were comparable to those found in personal monitoring studies. For many compounds, personal exposures are larger than outdoor concentrations, particularly if indoor concentrations were higher than outdoors. For example, mean personal exposure to benzene was twice the outdoor concentration (4.5 $\mu g/m^3$ versus 2.4 $\mu g/m^3$) while for formaldehyde, mean personal exposure was four times than of outdoors (20 $\mu g/m^3$versus 4.9 $\mu g/m^3$).

This point is further illustrated by the contrasts between Figures 1 and 2. Figure 1, shows the sum of the mean percent contributions from exposures in the home indoor, other indoor (dining/shopping and work), and outdoor microenvironments (including commuting and all other microenvironments) to personal exposure. As expected, the indoors dominates exposure, accounting for more than 70% of exposure, with at least 50% coming from inside homes, as these are the environments where we spend the most time.

If we then break down indoor concentrations into the relative contributions of indoor sources versus infiltration from the outdoors, we see more significant differences between the compounds (Figure 2). Figure 2 shows the contribution to VOC and PAH personal exposure from outdoor sources, indoor sources at home, and indoor sources in non-home microenvironments. While Figure 1 indicated that indoor exposures were consistently responsible for more than 70% of exposure for all compounds, we now see that for some compounds, indoor concentrations are more heavily influenced by infiltration from outside than indoor sources, while for others, exposure is dominated by sources to the indoor environment. Compounds with more than a 50% contribution to total exposure from indoor sources include formaldehyde, toluene, methylene chloride, chloroform, 1,4-dichlorobenzene, styrene, and naphthalene. Indoor concentrations for these compounds have sources such as building materials, or product emissions and secondary reactions. For acetaldehyde, 1,3-butadiene, benzene, Group 1 and Group 2 PAH's, Figure 1 shows that exposure still comes from time and concentrations indoors, however, Figure 2 shows that the indoor concentrations are actually derived primarily from outside. These compounds have less than 40% of exposure coming from indoor sources.

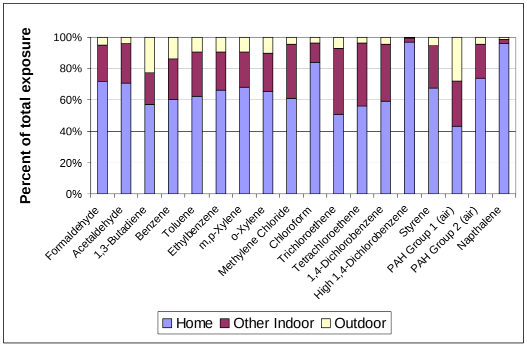

Figure 1: Contribution to personal exposure from the indoor and outdoor microenvironments.

Ethylbenzene, the xylenes, trichloroethene and tetrachloroethene had approximately equal contributions from both indoor and outdoor sources. Within the other indoor category in the figures, the workplace (office) contributed the most to indoor sources of exposure (not shown).

The PAH values in the figures are unweighted. If the sum of the Group 1 and 2 congeners are weighted by relative toxicity, exposure from time spent outdoors and commuting would increase from about 30% to 50% for Group 1 and from about 5% to 35% for Group 2. In terms of the contribution to exposure from indoor sources, the contribution for Group 1 remains about the same when toxicity weighted, but Group 2's contribution from the indoors decreases from about 20% (Figure 2) to 5%, due primarily to the increased significance of benzo[ghi]perylene, the compound with the highest cancer potency factor of the group, whose main sources are outdoors.

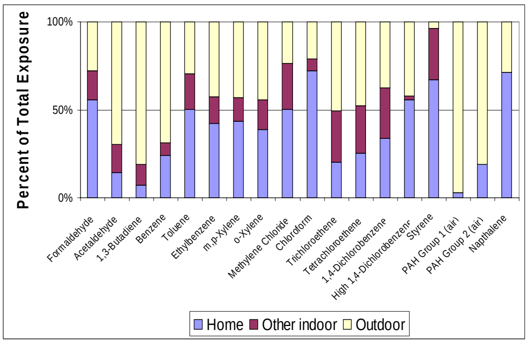

Figure 2: Percent attributable to total personal exposure from indoor and outdoor sources.

For 1,4-dichlorobenzene, considering an alternative scenario of homes with high concentrations showed that exposure for this subpopulation can be ten times more than the baseline for this compound. While the baseline group had slightly less than 40% of total exposure coming from home indoor sources and 10% from other indoor sources, the high group had almost all their indoor exposure coming from the home alone (over 50%). These high indoor concentrations are related to the use of moth repellents or deodorizers containing 1,4-dichlorobenzene.

Naphthalene can also be emitted from moth repellents, and, similar to 1,4-dichlorobenzene, high naphthalene exposures may be due to uses of these products. However, naphthalene sources include combustion processes, smoking, and other consumer products. Due to an insufficient amount of data on naphthalene sources in these studies, we could not determine if there were significant differences in exposures to a sub-population using mothball products.

Our results indicate that ignoring exposures in indoor microenvironments would greatly underestimate risks from organic chemicals. Homes are particularly important sources of indoor exposures, but workplaces also contribute a large amount to total exposure for some chemicals. The greatest limitation to this study is the difficulty in finding consistent data sources for concentrations across all microenvironments. However, the use of stochastic methods allows us to account for variability by creating concentration distributions for a general, baseline population. Reporting of the contribution of the indoor versus the outdoors in microenvironments either as ratios, differences, or correlation coefficients would better allow us to distinguish the effect of indoor and outdoor sources on exposure. We also examined the impact of high indoor concentrations for 1,4- dichlorobenzene, and found that exposures are significantly elevated, which would significantly change risk estimates from this compound. Future work in this area would benefit from exploration of different subpopulation distributions.

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How Far Respiratory Droplets Move in Indoor Environments?

Xiaojian Xie and Yuguo Li

The University of Hong Kong, Department of Mechanical Engineering, Pokfulam, Hong Kong SAR, China
email: xxjtulip@hkusua.hku.hk

Summary: *A simple physical model is employed to investigate the coupled evaporation and movement of droplets expelled during respiratory activities, which is essential for studying the transmission route of some respiratory infectious diseases. The exhaled air is treated as a steady non-isothermal jet horizontally issuing into stagnant surrounding and then the droplet is simulated to evaporate and move in this jet. Numerical calculations have been performed for physiological saline droplet, which focus on the study of droplet lifetime and how the droplet size changes, as well as how far the droplet moves. The results indicated that the droplet size predominately decides its evaporation and movement after being expelled. The sizes of the largest droplets that could totally evaporate before falling 2 meters were derived, as well as the maximum horizontal distances that droplets could reach during different respiratory activities. The effect of relative humidity on the dispersal of droplets in air was discussed.*

Keywords: *respiratory droplets, evaporation, movement, relative humidity (RH), infection transmission*
Category: *indoor air quality, environmental health*

1 Introduction

A large number of droplets of saliva and other secretions from the respiratory tract can be released into the air environment during talking, coughing, sneezing [1, 2] and during the use of certain medical instruments such as the nebulizer [3]. These respiratory droplets can carry microorganisms such as bacteria and viruses, and constitute a medium for the transmission of infectious diseases (large droplet transmission [4]). After released droplets start to evaporate, change their mass and size and finally dry out to become droplet nuclei which are sufficiently small to suspend in the air and may still be infectious (airborne route [4]). Two crucial issues related to disease transmission in which droplets are involved are what constitutes 'large droplets' and how far large droplets can move. Embil et al. [5], Teleman et al. [6] and Langley [7] deemed the 'short distance' to be 1 or 1.5 m from the source person. 'Large droplets' were first defined as droplets larger than 100μm in diameter by Wells [8]. Elsewhere in the literature, however, droplets larger than 5μm [4, 9] or 10μm [10] are often treated as large droplets. The critical size of the so-called large droplets is a function of many physical parameters such as relative humidity, the ambient air velocity, ambient air temperature etc. Knowledge of the critical size of large droplets is crucial for developing effective engineering control methods such as ventilation methods and selecting filtration efficiency. To answer the two questions, we need to return to the basic studies of the evaporation and movement of respiratory droplets carried out by Wells [8, 11] decades ago, but somehow overlooked in subsequent years.

In his now classical study of airborne transmission, Wells [8] studied the evaporation of free-falling droplets and obtained a classical curve that revealed the relationship between droplet size, evaporation and falling rate, which is referred to as *the Wells evaporation-falling curve of droplets* in this paper. From this curve, Wells found that under normal air conditions, droplets smaller than 100 μm in diameter would totally dry out before falling 2 m to the ground. This finding allowed the establishment of the theory of droplets and droplet nuclei transmission depending on the size of the infected droplet. According to Wells [8], droplet infection is transmitted by droplets larger than 100 μm in diameter, which rapidly settle out of the air by gravity, with the infective range being within a short distance of the source. Airborne infection applies to dried-out infectious droplet nuclei derived directly from droplets less than 100 μm, which remain suspended in the air for a long time and could be carried over long distances by the air current. The concepts of large droplet transmission and airborne transmission have been extended and investigated over the last 70 years [11-14]. However, the Wells evaporation-falling curve of droplets has probably been overlooked in the literature.

Our investigation revealed that Wells's evaporation model was an extremely simple one, and we suggest the curve was probably drawn through extrapolation based on an experiment result of droplet evaporation time using some assumptions for the processes of evaporation and falling rather than by calculation. The movement of droplets, the affect of the surrounding air movement, the jets produced by respiratory activities, and the effect of salinity concentration were not considered. Recently, Wang et al. [15] proposed a dynamic model to investigate quantitatively the effect of relative humidity on the transport of liquid droplets in air. The temperature difference between the surrounding air and exhaled air was ignored. Moreover, in the work of Wang et al. [15], the velocity field of the jet only included the axial velocity component, but not the radial velocity. More accurate and detailed analysis of the processes of droplet evaporation and movement in indoor environments is needed. Revisiting the Wells evaporation-falling curve of droplets, this paper sheds some insight into the questions of what constitutes large droplets and how far droplets of different sizes can move after being propelled through respiratory activities under various relatively humidity levels.

2 Physical model

During actual respiratory activities, droplets are expelled with the exhaled air, which has an initial horizontal velocity and could carry these droplets far away from the source. Take sneezing for example, the velocity of exhaled air can be as high as 100 m/s [11]. The diffusion of exhaled air is related with the dispersion of droplets liberated, thus the infective range of the droplets. Therefore, the simulation of respiratory activities should include three parts: the ambient air, the exhaled air and the expelled droplets. The expelled droplets evaporate and move in the combined background of ambient air and exhaled air. In our model, we assume that the ambient air is stagnant. For the exhaled air, we assume there is no inhalation but only continuous exhalation, and use a circular non-isothermal turbulent jet [16] to simulate the exhalation jet.

Airflow model of exhalation flows

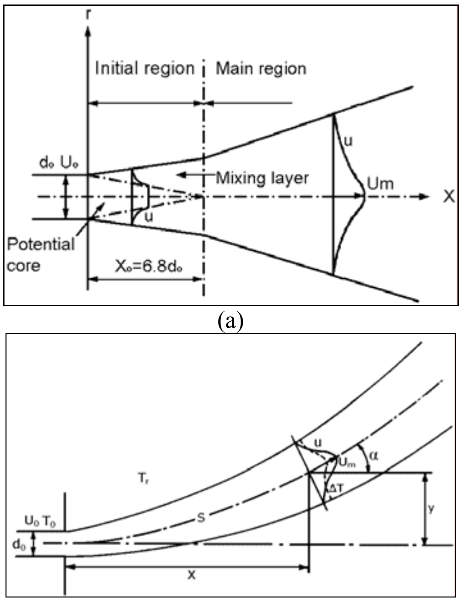
In the present study, an exhalation air jet is considered and we assume that exhaled air has the same composition as ambient air, except the concentration of water vapor. The relative humidity and temperature of ambient air, i.e. indoor air, may vary due to air-conditioning and the outdoor air climate, while exhaled air is saturated with water vapor, and its temperature depends mainly on the ambient air temperature [17]. If the temperature of an air jet and the ambient air is the same, the jet becomes an isothermal jet and its trajectory is rectilinear; if different, the jet is non-isothermal and its trajectory is curved. Air jets have been extensively studied; the theory of air jets and the equations governing the flows in different types of jet are presented in a number of textbooks [18-20].

In our model, we adapt the representation of the trajectory for non-isotheral jet proposed by Baturin [18]. For a horizontally projected circular jet (see Fig. 1b), the equation is:

$$y\big/\sqrt{A_0} = 0.0354 A_{r0}\left(x\big/\sqrt{A_0}\right)^3 \sqrt{T_0/T_r} \qquad (1)$$

where A_{r0} (defined as $A_{r0} = g\sqrt{A_0}\beta\Delta T_0 / U_0^2$) is the Archimedes number, A_0 is the area of the supply opening, T_0 is the initial temperature of the jet, T_r is the temperature of ambient air, $\Delta T_0 = T_0 - T_r$, U_0 is the initial velocity of the jet and β is the volumetric expansion coefficient.

Usually, two sections of a jet can be identified, i.e. the initial section consisting of the potential core and mixing layer, and the main section. In the initial section, the centerline velocity of the jet is constant and equal to the velocity at the outlet. In the main section, the centerline velocity decreases linearly with increasing distance from the opening. And the velocity profile (distribution) in the cross-section of the jet gradually changes from an almost rectangular shape at the beginning to a similar shape in the main section, which could be represented in dimensionless coordinates by one generalized distribution. We choose the empirical formulas for an isothermal jet presented in the thesis of Bocksell [21], which were constructed based on equations given by Yuu et al. [22] and detailed measurements in round jets by Wygnanski and Fiedler [23]. The velocity distribution in a non-isothermal jet is very similar to that of an isothermal jet. To account for the change in the diffusion characteristics of a non-isothermal jet due to buoyancy, we simply use the curve length of the centerline (S in Fig. 1b) as the axial distance (X in Fig. 1a) in the equations for an isothermal jet.



(a)

(b)

Fig. 1. Illustrations of: (a) an isothermal jet; and (b) a non-isothermal jet.

The centerline velocity decay U_m, mean axial velocity component $\overline{u_s}$ and mean radial velocity component $\overline{u_r}$ in the main section are represented as:

$$U_m = 6.8 U_0 / \bar{s} \qquad (2)$$

$$\overline{u_s} = U_m \sec h^2(\sigma\eta) \qquad (3)$$

$$\overline{u_r} = U_m \left[\frac{a\eta\left(1+\eta^2-(1+b)(1+\eta^2)^{1/2}\right)}{(1+\eta^2)\left(1-(1+b)(1+\eta^2)^{1/2}\right)^2} \right] \qquad (4)$$

where $\bar{r} = r/d_0$, $\bar{s} = s/d_0$, $\eta = \bar{r}/\bar{s}$, $\sigma = 10.4$, $a = 0.0046$ and $b = 0.0075$.

The expressions for temperature T and water vapor density ρ_v decay of non-isothermal jet as proposed by Chen and Rodi [16]:

$$\frac{T_m - T_r}{T_0 - T_r} = \frac{\rho_{vm} - \rho_{vr}}{\rho_{v0} - \rho_{vr}} = \frac{5.0}{\bar{s}} \sqrt{\frac{T_0}{T_r}} \qquad (5)$$

$$\frac{T - T_r}{T_m - T_r} = \frac{\rho_v - \rho_{vr}}{\rho_{vm} - \rho_{vr}} = \exp\left(- \frac{r^2 \ln 2}{(0.11 s)^2} \right) \qquad (6)$$

where T_m is the centerline temperature of the jet, ρ_{vm} is the water vapor density in the centerline of the jet, ρ_{v0} is the initial water vapor density of the jet and ρ_{vr} is the water vapor density in the ambient air. Water vapor is treated as an ideal gas, i.e. the density of water vapor ρ_v is related to p_v and T as:

$$\rho_v = M_v p_v / RT \qquad (7)$$

where p_v is a function of relative humidity and temperature. The above formulas for exhaled air jets can be used to calculate the velocity vector $\mathrm{U_g}$, temperature T and water vapor density ρ_v at any point in a non-isothermal jet.

Evaporation and dynamic model for a single droplet

This study follows the expression of mass flux from droplet surface used by Kukkonen et al. [24]:

$$-\frac{dm_p}{dt} = -\frac{4\pi p r_p M_v D_\infty C \cdot Sh}{RT_\infty} \ln\left(\frac{p - p_{va}}{p - p_{v\infty}}\right) \quad (8)$$

where m_p is the mass of the droplet, t is time, r_p is the droplet radius, M_v is the molecular weight of vapor, D_∞ is the binary diffusion coefficient far from the droplet, R is the universal gas constant, T is temperature, p is the total pressure and p_v is the vapor pressure. The subscripts '*a*' and '∞' refer to values in the gas at the droplet surface and far from the droplet. C is a correction factor due to the temperature dependence of the diffusion coefficient, which is given by:

$$C = \frac{T_\infty - T_p}{T_\infty^{\lambda - 1}} \frac{2 - \lambda}{T_\infty^{2-\lambda} - T_p^{2-\lambda}} \quad (9)$$

where λ is a constant, specific for each substance, with a value between 1.6 and 2. Equation 8 is used to calculate the mass flux of water vapor from a droplet surface, which is driven by partial pressure difference between the vapor immediately above the droplet surface and the ambient air far from the surface. The vapor pressure at the droplet surface p_{va} is assumed saturated and is sensitive to the droplet temperature T_p. For a saline water droplet, the dissolved substance (solute) lowers the saturation vapor pressure of water, which could be determined using Raoult's law:

$$p_{va,s} = \chi_w p_{va}(T_p) \quad (10)$$

$\chi_w = n_w / (n_s + n_w)$ is the mole fraction of water, and for a droplet:

$$\chi_w = \left(1 + \frac{6 i m_s M_w}{\pi \rho_L M_s d_p^3}\right)^{-1} \quad (11)$$

where d_p is the droplet diameter, n_s is the number of moles of solute, n_w is the number of moles of water; m_s is the mass of solute in the droplet, M_s is the molecular weight of solute, M_w is the molecular weight of solvent (water) and i is the ion factor (the number of ions that one molecule of substance dissociates into). For NaCl, i is equal to 2. In the present study, we only consider the effect of solute on the saturation vapor pressure of water and ignore other potential effects. Moreover, in calculating the droplet size, the volume of crystallized solute is not taken into account. Then the non-volatile solute concentration during droplet evaporation could be easily calculated.

The equation for droplet temperature is derived according to a heat balance that relates the enthalpy change in the droplet to the heat flux to the droplet surface, viz.:

$$m_p c_p \frac{dT_p}{dt} = 4\pi r_p^2 K_g \frac{T_\infty - T_p}{r_p} Nu - L_v I - 4\pi r_p^2 \Gamma (T_p^4 - T_\infty^4) \quad (12)$$

Heat is transferred to or from the droplet surface by thermal convection, evaporation and thermal radiation. In the above equation, c_p is the droplet heat capacity, K_g is the thermal conductivity of the gas, L_v is the latent heat of vaporization and Γ is the Stefan–Boltzmann constant.

The Sherwood number *Sh* and Nusselt number *Nu* are used to consider the effects of the relative velocity between the gas and the droplet on mass transfer and heat transfer respectively. And in the present study, the correlations of Ranz and Marshall [25] are used:

$$Sh = 1 + 0.3\, Re^{1/2}\, Sc^{1/3} \quad (13)$$

$$Nu = 1 + 0.3\, Re^{1/2}\, Pr^{1/3} \quad (14)$$

Re is the droplet Reynolds number, *Sc* is the Schmidt number and *Pr* is the Prandtl number. They are defined as:

$$\mathrm{Re} = \rho_g d_p \left| \mathbf{V_p} - \mathbf{U_g} \right| / \mu \quad (15)$$

$$Sc = \mu / (\rho_g D) \quad (16)$$

$$\mathrm{Pr} = c_g \mu / K_g \quad (17)$$

where $\mathbf{V_p}$ is droplet velocity vector, $\mathbf{U_g}$ is gas velocity vector, $\mathbf{V_p} - \mathbf{U_g}$ is the relative velocity of droplet and gas, ρ_g is gas density, μ is the dynamic viscosity of the gas, D is the binary diffusion coefficient of vapor through air, and c_g is the specific heat of the gas.

In Equations 8 and 12, the rate of mass and heat transfer are related to the droplet velocity $\mathbf{V_p}$, which could be obtained according to Newton's second law of momentum conservation for a droplet. This study concerns small water droplets, where the ratio of the droplet density to the density of the air is large, so gravity, buoyancy and the drag force due to air resistance are taken into account, while other forces can be assumed to be negligible [26]. The momentum equation of a droplet could be expressed as:

$$m_p \frac{d\mathbf{V_p}}{dt} = m_p \mathbf{g}\left(1 - \frac{\rho_p}{\rho_g}\right) - C_d \pi r_p^2 \frac{\rho_g \left| \mathbf{V_p} - \mathbf{U_g} \right| (\mathbf{V_p} - \mathbf{U_g})}{2} \quad (18)$$

where $\mathbf{g}$ refers to gravitational acceleration, and C_d is the drag coefficient, which is determined by the following [27]:

$$C_d = \begin{cases} 0.424 & \mathrm{Re} > 1000 \\ \frac{24}{\mathrm{Re}}\left(1 + \frac{1}{6}\mathrm{Re}^{2/3}\right) & \mathrm{Re} \le 1000 \end{cases} \quad (19)$$

The equation for droplet displacement $\mathrm{X_p}$ is:

$$\frac{d\mathbf{X_p}}{dt} = \mathbf{V_p} \quad (20)$$

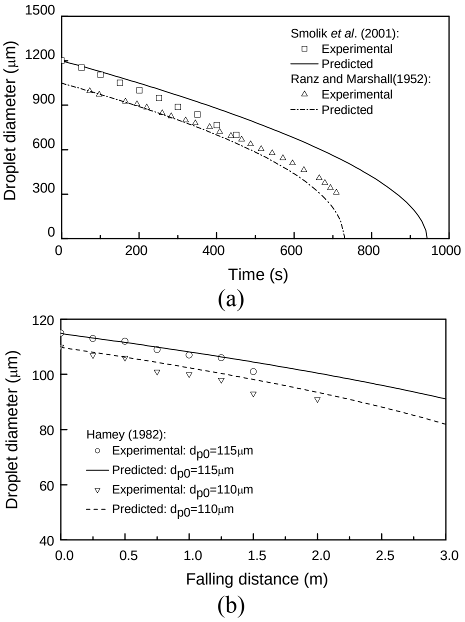
Equation 8, 12, 18 and 20 constitute a coupled ordinary differential system and could be applied to calculate the evaporation process and trajectory of a droplet after being expelled with the exhaled air jet. The unknown variables are related with the environment in which the droplet evaporates and moves. The local air velocity, temperature and relative humidity change along the droplet trajectory and need to be updated using the exhaled airflow model at every time step during a numerical calculation.

3 Results and discussion

On the basis of the above model, we investigated the evaporation and movement of pure water droplets and 0.9% saline droplets (respiratory droplets) under different conditions. The physical and chemical properties of the water used in this study were taken from Kukkonen et al. [24]. In the numerical calculations, the forth-order Runge–Kutta method was used to numerically solve the transient governing equations for droplet size, temperature, velocity and displacement. The droplet size studied was 200 μm and less. Calculations were performed until the droplet diameter was less than 0.3 μm, at which time droplet nuclei was assumed to be created [28].

Comparison with previous experimental results

To validate the evaporation model used, we compared the predicted results with those of three previous experimental studies. The comparisons of experimental results with the results predicted by our model under the same conditions are shown in Fig. 2. There is a surprising lack of experimental data on droplet evaporation and movement. We have only been able to identify three such studies: (i)Ranz and Marshall's [25] investigation of the evaporation of motionless water droplets in dry stagnant air (T_{p0} = 282 K, T_∞ = 298 K, RH = 0%); (ii)Hamey's [29] study of free-falling droplets in humid stagnant air (T_{p0} = 289 K, T_∞ = 293 K, RH = 70%); (iii) Smolík et al. 's[30] experiment with a suspended droplet in an airstream of constant velocity (T_{p0} = 287 K, T_∞ = 297 K, RH = 35%, V_a = 0.203 m/s). As can be seen from Figure 3, the model overpredicted the evaporation rate in their experiments of Smolík et al. [30]. However, the prediction agreed well with the experimental results of motionless and freely falling droplets.



(a)

(b)

Fig. 2. Comparison of the present predicted and the measured temporal change of droplet diameter by Ranz and Marshall [25], and Smolík et al. [30] (a); and Hamey [29] (b).

Droplet dispersion due to different respiratory activities

Droplet dispersion due to different respiratory activities was numerically obtained using our simple simulation model. Non-isothermal jet flows with initial velocities of 1, 5, 10, 20 and 50 m/s were used to approximate the exhaled air flow produced during different respiratory activities (e.g. normal breathing 1 m/s, talking 5 m/s, coughing 10 m/s and sneezing 20–50 m/s). In the numerical examples shown below, we set the ambient air temperature at 20°C and relative humidity at 50%. The exhaled air was saturated with water vapor, and its temperature was 33°C. The salinity of those expelled droplets was set at 0.9% w/v. The diameter of the circular 'mouth' opening was 0.04 m.

Fig. 3 shows the trajectories of droplets of varying sizes when the jet initial velocity was 10 m/s. At first, droplets of all sizes moved forward with the exhaled air jet. Large droplets left the jet quickly and deposited to the ground, and intermediate droplets left the jet and totally evaporated in the ambient air, whereas small droplets moved with the jet, where they completely dried up.

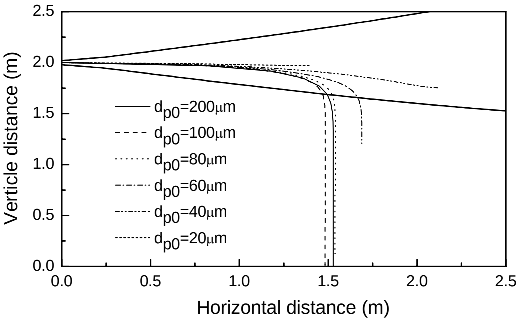
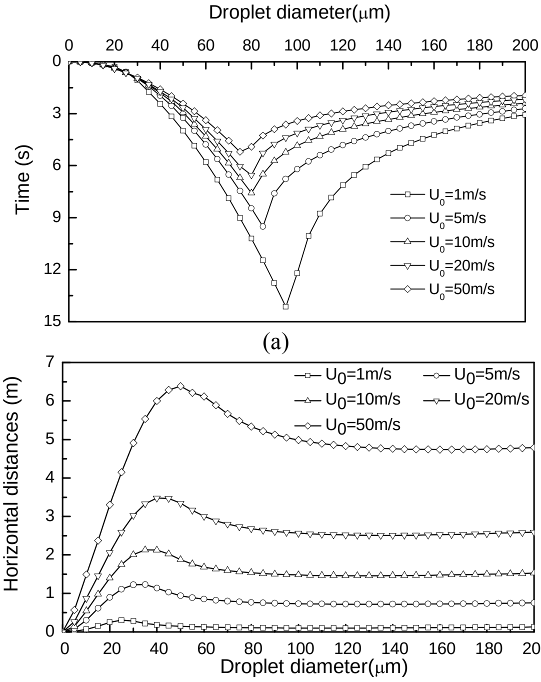


Fig. 3. Trajectories of droplets of varying diameter in a non-isothermal jet (T_{p0} = 33°C, T_∞ = 20°C, RH = 50%, U_0 = 10 m/s).



(a)

(b)

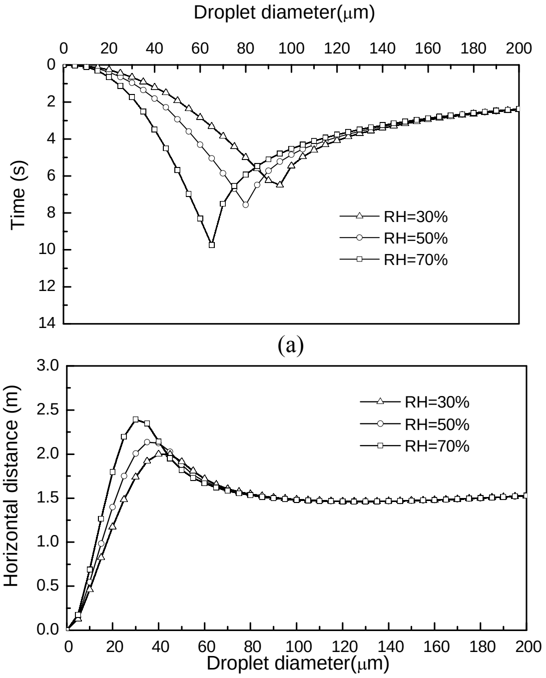
Fig. 4. Predicted behavior of moving droplets of different initial sizes during different respiratory activities (T_{p0} = 33°C, T_∞ = 20°C, RH = 50%): (a) evaporation time and falling time; and (b) horizontal travel distances at different velocities.

The effect of droplet size on droplet evaporation and dispersion is best illustrated in Fig. 4. Fig. 4a shows modified Wells evaporation-falling curves under different respiratory activities. For each curve there are two parts: the left one is the evaporation time and the right one is the falling time (2 m to the ground). Compared with the small droplets, the large droplets evaporated more slowly, fell down quickly and took less time to fall 2 m. Intersection point represents the largest droplet size (*critical droplet size*) that totally evaporated before falling 2 m. Fig. 4a summarizes the effect of initial jet velocity on evaporation and falling of droplets, and show that it took less time to fall 2 m when the initial jet speed was faster. Therefore, critical droplet size increased with increased initial jet velocity, which was found to be from 75 to 95μm at velocity between 1m/s and 50m/s. More droplet nuclei will suspend in air at a slower initial jet velocity given the same amount of droplet numbers at source.

We also measured the horizontal distance a droplet of a certain diameter traveled at different initial jet velocities (shown in Fig. 4b). Because of the short lifetimes (evaporation times) of small droplets and the large gravitational settling velocities of large droplets, the maximum horizontal distance was achieved by droplets of medium diameter. The horizontal travel distance of a droplet of the same size increased with increasing initial jet velocity. As can be seen in Fig. 4b, the exhaled air carried droplets less than 1 m away when the velocity was 1 m/s (normal breathing), and more than 6 m away when the velocity was 50 m/s (sneezing).

Droplet dispersion at different relative humidities

Relative humidity was known to greatly affect droplet evaporation and thus also droplet falling rate. In an indoor environment, the relative humidity is normally within the range of 30–70%. Our numerical calculations were performed at an initial jet velocity of 10 m/s (coughing) and relative humidities of 30, 50 and 70%.



(a)

(b)

Fig. 5. Predicted behavior of moving droplets of different initial sizes under different relative humidity levels (T_{p0} = 33°C, T_∞ = 20°C, U_0 = 10 m/s): (a) evaporation time and falling time; and (b) horizontal travel distances.

The effect of relative humidity on droplet evaporation and dispersion is shown in Fig. 5. We have also drawn the trajectories of droplets with initial diameters of 80, 60, 40 and 20 μm at relative humidities of 30, 50 and 70% (not shown). It was found the horizontal travel distance increased with the relative humidity for droplets of ≤40 μm diameter, it decreased for droplets of around 60 μm diameter, and it remained almost unchanged (about 1.5 m) for droplets of ≥80 μm diameter. This tendency can also be seen in Fig. 5b, which shows that the droplet size at which the horizontal distance decreased with relative humidity was between 50 and 80 μm. The maximum horizontal distances increased with increased relative humidity, and these were reached by 45 μm diameter droplets at 30% RH, 40 μm at 50% RH and 30 μm at 70% RH. These results indicate that most droplets would be transported more than 1.5 m, and that infection risk would be greatest for people within this vicinity.

Falling distance increased with relative humidity for droplets of all sizes. The falling distance was <0.5 m for droplets of 40 μm diameter, and <0.05 m for 20 μm diameter droplets (not shown). Fig. 5a shows the effect of relative humidity on evaporation and dispersion. With the current model, relative humidity does not change the velocity field of the air, so it can't affect the droplet velocity directly as the initial jet velocity does, but through the evaporation rate. At a higher relative humidity, droplets evaporate much slower and thus fall more quickly. Thus, it takes more time for them to leave a jet and fall 2 m. Therefore the largest droplet size (*critical droplet size*) that totally evaporated before falling 2 m decreases with increased relative humidity, which was found to be 95, 80 and 65 μm at 30, 50 and 70% RH respectively. This means that more droplets/droplet nuclei will suspend in air at lower relative humidity given the same source strength.

The effects of relative humidity on physiological processes (direct effects) and on pathogenic organisms or chemicals were reviewed by Arundel et al. [31]. Indoor relative humidity can have an affect on at least two aspects of airborne-transmittible infectious diseases: the settling of aerosols and the survival of airborne pathogens. Low relative humidities result in rapid evaporation and an increase in the abundance of suspended aerosols, and mid-range relative humidities (40–70%) minimize the survival or viability of bacterial or viral organisms. Wang et al. [15] estimated the number of droplets that would be inhaled by a person at a distance of 1.5 m from source under different relative humidity conditions, and found that a higher relative humidity reduced droplet inhalation, which had been suggested (without epidemiological evidence) as one of the key factors of SARS transmission in some areas. Our numerical calculations confirmed the effect of relative humidity on the number of suspended aerosols. At lower relative humidity, the maximum size of droplets that can fall 2 m before evaporation is larger, which means more droplets could suspend in the air. After evaporation, more droplet nuclei form and move around with the air current. Moreover, the falling distance before evaporation increases with higher relative humidity, which could affect the inhalation of droplets.

4 Conclusions

We have analyzed the evaporation and movement of droplets expelled due to respiratory activities using a simple physical model. In the model, an existing evaporation theory was used to describe the evolution of droplets, and a theory of non-isothermal jet was employed to simulate exhaled air movement due to respiratory activities. The effects of droplet size, exhaled air velocity and relative humidity on droplet evaporation and dispersion were examined by numerical computations. It was found that small droplets evaporate rapidly and large droplets fall to the ground quickly. At a low relative humidity, more droplets and droplet nuclei could suspend in air, increasing the probability of subsequent inhalation.

For respiratory exhalation flows, the critical size of large droplets was between 60 and 100 μm, depending on the exhalation air velocity and relative humidity of the ambient air. Expelled droplets were carried more than 6 m away by exhaled air at a velocity of 50 m/s (sneezing), more than 2 m at a velocity of 10 m/s (coughing) and less than 1 m at a velocity of 1 m/s (breathing). These findings are useful for developing engineering methods for controlling infectious disease transmission via large droplets or airborne routes.

Acknowledgements

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A Web Graphic Tool For Travelling Through A Virtual Home, School Or Office To Improve Our Awareness On Indoor Air Risk

M. G. Simeone, V. Ubaldi, A. Lepore, M.C. Cirillo

National Environmental Protection Agency (APAT) - State of Environment and Environmental Metrology Department - Via V. Brancati 48, 00144 Rome, Italy
email: simeone@apat.it http://www.apat.it

Summary: *The knowledge of the main sources of indoor air pollutants in our life environment is an important step to face and reduce related health risks. In this paper a virtual web based travel through some indoor environments is used as an easy tool to inform about the major concerns on indoor air pollution risk. Three different environments are described: a home, a school, an office and their main rooms, with a simple graphic style that helps to drive the exploration in the different environments.*

Keywords: *indoor air pollution, communication, information*
Category: *Policies And Practice Issues In Creating Healthy Buildings*

1 Introduction

In the last few years there is a growing interest on indoor air pollution topic, driven by the experimental evidence that air within buildings can be more polluted than outdoor. This evidence, linked with a life style where people spend a share up to the 90% of their time indoor (offices, homes, schools), suggests an increasing attention on the health risks due at the exposure to indoor air pollutants.

Sources of indoor air pollution can be divided in two categories, the so called primary sources and the secondary ones. Both of them can emit gases or particles responsible of a poor indoor air quality. Among the first category are for example the building materials, the furniture, carpets. While secondary sources are objects introduced or activities which are being performed in that specific environment and releasing mixture of gases, vapours and particles. As an example the smoke released by tobacco products, or the use of specific cleaning products.

Indoor air topic can be considered a multi-disciplinary issue, linked to a wide range of subjects from construction science to medical, social ones.

Of course the architecture and the design of the buildings, the construction materials and technologies, together with the operation and the restoration have a fundamental role on indoor air pollution prevention. But it is to be underlined how the behaviours and the choices on what is introduced in an indoor environment can significantly influence the release of indoor pollutants. This focuses on the importance of the communication and education to improve the general self awareness on the problem.

The difficulties encountered to enforce regulations on the indoor air quality mainly due to the private nature of dwellings, can be overcome by the spreading of best practices on products and behaviours which can be adopted to minimize the risks connected to indoor air pollution.

In this paper we present a virtual travel through several indoor life environments. The tool is intended for being published on the WEB assuring a wide diffusion. It has been designed to give easy and comprehensive information about the main concern on indoor air pollution sources and their related risks. The user can travel through every day environments and objects, receiving information on possible indoor sources and related risks.

2 Description

The web tool is designed for a wide diffusion. The used graphic design is simple and immediate to help the exploration of the different environments. A home, a school and an office are described, each of them with their main rooms.

The virtual tour is organized on three different levels.

- 1st level: Home or office or school.

The user has been asked to choose one of the three environments (Fig.1).

Fig. 1. First level of tour exploration.

- 2nd level: Choice of the microenvironments.

The second level is the presentation of a list of rooms among those which are normally in a home, a school and an office. These are reported in the following table:

Environment	Micro-environment
Home	Living room
	Bedroom
	Kitchen
	Bathroom
	Garage
Office	Office room
	Copy room
	Garage
School	Classroom
	Library
	Didactic laboratory

Table 1. Environments and relative microenvironments considered.

- 3rd level: The microenvironment is graphically described with objects of daily use. Each of them is presented with a short description concerning the possibility of being an indoor pollutant source. The information is completed from some advice on the associated health risks.

To make the consultation easy and immediate, the mouse is used to highlight the main polluting sources. Only a click is needed to open a window on the screen with an essential but complete information on the source and the associated indoor pollutants.

Aiming to a complete description for each microenvironment, the entire list of possible source pollutants has been always reported, also when the same contaminants are present in other microenvironments.

In the description of the school and office environment the emphasis is not only on the objects but also on the behaviours which can be dangerous for the community, among which the smoke. In Italy is now enforced a law regarding the prohibition to smoke in the public offices, school, restaurants and so on.

At the warning notice "No smoke" has given prominence in the picture and the related window gives a brief description not only on the risk for the smoker but also on the consequence from indoor smoke.

Following it is illustrated the description of the different microenvironments with their indoor pollutant sources. Three different examples have been reported going from the first at the third level.

First Level: Home

Second Level: Bedroom

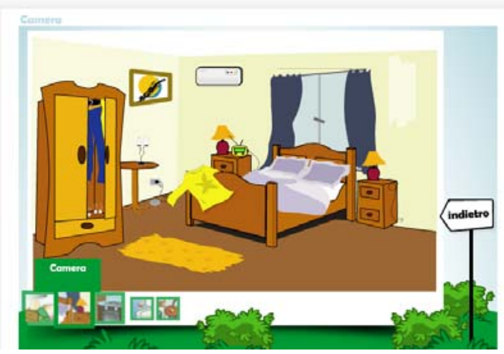

Fig.2 The bedroom as pictured on the screen.

If we pass with the mouse on the air conditioner a window has opened with the following description:

"*The risks related to the air conditioners are linked to an improper use and insufficient maintenance. Each of the single constituent elements the air conditioner may be a source of indoor pollutants. Each element can be both the growth or multiplication site of the biological contaminants, and the transport or dissemination media of the same.*"

In the table there is the list of the sources identified and their relative contaminants.

Sources	Contaminants
Furniture	Formaldehyde, VOC, allergens, mites, mold
Walls, pavements and ceilings	Asbestos, formaldehyde, VOC, bacteria, mold, radon.
Environmental Tobacco Smoke	CO, NO, benzene, formaldehyde, PAH, VOC, particulate matter, etc.
Tapestry	Mites, mold, bacteria, formaldehyde, VOC, particulate matter
Paints	Benzene, formaldehyde, VOC, pesticides
Clothes	Formaldehyde, VOC, PAH, mites
Insecticides	Pesticides, VOC
Air conditioner	Mites, mold, allergens, particulate matter
Domestic electrical appliances	Electromagnetic fields
Candles, incenses and deodorant	CO, NO_2, SO_2, particulate matter, formaldehyde, benzene, PAH, VOC
Pets	Allergens, mites, bacteria, fungi
Outdoor environment	CO, NO_2, SO_2, particulate matter, O_3, pesticides, benzene, PAH, Pollens, asbestos, noise, electromagnetic fields, radon

Table 2. Bedroom: indoor air pollution sources and their relative contaminants.

First Level: Office

Second Level: Office room

Fig. 3. The office room as pictured on the screen.

In this case, again, the microenvironment is described through objects with an easy and immediate reminder at a daily situation.

The following description gives information on laser print and the associated risks.

"Laser print can release both volatile organic compounds and particulate matter emitted from the toner, while the high voltage process can be the cause of ozone formation. These contaminants can be emitted from the ink or other substances used for the printing process."

In this case the complete list of pollutant sources is the following.

Sources	Contaminants
Furniture	Formaldehyde, VOC, allergens, mites, mold
Walls, pavements and ceilings	Asbestos, formaldehyde, VOC, bacteria, mold, radon.
Environmental Tobacco Smoke	CO, NO, benzene, formaldehyde, PAH, VOC, particulate matter, etc.
Tapestry	Mites, mold, bacteria, formaldehyde, VOC, particulate matter
Paints	Benzene, formaldehyde, VOC, pesticides
Clothes	Formaldehyde, VOC, PAH, mites
Air conditioner	Mites, mold, allergens, particulate matter
Laser print	O_3, formaldehyde, VOC, breathable particulate
Personal care products	Aliphatic hydrocarbon, formaldehyde, VOC, acetone, benzene
Photocopiers	O_3, formaldehyde, VOC, carbon black, benzene
Electrical appliances	Electromagnetic fields
Outdoor environment	CO, NO_2, SO_2, particulate matter, O_3, pesticides, benzene, PAH, Pollens, asbestos, noise, electromagnetic fields, radon

Table 3. Office room: indoor air pollution sources and their relative contaminants.

First Level: School

Second Level: Classroom

Fig. 4. The classroom as pictured on the screen.

A classroom is illustrated in a typical situation: there are some students listening a teacher.

The hints are easy and, again, the suggestions are on the best practices concerning the behaviours and the correct use of daily objects.

About the correct use of felt pens, highlighters and liquid correctors the text reports the advice often written on these.

"Felt pens, highlighters and liquid correctors can contain an high amount of solvents which can easily evaporate in the air. Products based on organic solvents are very dangerous as they can contain xylene or toluene or other volatile organic compounds. The liquid correctors contain 1,1,1-trichloroethane, a toxic and irritating substance."

The table below listed the following identified pollutant sources.

Sources	Contaminants
Furniture	Formaldehyde, VOC, allergens, mites, mold
Walls, pavements and ceilings	Asbestos, formaldehyde, VOC, bacteria, mold, radon.
Environmental Tobacco Smoke	CO, NO, benzene, formaldehyde, PAH, VOC, particulate matter, etc.
Paints	Benzene, formaldehyde, VOC, pesticides
Clothes	Formaldehyde, VOC, PAH, mites
Air conditioner	Mites, mold, allergens, particulate matter
Personal care products	Aliphatic hydrocarbon, formaldehyde, VOC, acetone, benzene
Cleaning products	
Highlighters and liquid correctors	VOC, trichloroethane,
Dust	Allergens
Moisture	Mould, fungi
Outdoor environment	CO, NO_2, SO_2, particulate matter, O_3, pesticides, benzene, PAH, Pollens, asbestos, noise, electromagnetic fields, radon

Table 4. Classroom: indoor air pollution sources and their relative contaminants.

3 Conclusion

To improve the awareness on indoor air topic has been designed an easy to use and comprehensive tool for the net.

The graphic design allows the use as a short introduction on indoor theme, giving the major hints on indoor air pollution sources and the precautions to minimize the associated risks. The consultation is fast and intuitive. The description of commonly used daily objects helps the user to explore the environment, with an improvement on his self awareness on which behaviours should be adopted for minimizing the risks.

On the other hand the presentation of the Tour through a virtual life environment on a dedicated Web site joins an easy introduction to the possibility of a deeper knowledge.

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Within-house and Between-house Variability in Concentrations of VOCs and Carbonyl Compounds in Indoor Air for Risk Assessment

N. Shinohara[1], T. Kataoka[2], K. Takamine[2], T. Nakamura[2], K. Motohashi[2],
H. Nishijima[3], M Gamo[1]

[1] Research Center for Chemical Risk Management, National Institute of Advanced Industrial Science and Technology, 16-1 Onogawa, Tsukuba, Ibaraki, 305-8569, Japan, e-mail: n-shinohara@aist.go.jp
[2] Chemicals Evaluation and Research Institute, [3] Sigma-Aldrich Japan K.K.

Summary: *A method was developed to estimate the between-house distribution of long-term average level of indoor air pollutants, which is considered to be adequate for use in quantitative risk assessment, from the distribution of short-term measurement (typically a 24 hour average for a room in each house) which have been reported in many previous studies. The information necessary for the estimation is the extent of within-house variabilities (day-to-day variabilities and between-house variabilities). To obtain the extent of those variabilities, a survey that 39 VOCs and 4 carbonyl compounds were measured in 3 rooms and immediately outside 26 houses for 7 days in each of the four seasons was conducted. The within-house variabilities were small for most chemicals (median of geometric standard deviation (GSD): 1.2 to 1.5). Using acetaldehyde as an example, we compared the number of people whose exposure levels exceeded the Japanese indoor guidelines using between-house distribution of long-term average levels with that using the distribution for short-term measurement.*

Keywords: *Distribution, Day-to-day variability, Between-house variability Volatile organic compounds (VOCs), Carbonyl compound*
Category: *Measurements and monitoring IAQ*

1 Introduction

To conduct a quantitative risk assessment of indoor air pollutants, the distribution (between-house variability) in exposure levels is essential information. Since adverse health effects might result from chronic exposure, the measurement of variability in exposure levels should be carried out on the basis of long-term average levels. In most previous studies, however, only daily or weekly levels in a room were reported. The distribution in short term exposure levels in a room is considered to be different from the distribution in the long-term exposure level in a house because of the day-to-day and season-to-season variability within that house. The distribution of indoor concentrations have to be evaluated by subtracting the within-house variabilities from the variability in short term mean concentrations reported in previous studies. In the study reported here, for the purpose of developing a method to evaluate the distribution of long-term mean indoor concentrations of volatile organic compounds (VOCs) and carbonyl compounds based on short term measurements, the within-house and between-house variabilities were measured in 26 houses and the method was validated.

2. Methods

Survey

Twenty four-hour average concentrations of 39 VOCs and 4 carbonyl compounds were measured every day for a week in the summer of 2005 in three rooms and the immediate outdoors of 26 houses, which had different family structures, different types of residential structure and different residential ages.

Analytical

For the sampling of carbonyl compounds and VOCs, DSD-DNPH and VOC-SD (Supelco Ltd.) respectively, were used. Carbonyl compounds, extracted with 5 mL of acetonitrile from the sampling cartridge, were analyzed by HPLC (LC-10A, Shimadzu Co.). VOCs, extracted from the charcoal cartridge with 1 ml of carbon disulfide, were analyzed by GC-MS (HP6890-HP5973, Hewlett Packard Co.). Analytical conditions are shown in Table 1. In addition, 24 hour averages of air exchange rates were measured by the PFT method and temperature and humidity were measured with a thermohygrometer (HL3631, AS ONE Co.). The residents of each house were asked to complete a questionnaire on their daily activities every day.

Table 1. Analytical conditions

Instrument		Condition
HPLC	Column	L-Column ODS 150 mm × 4.6 mm ID
	Mobile phase	$CH_3CN : H_2O = 60 : 40$ (v/v)
	Flow rate	1.0 mL/min
	Injection volume	20 µL
	Column temperature	40 °C
	Detector	Ultraviolet absorption detector (UV) 360 nm
GC-MS	Column	Equity-1 (60 m × 0.32 mm 5 µm)
	Carrier gas	He
	Flow rate	2.0 mL/min
	Injection volume	1 µL
	Split mode	Splitless
	Injector temperature	200 ºC
	Interface temperature	250 ºC
	Column temperature	30 ºC (5 min) - (3 ºC /min) - 100 ºC - (8 ºC /min) - 250 ºC (10 min)

Distribution

In this study, we wanted to develop a method to estimate the distribution of long-term average indoor air concentrations of VOCs and carbonyl compounds for risk assessment using the short-term average indoor concentrations recorded in previous studies. The distributions of indoor concentrations were assumed to be lognormal according to the previous study [1]. Thus, the geometric mean (GM) and the geometric standard deviation (GSD) were used as indicators of distribution. Variabilities of long-term mean concentrations can be obtained by subtracting the within-house variability from the between-house variabilities in short-term mean concentrations. The GM of short-term mean concentrations is the same as the GM of long-term GM concentrations. For considering chronic exposure to chemicals, the GM of the long-term arithmetic mean (AM) related to the total dose is necessary. The GM of the long-term AM can be obtained by multiplying the within-house AM/GM ratio of the short-term concentration by the GM of the long-term GM of the 24 hour average concentration. The within-house AM/GM ratio is correlated with the within-house variability. The developed method is shown in Figure 1. The GM and the GSD of the distribution for the risk assessment is expressed by the following equations,

$$GM_{\textit{long-term level}} = GM_{\textit{short-term level}} \times \frac{AM_{\textit{within-house distribution}}}{GM_{\textit{within-house distribution}}}$$

$$GSD_{\textit{long-term level}} = exp\sqrt{lnGSD^2_{\textit{short-term level}} - lnGSD^2_{\textit{day-to-day}} - lnGSD^2_{\textit{between-house}}}$$

The between-house distributions of the indoor concentrations, converted by this method with the between-house distribution in short-term average levels were defined as the "converted distribution". To obtain the parameters for use in the method, within-house variability: day-to-day variability and between-room variability, and within-house AM/GM ratio of 24 hour average indoor concentrations were obtained from the results of this survey. In this study, within-house variability and the AM/GM were calculated for the data sets which did not have more than 1 undetermined sample, and between-house variability was calculated for substances which had more than 70% of samples determined.

This method was validated using two types of between-house distribution. The first was on the basis of the concentrations averaged for the rooms in each house over the days in the week in this survey (between-house distribution Type I) as the long-term average level. Second was the between-house distribution on the basis of the concentrations in a room randomly selected in each house on a day randomly selected within the week (between-house distribution Type II) as the short-term average level. This corresponded to the between-house distribution that has been usually reported in previous studies. Calculation of the between-house Type II distribution was based on the concentration in a room randomly selected in each house on a day randomly selected within the week by Monte Carlo simulation (100,000 trials). To confirm the suitability of the method, the converted distribution from Type II distributions was compared with Type I distributions.

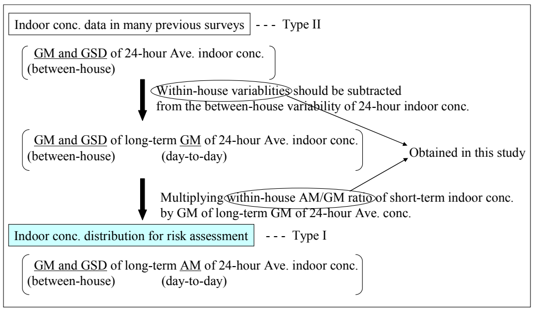

Figure 1. The method to obtain the distribution in long-term average indoor concentrations. By this method, indoor concentration data in many previous surveys can be converted to a distribution of indoor concentrations usable for risk assessment. This method was validated by comparing the converted distribution from Type II with Type I distribution instead of previous data

Risk Analysis

As a typical example of risk assessment, the number of people whose exposure level exceeds the Japanese indoor guidelines was calculated for formaldehyde, acetaldehyde, toluene and p-dichlorobenzene. This calculation was conducted using the between-house converted distribution as the long-term average distribution and the between-house distribution in short-term measurement. The 24-average indoor air levels reported by Ando et al.[2] were used for the distribution in short-term measurement and converted to the converted distribution by the method. For formaldehyde and acetaldehyde, the median 24-hour average indoor concentrations in 185 houses reported in the paper of Ando et al. [2] (24.1 and 20.2µg/m^3) were substituted for the $GM_{\textit{short-term level.}}$ For toluene and p-dichlorobenzene, the GMs of the 24-hour average indoor concentrations in 188 houses (26.3 and 6.90 µg/m^3) were used as the $GM_{\textit{short-term-level}}$. The GSDs$_{\textit{short-term-level}}$ of the indoor concentrations were calculated as 1.7, 1.9, 5.0 and 9.4 for formaldehyde, acetaldehyde, toluene and p-dichlorobenzene, respectively, by the following equation and the GM (median) and AM reported in Ando et al. [2],

$$GSD = exp\sqrt{2 \times ln\ \frac{AM}{GM}}$$

$AM_{\textit{within-house}}/GM_{\textit{within-house}}$, $GSD_{\textit{day-to-day}}$ and $GSD_{\textit{between-house}}$ were obtained in this survey.

Endpoints and inhalation reference concentrations of each substance were the Japanese indoor guidelines of 100, 48, 260, and 240 µg/m^3 for formaldehyde, acetaldehyde, toluene and p-dichlorobenzene, respectively. Although the yearly mean and distributions of the exposure levels should be used for risk assessment of chronic effects, the parameters used in the method were obtained only in the summer survey under the assumption that there is very little season-to-season variability.

Table 2. Indoor and Outdoor concentrations of VOCs and carbonyl compounds in summer 2005 (N=3 rooms × 26 houses)

	Indoor levels [μg/m³]							Outdoor levels [μg/m³]						
	Arithmetic		Geometric		Min	Median	Max	Arithmetic		Geometric		Min	Median	Max
	Mean	SD	Mean	SD				Mean	SD	Mean	SD			
Formaldehyde	93.2	86	70.3	2.1	6.10	70.6	592	8.59	6.7	6.65	2.2	N.D. (<0.16)	7.15	46.0
Acetaldehyde	47.9	49	28.8	3.0	t.r. (<1.4)	30.6	278	3.66	4.4	2.23	2.7	t.r. (<1.4)	2.13	26.1
Acetone	40.9	76	21.7	3.6	N.D. (<0.21)	23.9	1130	2.27	2.9	0.690	5.9	N.D. (<0.21)	0.987	14.3
Nonanal	52.6	36	40.9	2.2	N.D. (<1.9)	48.3	264	4.43	5.9	2.19	3.1	N.D. (<1.9)	N.D. (<1.9)	38.1
Ethanol	57.3	110	14.4	8.8	N.D. (<0.06)	20.5	1300	0.641	1.1	0.216	4.9	N.D. (<0.06)	0.289	10.9
Dichloromethane	226	1300	0.917	9.0	N.D. (<0.17)	0.772	10400	4.01	16	0.633	4.9	N.D. (<0.17)	0.677	131
Methyl Ethyl Ketone	14.8	26	8.14	2.9	N.D. (<0.29)	7.70	288	5.90	5.9	3.70	2.9	N.D. (<0.29)	4.51	36.9
Ethyl Acetate	12.5	24	8.65	2.2	N.D. (<0.24)	8.50	3170	7.09	5.7	5.26	2.4	N.D. (<0.20)	6.01	38.4
n-Hexane	2.73	11	1.08	2.8	N.D. (<0.21)	1.06	194	1.02	0.83	0.747	2.5	N.D. (<0.21)	0.877	7.27
Chloroform	4.73	3.0	3.47	2.7	N.D. (<0.19)	4.39	18.5	3.69	2.0	2.50	3.4	N.D. (<0.19)	4.19	6.99
i-Butanol	2.24	8.6	0.503	5.2	N.D. (<0.13)	0.570	132	t.r. (<0.42)	-	t.r. (<0.42)	-	N.D. (<0.13)	N.D. (<0.13)	27.5
n-Butanol	3.96	4.9	1.67	4.9	N.D. (<0.13)	2.20	37.3	N.D. (<0.13)	-	N.D. (<0.13)	-	N.D. (<0.13)	N.D. (<0.13)	1.74
Benzene	3.75	1.7	3.36	1.7	N.D. (<0.21)	3.68	23.4	3.84	1.6	3.40	1.8	N.D. (<0.21)	3.67	8.29
Tetrachloromethane	t.r. (<1.0)	-	t.r. (<1.0)	-	N.D. (<0.34)	t.r. (<1.0)	7.63	1.18	0.77	0.951	2.0	N.D. (<0.17)	1.23	7.23
1,2-Dichloropropane	N.D. (<0.30)		N.D. (<0.29)	-	N.D. (<0.29)	N.D. (<0.29)	1.05	N.D. (<0.29)	-	N.D. (<0.29)	-	N.D. (<0.29)	N.D. (<0.29)	t.r. (<0.88)
Trichloroethylene	1.66	2.3	t.r. (<0.92)	-	N.D. (<0.32)	t.r. (<0.92)	17.8	1.86	2.7	t.r. (<0.92)	-	N.D. (<0.32)	t.r. (<0.92)	15.0
n-Heptane	5.81	11	2.54	4.0	N.D. (<0.27)	2.81	156	1.56	1.4	1.02	2.8	N.D. (<0.27)	1.30	11.3
Methyl iso-Butyl Ketone	7.12	15	2.20	4.3	N.D. (<0.32)	1.96	88.3	1.23	1.3	t.r. (<0.98)	-	N.D. (<0.32)	t.r. (<0.98)	8.77
Toluene	25.9	49	5.72	7.8	t.r. (<0.69)	10.4	357	9.29	13	1.67	11	N.D. (<0.22)	5.30	89.2
Chloro Dibromomethane	N.D. (<1.0)	-	t.r. (<0.34)	-	N.D. (<0.34)	N.D. (<1.0)	4.94	N.D. (<0.34)	-	N.D. (<0.34)	-	N.D. (<0.34)	N.D. (<0.34)	N.D. (<0.34)
Butyl Acetate	23.1	140	3.77	4.4	N.D. (<0.36)	3.05	1850	1.14	1.5	t.r. (<1.1)	-	N.D. (<0.36)	t.r. (<1.1)	15.1
n-Octane	3.27	7.0	1.39	3.1	N.D. (<0.30)	1.15	72.5	t.r. (<0.84)	-	t.r. (<0.84)	-	N.D. (<0.28)	t.r. (<0.84)	2.93
Tetrachloroethylene	0.989	1.9	t.r. (<0.96)	-	N.D. (<0.32)	t.r. (<0.96)	28.0	t.r. (<0.96)	-	t.r. (<0.96)	-	N.D. (<0.32)	t.r. (<0.96)	18.8
Ethyl Benzene	12.4	13	8.50	2.3	t.r. (<0.86)	7.97	77.5	6.28	8.4	4.59	2.2	N.D. (<0.29)	4.66	106
p-Xylene,m-Xylene	25.5	30	17.3	2.4	1.15	17	289	12.8	8.4	9.83	2.2	0.926	11.2	42.6
Styrene	N.D. (<1.0)	-	t.r. (<0.34)	-	t.r. (<1.0)	N.D. (<1.0)	155	N.D. (<1.0)		N.D. (<1.0)		N.D. (<1.0)	t.r. (<0.34)	4.63
o-Xylene	5.70	5.8	4.17	2.1	t.r. (<0.93)	3.75	54.8	3.37	11.2	2.04	2.3	N.D. (<0.32)	2.29	152
n-Nonane	8.99	20	3.44	3.3	t.r. (<1.0)	3.12	154	2.20	2.0	1.59	2.3	N.D. (<0.33)	1.84	15
alpha-Pinene	137	410	17.6	7.6	N.D. (<0.39)	13.5	4300	5.48	19.4	1.65	3.4	N.D. (<0.39)	1.45	239
1,3,5-Trimethylbenzene	2.26	2.8	1.44	2.5	N.D. (<0.34)	1.47	20.9	1.22	2.0	0.853	2.1	N.D. (<0.34)	t.r. (<1.1)	24.9
1,2,4-Trimethylbenzene	7.03	8.0	4.99	2.2	N.D. (<0.32)	4.96	61.0	3.96	6.3	2.89	2.1	N.D. (<0.32)	3.11	82.1
n-Decane	28.5	19	18.3	4.0	N.D. (<0.23)	27.1	117	23.6	12	14.8	4.5	N.D. (<0.23)	26.7	64.1
p-Dichlorobenzene	346	1100	32.4	7.5	1.53	17.4	12600	8.25	11	5.26	2.7	N.D. (<0.37)	5.47	108
1,2,3-Trimethylbenzene	1.75	2.6	1.09	2.4	N.D. (<0.34)	1.12	19.8	t.r. (<1.0)	-	t.r. (<1.0)	-	N.D. (<0.34)	t.r. (<1.0)	17.0
d-Limonene	32.9	46	15.0	4.0	N.D. (<0.39)	17.3	431	t.r. (<1.2)	-	t.r. (<1.2)	-	N.D. (<0.39)	t.r. (<1.2)	6.12
n-Undecane	13.1	32	3.75	4.5	N.D. (<0.30)	3.65	308	2.84	3.5	1.59	3.1	N.D. (<0.30)	2.11	22.0
n-Dodecane	20.8	43	9.55	4.4	N.D. (<0.39)	13.8	612	10.3	8.2	6.44	3.6	N.D. (<0.40)	9.61	49.6
Tetradecane	879	2800	210	5.4	N.D. (<18)	244	42100	102	130	47.6	3.7	N.D. (<18)	55.6	758

Table 3. Within-house and between-house variability (GSD) and within-house AM/GM ratio of Indoor VOCs and carbonyl compounds in the summer survey

	Within-house variability (GSD)		Between-house variability of weekly levels (GSD)	Within-house AM/GM ratio of indoor concentration
	Day-to-day variability (N=78)	Between-room variability (N=182)	(N=26)	(N=26)
Formaldehyde	1.2 (1.1-1.5)	1.2 (1.0-1.6)	2.0	1.03 (1.0 - 1.1)
Acetaldehyde	1.4 (1.1-2.1)	1.2 (1.0-2.0)	2.7	1.07 (1.0 - 1.3)
Acetone	1.4 (1.1-3.5)	1.2 (1.0-2.1)	2.6	1.09 (1.0 - 2.4)
Nonanal	1.3 (1.1-2.5)	1.2 (1.0-1.8)	2.0	1.04 (1.0 - 1.3)
Ethanol	2.0 (1.3-11)	2.2 (1.1-23)	3.4	1.45 (1.1 - 4.3)
Dichloromethane	-	-	-	-
Methyl Ethyl Ketone	1.5 (1.1-2.9)	1.3 (1.1-2.5)	2.5	1.09 (1.0 - 1.4)
Ethyl Acetate	1.5 (1.1-3.2)	1.3 (1.1-2.8)	2.7	1.10 (1.0 - 3.2)
n-Hexane	1.5 (1.1-2.5)	1.3 (1.0-3.2)	2.3	1.10 (1.0 - 1.7)
Chloroform	1.3 (1.1-2.5)	1.2 (1.0-2.5)	2.1	1.03 (1.0 - 1.4)
i-Butanol	-	-	-	-
n-Butanol	1.5 (1.2-4.2)	1.4 (1.4-4.0)	3.8	1.13 (1.0 - 2.0)
Benzene	1.3 (1.1-1.9)	1.2 (1.0-1.6)	1.5	1.02 (1.0 - 1.2)
Tetrachloromethane	-	-	-	-
1,2-Dichloropropane	-	-	-	-
Trichloroethylene	-	-	-	-
n-Heptane	1.4 (1.1-2.1)	1.3 (1.1-2.5)	3.4	1.11 (1.0 - 1.4)
Methyl iso-Butyl Ketone	1.3 (1.1-2.7)	1.3 (1.0-3.9)	3.7	1.08 (1.0 - 1.7)
Toluene	1.5 (1.3-3.3)	1.4 (1.1-6.8)	5.7	1.16 (1.1 - 2.3)
Chloro Dibromomethane	-	-	-	-
Butyl Acetate	1.3 (1.1-4.4)	1.3 (1.1-3.2)	4.3	1.07 (1.0 - 3.3)
n-Octane	1.3 (1.1-1.8)	1.3 (1.1-2.9)	2.8	1.08 (1.0 - 1.7)
Tetrachloroethylene	-	-	-	-
Ethyl Benzene	1.3 (1.1-2.0)	1.2 (1.0-2.0)	2.2	1.05 (1.0 - 1.4)
p-Xylene,m-Xylene	1.3 (1.1-1.7)	1.2 (1.0-2.1)	2.2	1.05 (1.0 - 1.1)
Styrene	-	-	-	-
o-Xylene	1.3 (1.1-1.7)	1.2 (1.1-2.0)	1.9	1.04 (1.0 - 1.2)
n-Nonane	1.3 (1.1-1.7)	1.2 (1.0-1.9)	3.0	1.06 (1.0 - 1.1)
alpha-Pinene	1.5 (1.2-3.0)	1.3 (1.0-3.5)	7.1	1.14 (1.0 - 1.7)
1,3,5-Trimethylbenzene	1.3 (1.1-1.7)	1.2 (1.1-1.8)	2.2	1.04 (1.0 - 1.1)
1,2,4-Trimethylbenzene	1.3 (1.1-1.8)	1.2 (1.0-1.7)	2.0	1.04 (1.0 - 1.1)
n-Decane	1.2 (1.1-2.2)	1.2 (1.1-3.1)	2.7	1.02 (1.0 - 1.9)
1,2,3-Trimethylbenzene	1.3 (1.1-2.0)	1.3 (1.1-2.1)	2.1	1.07 (1.0 - 1.2)
d-Limonene	1.5 (1.2-3.6)	1.5 (1.1-5.5)	3.2	1.16 (1.0 - 1.7)
p-Dichlorobenzene	1.3 (1.1-2.2)	1.4 (1.1-2.9)	7.6	1.06 (1.0 - 1.4)
n-Undecane	1.8 (1.2-3.9)	1.7 (1.1-7.2)	2.9	1.27 (1.1 - 1.9)
n-Dodecane	1.2 (1.1-5.3)	1.3 (1.0-8.2)	3.2	1.05 (1.0 - 2.0)
Tetradecane	1.7 (1.2-8.4)	1.5 (1.1-7.4)	4.2	1.34 (1.1 - 2.7)

*The value used in this table shows the median (5%ile-95%ile).

3. Results and Discussion

Concentrations

Table 2 shows a summary of the indoor and outdoor concentrations in 26 houses. For formaldehyde, acetaldehyde, toluene and p-dichlorobenzene, 24-hour average levels (N=560) were 93.2 ± 86, 47.9 ± 49, 25.8 ± 49, 346 ± 1100 $\mu g/m^3$ respectively.

Distribution

The results of the day-to-day variability, between-room variability and within-house AM/GM ratios are shown in Table 3. For many compounds, the median of the day-to-day variability of the 24-hour average concentration within a room over 7 days and the median of the between-room variability within a house were small (from 1.2 to 1.5). This is probably because the emissions from the sources were quite stable during the sampling period as the temperature and humidity variations were not large. Only for ethanol, the mean day-to-day and between-room variabilities were relatively large (2.0 and 2.2). This was probably because ethanol is emitted from cooking and from the drinking of alcoholic beverages.

The between-house variability was significantly higher than the within-house variability described above for all chemicals (Table 3). The between-house Type I variability for risk assessment, which was based on the long-term average concentrations, was between 1.5 and 7.6. Only the Type I variability of benzene was small (1.5). This was probably because most indoor benzene came from outdoors since the mean indoor/outdoor ratio of benzene was 1.0 (5%ile-95%ile: 0.63-1.7) and the variation in outdoor benzene concentration was not large. Type I variability of alpha-pinene and p-dichlorobenzene were quite large (7.1 and 7.6, respectively). This probably resulted from the different amounts and types of deodorizer and insect repellents, containing these chemicals, used in the different houses. The median of the within-house AM/GM ratio was

Table 4. Comparison of Type I distribution, Type II distribution, and the converted distribution.

	Distribution Type I (N=26) Based on the long-term levels		Distribution Type II (100,000 trial) Based on the short-term levels		Converted distribution by the protocol	
	GM	GSD	GM	GSD	GM	GSD
Formaldehyde	73.2	2.0	69.2 (62-76)	2.1 (2.0-2.5)	71.4 (64-78)	2.0 (1.8-2.4)
Acetaldehyde	31.6	2.7	28.3 (25-33)	3.1 (2.7-3.6)	30.2 (26-35)	2.9 (2.5-3.4)
Acetone	27.0	2.6	22.0 (18-27)	3.3 (2.4-5.2)	24.1 (19-30)	3.1 (2.2-4.9)
Nonanal	43.4	2.0	40.2 (35-45)	2.1 (1.9-2.9)	41.8 (36-47)	2.0 (1.7-2.8)
Ethanol	29.9	3.4	14.5 (8.9-22.5)	9.1 (5.0-14)	21.0 (13-33)	7.0 (3.5-12)
Dichloromethane	-	-	-	-	-	-
Methyl Ethyl Ketone	9.28	2.5	8.28 (6.9-9.7)	3.0 (2.4-3.8)	9.00 (7.5-11)	2.7 (2.1-3.5)
Ethyl Acetate	11.9	2.7	8.99 (7.2-11)	2.7 (1.9-4.4)	9.83 (7.9-12)	2.4 (1.5-4.1)
n-Hexane	1.26	2.3	1.04 (0.87-1.2)	2.5 (2.1-3.1)	1.14 (0.95-1.4)	2.2 (1.7-2.8)
Chloroform	3.88	2.1	3.41 (2.9-4.0)	2.9 (2.2-3.4)	3.51 (3.0-4.1)	2.8 (2.0-3.3)
i-Butanol	-	-	-	-	-	-
n-Butanol	2.10	3.8	1.68 (1.3-2.1)	5.0 (3.9-6.2)	1.90 (1.5-2.4)	4.5 (3.5-5.7)
Benzene	3.53	1.5	3.31 (3.0-3.7)	1.6 (1.5-2.2)	3.39 (3.0-3.7)	1.5 (1.3-2.1)
Tetrachloromethane	-	-	-	-	-	-
1,2-Dichloropropane	-	-	-	-	-	-
Trichloroethylene	-	-	-	-	-	-
n-Heptane	3.16	3.4	2.59 (2.1-3.2)	4.2 (3.5-5.1)	2.87 (2.4-3.5)	3.9 (3.2-4.8)
Methyl iso-Butyl Ketone	2.79	3.7	2.19 (1.8-2.6)	4.4 (3.6-5.4)	2.36 (2.0-2.9)	4.2 (3.4-5.2)
Toluene	9.02	5.7	5.76 (4.3-7.7)	8.2 (6.7-9.8)	6.69 (5.0-9.0)	7.6 (6.2-9.1)
Chloro Dibromomethane	-	-	-	-	-	
Butyl Acetate	4.98	4.3	3.67 (3.1-4.6)	4.3 (3.5-6.2)	3.93 (3.3-4.9)	4.1 (3.3-6.0)
n-Octane	1.56	2.8	1.34 (1.2-1.6)	3.0 (2.6-3.6)	1.42 (1.3-1.7)	2.8 (2.4-3.4)
Tetrachloroethylene	-	-	-	-	-	-
Ethyl Benzene	9.20	2.2	8.38 (7.3-9.6)	2.5 (2.1-2.9)	8.80 (7.6-10)	2.3 (2.0-2.7)
p-Xylene,m-Xylene	18.6	2.2	16.9 (15-19)	2.4 (2.1-2.8)	17.7 (16-20)	2.3 (2.0-2.7)
Styrene	-	-	-	-	-	-
o-Xylene	4.44	1.9	4.03 (3.6-4.6)	2.1 (1.9-2.5)	4.19 (3.7-4.8)	2.0 (1.7-2.3)
n-Nonane	3.57	3.0	3.32 (3.0-3.7)	3.2 (2.8-3.6)	3.51 (3.1-4.0)	3.0 (2.6-3.4)
alpha-Pinene	19.9	7.1	16.8 (14-20)	7.8 (6.5-9.3)	19.1 (15-23)	7.4 (6.1-8.8)
1,3,5-Trimethylbenzene	1.52	2.2	1.38 (1.2-1.6)	2.4 (2.2-2.8)	1.42 (1.2-1.6)	2.3 (2.0-2.6)
1,2,4-Trimethylbenzene	5.18	2.0	4.81 (4.3-5.4)	2.1 (1.9-2.5)	4.98 (4.4-5.6)	2.0 (1.7-2.4)
n-Decane	21.0	2.7	18.0 (15-22)	4.2 (2.5-6.4)	18.4 (15-22)	4.1 (2.4-6.2)
1,2,3-Trimethylbenzene	1.17	2.1	1.03 (0.90-1.2)	2.3 (2.1-2.7)	1.10 (0.95-1.3)	2.2 (1.9-2.5)
d-Limonene	18.7	3.2	15.4 (12-19)	4.0 (3.2-5.4)	17.8 (14-22)	3.5 (2.7-4.9)
p-Dichlorobenzene	35.5	7.6	30.8 (27-36)	7.6 (6.7-8.7)	32.8 (28-38)	7.3 (6.4-8.4)
n-Undecane	5.27	2.9	3.76 (2.8-5.0)	4.3 (3.5-5.5)	4.78 (3.5-6.3)	3.4 (2.6-4.5)
n-Dodecane	12.1	3.2	9.70 (7.3-13)	4.5 (3.3-5.8)	10.2 (7.7-13)	4.3 (3.2-5.7)
Tetradecane	297.0	4.2	208 (151-283)	5.6 (4.1-7.4)	278 (200-380)	4.9 (3.5-6.7)

*The value used in this table shows the median (5%ile-95%ile).

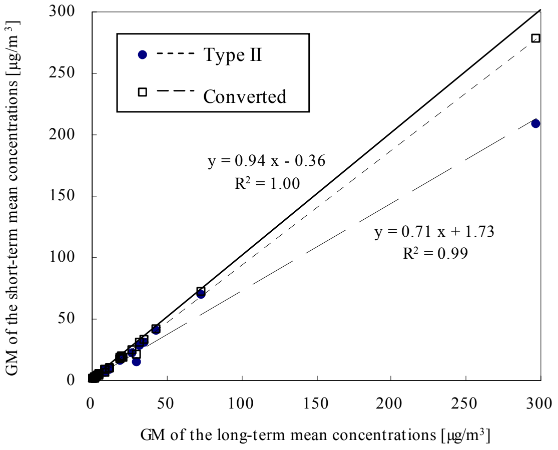

Figure 2. GM of the long-term mean concentration (Type I) vs. GM of the short-term mean concentration (Type II). GMs of converted distributions were closer to GMs of long-term mean concentrations (Type I) than to GMs of short-term mean concentrations (Type II).

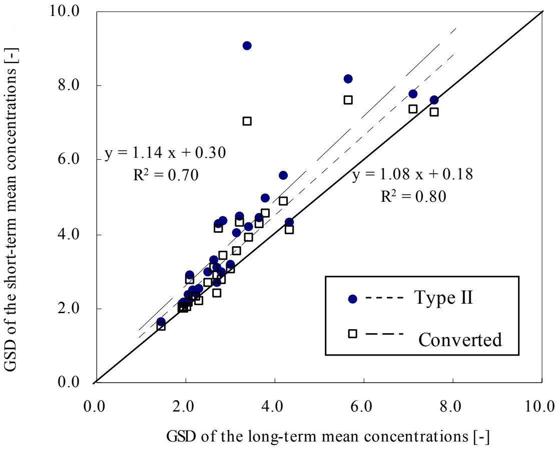

Figure 3. GSD of the long-term mean concentration (Type I) vs. GSD of the short-term mean concentration (Type II). Differences in GSDs between long-term mean concentrations and converted distributions were obvious for ethanol, toluene and undecane because the within-house variability was large in parts of the houses.

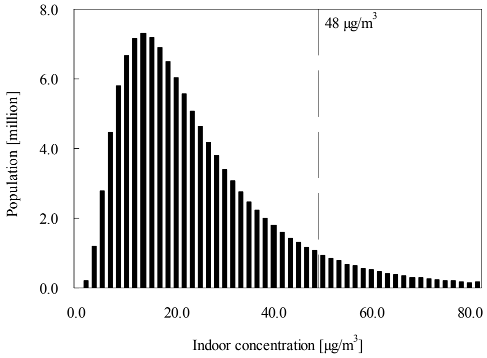

Figure 4. Distribution of indoor acetaldehyde concentration based on short-term mean levels. 8.6% of the population exceed the Japanese guideline value (48 μg/m^3)

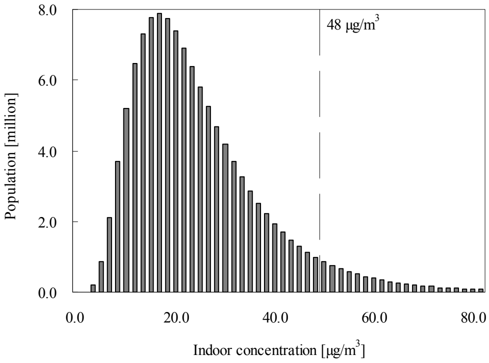

Figure 5. Converted distribution of indoor acetaldehyde concentrations. 5.9% of the population exceed the Japanese guideline value (48 μg/m^3)

between 1.02 and 1.45. The within-house AM/GM ratio was large for those substances, such as ethanol, n-undecane, n-dodecane and n-tetradecane, that had large day-to-day and between-house variabilities.

The between-house Type I, Type II and the converted distribution are shown in Table 4. The GM of Type II was lower than that of Type I and the GSD of Type II was higher than that of Type I. The GM and GSD of the converted distributions were closer to Type I (Figure 2, 3). The results indicated that the distribution of the short-term average concentration was adjusted to that of the long-term average concentration by use of this method. Differences between long-term average distribution and the converted distribution were obvious for ethanol, toluene and some long chain alkanes because the within-house variability varied greatly depending on the houses and within-house AM/GM ratios were underestimated.

Risk Analysis

The distribution of short-term mean concentrations in a previous study predicted that 0.25.%, 8.6%, 7.7% and 5.7% of the population would exceed the Japanese indoor guideline for formaldehyde, acetaldehyde, toluene and p-dichlorobenzene, respectively, while 0.035%, 5.9%, 7.9% and 5.7% of the population would exceed the Japanese indoor guideline when the converted distribution was considered. Figures 4 and 5 show the distribution of indoor acetaldehyde concentrations. The population exceeding the guideline value was overestimated by 0.3 million people (0.21%) and 3 million people (2.7%) for formaldehyde and acetaldehyde, respectively. For toluene and p-dichlorobenzene, the populations exceeding the guideline values did not differ between the two distributions. This was probably because the within-house variability was much lower than the between-house variability for toluene and p-dichlorobenzene. Even for toluene and p-dichlorobenzene, however, the population exceeding the guideline value may be underestimated because the season-to-season variabilities were disregarded in this study.

4. Conclusions

A method was developed to estimate the distribution of long-term average indoor levels of contaminants in indoor air for quantitative risk assessment using the short-term average indoor levels reported in many previous studies. To obtain the parameters for use in the method and to validate the method, within-house and between-house variability in the concentrations of 39 VOCs and 4 carbonyl compounds were measured in 3 rooms and immediately outside 26 houses for 7 days in each of the four seasons. Two types of within-house variability (day-to-day variability and between-room variability) were small for most chemicals (median of GSD: 1.2 to 1.5). The between-house variability was significantly higher than the within-house variability for all chemicals. The distribution of the short-term average concentration was confirmed to be convertible to that of long-term concentration by the developed method. In the example of risk assessment, it was shown that the previous results overestimated the number of people exposed to levels of acetaldehyde that exceeded the Japanese indoor guidelines by 3 million (2.7% of the total population). The results of this study suggest that if the distribution of the concentration was based on the short-term mean concentration the population who are exposed to high concentrations will be overestimated especially for those substances whose within-house variability is not negligible compared to between-house variability. In future, it is necessary that we determine the season-to-season variability and revise the method and parameters.

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Health Risk Assessment of Mould Exposure

G.A. Wiesmüller, W. Dott and G. Fischer

Inst. of Hyg. and Environ. Medicine, RWTH Aachen University, Pauwelsstraße 30, 52074 Aachen, Germany
Email: ga.wiesmueller@post.rwth-aachen.de http://www.hygiene.ukaachen.de

Summary: *Activities aiming at mould decontamination require a detailed risk assessment with respect to estimated time and the extent of decontamination. Therefore, based on available knowledge on the mould-related health effects "infection", "sensitization/allergy" and "intoxication" corresponding predispositions risk matrices were compiled, which must be scrutinized in experimental and epidemiological studies.*

Keywords: *mould, health, risk assessment*
Category: *Risk assessment*

1 Introduction

Only few valid data are available on health effects due to mould exposure in non-occupational indoor concentrations. Possible health effects of indoor mould exposure are mainly *sensitization/allergy*, *infection* as well as *intoxication*. Furthermore, mucous membrane irritation syndrome (MMIS) [2], odor annoyance [17, 19] and environment-related syndromes, like Sick Building Syndrome (SBS) [13], Multiple Chemical Sensitivity (MCS) [15] and Chronic Fatigue Syndrome (CFS) [5] are discussed as possible mould exposure related health disorders. As possible health effects due to indoor mould exposure can not be excluded with certainty it is principally considered that indoor mould growth can not be accepted. But resulted mould elimination needs a detailed risk assessment for estimated time and decontamination extent.

Study aim

Therefore, the aim of our study was to identify possible predispositions for the possible mould-related health effects *sensitization/allergy*, *infection*, and *intoxication* and in consequence to suggest a scheme for risk assessment.

2 Material and Methods

In the present presentation schemes for risk assessment are proposed for the three major mould-related health effects *sensitization/allergy*, *infection*, and *intoxication*. Possible predispositions are compiled and critically considered. Based on the knowledge available on these mould-related health effects and the corresponding predispositions appropriate risk matrices were compiled.

3 Proposed risk matrices for mould exposure

The three risk matrices compiled for the above mould-related health effects are discussed in detail in the following three chapters and summarized in Tables 1 to 3. The possible health risk is indicated by different shades of grey. The darker a box in the tables is the higher is the risk.

3.1 Sensitization/allergy risk of indoor mould exposure

The incidence of mould allergies in persons with airway symptoms ranges between 1% and 10% [8, 10, 12], in atopic persons up to 30% [9, 21]. About 5% of the overall population seems to be sensitized to moulds [6]. Monovalent sensitization to one mould species is rare and estimated to be below 1% [8]. For this reason, moulds do not seem to be dominant allergens.

Moulds can induce seasonal or perennial allergic rhinoconjunctivitis as well as allergic asthma bronchiale. Principally, moulds can lead to urticaria as well as be a trigger of atopic dermatitis (atopic eczema, neurodermatitis) [16]. In workplace-related concentrations moulds can induce exogenic allergic alveolitis [7]. The real allergologic relevance of moulds is still unknown because available allergologic tests cover only a small spectrum of fungal allergens [16].

Until now, no data are available on primary sensitization. Generally, it is assumed that each mould species can induce sensitization and allergization. Nevertheless, for serveral fungal species sensitization and allergic effects are still unknown.

Based on actual scientific knowledge, a numeric sensitization/allergy risk of indoor mould exposure can not be deduced. Therefore, a semi-quantitative risk assessment for the sensitization/allergy risk of indoor mould exposure is given in Table 1.

Table 1. Risk matrix for sensitization/allergy risk with respect to indoor mould exposure.

Predisposition / Species	No allergy		Allergy[3] without mould allergy	Allergy[3] to moulds	Allergie[3] to specific moulds
	without familial disposition	with familial disposition			
Fungi without known sensitizing/ allergic effects					
Fungi with sensitizing/ allergic effects e.g. *A. fumigatus, A. alternata, P. chrysogenum*		░	▒	▓	█

[3] Clinical relevance of sensitization must be verified.

Microbial preconditions: basic requirement for a sensitization and/or allergic reaction is the production of allergens which depends on both the genetic determination and environmental conditions, especially on the available substrate.

Human preconditions: familial disposition to atopic diseases, preexisting sensitization and/or existence of one or more atopic disease(s) are predisposing factors for exposed persons. The relevance of these predispositions increases in the order given above. In case of sensitization and/or atopic diseases, the predisposition is more distinct the more mould-specific the sensitization and/or atopic disease(s) are.

3.2 Infection risk of indoor mould exposure

In the majority of cases fungal infections arise in the respiratory organs. The lungs are mostly the primary location of fungal infections, only rarely the sinuses, the ears or the damaged skin are affected. Starting from the respiratory system the fungi can spread via the blood and lymphatic system and so affect other organ systems. Mycoses are rarely clinically characteristic, and present severe diseases with poor prognosis. Asperillosis and Mucormycosis are severe mycoses [14].

Based on up-to-date scientific knowledge, a numeric infection risk connected with indoor mould exposure cannot be deduced. Therefore, a semi-quantitative risk assessment of the risk for infection due to indoor mould exposure is given in Table 2.

Microbial preconditions: first of all the fungi must be able to penetrate the target organ and, secondly, be able to grow at body temperature. Furthermore, pathogenic factors such as adhesive factors (e.g. binding to fibrinogen and laminin, complement-binding factor), enzymes (e.g. proteases, katalase, phosphatase), toxins (e.g. gliotoxin) and melanin (phagocytosis protection) play an essential role for the infectious potential of fungi [1].

Human preconditions: the most important predisposing factor for fungal infections is an immunosuppression of exposed persons because mycoses caused by moulds are opportunistic infections. Intensive care patients and patients with transplantations, AIDS, cancer or mucoviscidosis bear the highest risk for mould infections.

However, mould infections could become an increased risk factor for human health because the amount of immunosuppressed persons in the overall population increases in parallel to a longer survival time of these patients.

Table 2. Risk matrix for infection risk with respect to mould exposure.

Predisposition / Species	No immuno-suppression	Slight immuno-suppression[1]	Severe immuno-suppression[2]
Non-infectious fungi e.g. *C. herbarum, C. cladosporioides*			
Opportunistic fungi e.g. *A. niger, A. clavatus, A. alternaria*		▒	▓
Infectious fungi e.g. *A. fumigatus, A. flavus*	▒	▓	█

[1] Age > 64 years, diabetes mellitus, chronic heart, lung, liver and kidney disease, alcohol-abuse, HIV-infection (depending on CD4 cell-count, CDC-stage, opportunistic infections)

[2] Organ transplantation, severe cancer, chemotherapy, radiotherapy, connectivitis, steroid-therapy (> 20 mg per day and more than 14 days), other immunosuppressants, HIV-infection (depending on CD4 cell-count, CDC-stage, opportunistic infections)

3.3 Intoxication risk of indoor mould exposure

Only little is known about airborne intoxications with mycotoxins in the indoor environment.

Based on up-to-date scientific knowledge, a numeric intoxication risk of indoor mould exposure cannot be deduced. Therefore, a semi-quantitative risk assessment of intoxication risk of indoor mould exposure is given in Table 3.

Microbial preconditions: the basic condition for an intoxication risk is that genetically determined toxin-producing fungi occur. Moreover, the environmental conditions, especially the available substrata, decide whether a toxin-producing mould species will produce the toxin or not. Whether the mycotoxin concentrations in indoor air are toxicologically relevant is still under debate [3, 4].

No information about possible predisposing factors on the humans' side concerning the risk for intoxication is available. Nevertheless, predisposing factors on the level of the target organ of the mycotoxins are possible from the scientific point of view. It is thus conceivable that a damaged liver could be a predisposing factor for organ-specific aflatoxin effects.

At the workplace, toxic alveolitis and organic dust toxic syndrome (ODTS) are well known as toxic effects caused by mould exposure [18].

Table 3. Risk matrix for intoxication risk with respect to mould exposure.

Predisposition Species	No predisposition[4]	Slight predisposition[4]	Severe predisposition[4]
Non-toxic species e.g. *Cladosporium spp.*			
Facultative toxin-producer e.g. *Aspergillus, Penicillium (<u>substrate- dependent</u>)*		░	▓
Obligate toxin-producer e.g. *Stachybotrys, Aspergillus, Penicillium, Fusarium*	░	▓	█

[4] Actually, no predisposing factors known, but organ-related predispositions are conceivable.

4 Discussion

On the basis of the up-to-date knowledge it can be summarized that especially allergic persons who live/stay in damp and mouldy rooms are at risk for allergic effects due to moulds. Furthermore, immunosuppressed persons are at risk for infectious diseases.

A distinct evaluation of health effects due to mould exposure in indoor air is yet not possible, because of a) simultaneously existing increased concentrations of moulds and other bioaerosol components and b) a lack of species-differentiated and valid exposure data.

For a valid risk assessment, the risk matrices proposed here indicate the need for further research in the field, e.g. about modulatory effects of other primary and secondary intermediate catabolic products of fungi and other microorganisms (e.g. actinomycetes, other bacteria).

Independent of the uncertainties in the evaluation, mould growth in indoor environments is a hygienic problem which can not be accepted. According to existing preventative concepts mould exposure should be minimized to a natural background level [11, 14, 20].

5 Conclusions

The suggested schemes for risk assessment must be further scrutinized in experimental and epidemiological studies.

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