Dissecting Interaction Among Indoor Environmental Quality Factors

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Dissecting Interactions among Indoor Environmental Quality Factors

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Introduction

Many aspects of indoor environmental quality (IEQ) and the technologies that control or otherwise affect it are interactive and often closely connected. Yet the technologies to control the indoor environment are usually designed, installed and operated without considering the interactions. This has important implications for the design and construction of buildings as well as for operation, maintenance, and trouble-shooting in occupied buildings. ASHRAE Guideline 10*, Interactions Affecting the Achievement of Acceptable Indoor Environments*, was published in 2011 to call attention to and provide understanding of the many interactions that designers might not have previously recognized or understood.

Indoor air quality (IAQ), thermal environment, sound, and light are widely regarded as the primary factors for defining the acceptability of an indoor environment. Many if not most of the same technologies are used to control the thermal environment and IAQ. Many of the same technologies have impacts on the acoustic environment. Together with illumination, the collection of environmental control technologies can have dramatic impacts on building energy use and occupant environmental health.

Each of the primary factors includes several separate aspects. Within the thermal comfort factor alone, there are four environmental aspects (temperature, air speed, humidity, thermal radiation) and two human factors (level of physical activity and thermal insulation of clothing) that determine human responses to thermal conditions (ASHRAE 2010d). These aspects interact to produce the overall environment and exposure that determines human experience and perception of the thermal environment and thermal comfort.

Interaction Examples

Outdoor air ventilation requirements
Ventilation requirements should strongly depend on pollution sources and on human occupancy and activity. ASHRAE Standard 62.1 and 62.2 are based primarily on perceived air quality and establish ventilation rates based on occupancy and area requirements. Buildings with few indoor pollutant sources need less outdoor air ventilation to maintain pollutant concentrations at acceptable or healthy concentration levels. Individual occupant differences such as health status (including but not limited to circulatory disorders or hormonal dysregulation) can also affect thermal comfort and lead to a host of other interactions.

Where outdoor air quality is poor, ventilation to dilute pollutants from indoor sources with outdoor air may result in less healthful or acceptable indoor air quality. The level or removal efficiency of outdoor air filtration and air cleaning to control outdoor air pollution depends on outdoor air quality, ventilation flow rates, and the requirements related to the intended uses of the indoor environment. While the size of particles in outdoor air determine the filter type (e.g., as indicated by the minimum efficiency reporting value (MERV)) required to capture them, their concentrations and air flow volumes through the filters determine the useful life and details of filter performance.

Temperature and Relative Humidity

ASHRAE Standard 62.1-2010 prescribes ventilation rates without regard to temperature or relative humidity as the latter two characteristics are defined by Standard 62.1-2010 as outside its scope. The Standard is focused primarily on ventilation system characteristics and rates of outdoor air supply.(ASHRAE 2009; 2010) But, when indoor temperatures are elevated, emissions and indoor concentrations of volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) will be greater (Tichenor 1996; ASHRAE 2009). Human responses to VOCs are also stronger at warmer temperatures (Mølhave et al, 1993; Fang et al, 1998a,1998b, 1999; ASHRAE 2011a.). The combination of higher concentrations and stronger human responses at higher temperatures suggests that more dilution ventilation or other pollutant control strategies are necessary when temperatures are at the upper end of the thermal comfort envelope defined in Standard 55. High humidity will increase airborne concentrations of formaldehyde (and other water soluble contaminants) and occupant exposure. However, depending on ambient conditions, lower energy use may be achieved by reducing indoor temperature rather than increasing ventilation, or use of other pollutant control strategies e.g,, source elimination, reduction, or isolation). On the other hand, a cold environment may result in failure of occupants to perceive odors of harmful airborne chemicals and subject the occupants to health risks. A dry environment has been associated with mucosal irritation, irritation of eyes and nasal passages. (Nagda and Hodgson, 2001) Dry air may also result in a reduction of natural defenses in the human upper respiratory tract and a higher rate of upper respiratory tract infections . (Nagda and Hodgson, 2001)

Chemical interactions

Chemical interactions, including (but not limited to) secondary emissions, may cause potential health and comfort impacts on occupants. Secondary emissions describe products formed by the reactions of chemicals with each other, in air, and on surfaces (including airborne and dust particle surfaces). Ozone is a common outdoor air pollutant, although occurring at lower indoor concentrations due to its removal by reaction with surfaces and many common chemicals found indoors. The reactions are favored in chemicals - specifically chemicals with unsaturated double carbon bonds such as terpenes and alkenes, e.g., pine oil, citrus oil, limonene. Many of these chemicals are found in “green” products such as cleaners and solvents. Outdoor air ozone is brought into buildings by mechanical or natural ventilation or by emission from corona discharge occurring during arcing in laser printers and some types of air cleaners. Ozone reaction products can result in significant deterioration in indoor air quality and adverse occupant perceptions of air quality and health outcomes (Weschler 2000, ASHRAE 2011b).

Occupant behaviors

Whether ventilation and thermal control are provided by mechanical or natural (passive) means, system installation, operation and maintenance or changes in occupancy patterns or occupant behaviors can alter the energy and indoor environmental performance of a building. The same is true of illumination, whether it is provided by electrical sources or daylight, and at what wavelength and intensity. Similarly, none of these factors alone determines the quality of the indoor environment and its impact on occupants. In the end, occupant experience, preferences, and interactions with the environment can have important influences on the environment and its impact on the occupants themselves.

As seen above, the strong interrelationships among many important aspects of the indoor environment emerge from an abundance of diverse interactions that produce IAQ and associated thermal, lighting and acoustic characteristics of the indoor environment.

Interactions modify occupant impacts

Types of interactions

Environmental factor interactions can modify the environmental health impact of any single factor or the collection and combination of factors. The various details of indoor environmental quality interact with each other in a variety of ways ranging from additive, cumulative, or synergistic to prophylactic or antagonistic.

Individual occupant variability

Individual humans vary quite widely in their responses to the environment due to physiological and psychological differences in the processing of environmental stimuli. Expectations have been shown to play an important role in perception of the indoor environment, and these are strongly dependent on context and on an individual's prior experience. Age, activity, preferences, and health status all affect the impact of the environment on individual building occupants. Sensitivity to odors varies by two to five orders of magnitude among individuals. Some people feel nausea when exposed to certain odorswhile other people may find the same odors pleasant. Some people enjoy the odors of perfume or other scented products while other individuals may actually become ill from exposure to the same scent. Thus, while an odor may be perceived and found offensive or desirable by one occupant, another might not even be aware of it.

The U.S. EPA has recently identified individual variability as a major factor in the conduct of health risk assessments. The significance of individual variability was described by Zeise et al (2013).

Moisture and its complex interactions

Moisture management in buildings is a complex and important challenge because it involves relationships between air, surface and material moisture content and air temperatures change the relationships. Moisture accumulation on surfaces or in materials can result in exposures to microbes or VOCs or both that can adversely affect IAQ and occupant health. Condensation on cool surfaces and leaks in plumbing or in the building enclosure are common sources of excess moisture. Human activities including cooking, bathing, and washing/drying of dishes or clothes are known sources of significant amounts of water indoors. Human respiration, unvented combustion appliances, indoor plants, and firewood are also important moisture sources. Obviously, in warm, humid climates, outdoor air carries a large amount of water that can condense on cold indoor surfaces. Evidence for moisture's association with health effects is more available than for an association with mold for many of the same effects such as allergy and asthma. (Mendell et al, 2011)

Implications for Building Design and Operation

An emerging concern, reminiscent of the rise in reported health symptoms indoors during the late 1970s and early 1980s, is the increasing focus on energy conservation and efficiency approaches and techniques. The negative impacts of some energy efficiency measures on thermal comfort and indoor air quality have been widely documented (Levin and Phillips, 2013). Levin and Phillips identified the linkages between energy-related building processes, energy, and IAQ and health in their report to the California Energy Commission. Table 1 lists a large number of energy efficiency measures and their related potential indoor environmental health impacts (Levin and Phillips, 2013). Energy efficiency measures can have either positive or negative impacts on IEQ.

An effort to conserve energy (improve energy efficiency) in delivering an aspect of the indoor environment carries with it the risk of adversely changing the performance of other building characteristics that were not the intended subject of that individual change. This presents challenges to designers and facility operators that cannot be met by complying separately with each of the standards for the various aspects of the indoor environment, e.g., ASHRAE Standards 55, 62.1 and 62.2. These standards are intended to describe minimum building code requirements. Guidance that goes beyond merely meeting minimum code standards is available for designers in the ASHRAE IAQ Guide (freely downloadable from the ASHRAE web site), ASHRAE Guideline 10 (interactions affecting the acceptability of indoor environments); and ASHRAE Guideline 24 (achieving good IAQ, as opposed to minimum requirements, in low-rise residential buildings).

A hot or cold air temperature or a very noisy or odorous environment can make a space unusable for its intended purpose if not completely uninhabitable. While extreme conditions don't often exist in modern indoor environments, we all have experienced restaurants that were too noisy for conversation, offices that were too cold for reasonable task performance, or rooms that were too dark for navigation. Too much bright illumination can make for glare off of the increasingly ubiquitous large LED screens on our televisions or in airport information monitors.

Methods for evaluating acceptability (e.g., ASHRAE 2010c) of indoor environments that do not consider interactive effects can produce misleading results. More effective assessments and mitigation or remediation of problems or harmful interactions can be performed when interactions are considered. If only ventilation rates or individual air pollutant concentrations are measured, a facility manager or an assessor or investigator can be misled into thinking that the environment is acceptable. But if interactions occur that reinforce the effects of one or both of them, such as high temperatures and strong VOC emissions, then the overall acceptability will be low.

Methods for integrated design processes and projects are needed to address interactive effects. A cross-disciplinary, integrated team of designers can meet to develop a project conceptual design, considering thermal control and ventilation as well as illumination and acoustics all at the stage of determining the overall configuration and layout of a building. This sort of integrated design process is thought to be far more likely to succeed in producing a building with acceptable indoor environmental quality as well as good energy performance. (ASHRAE 2009).

Occupant physiological responses to IEQ parameters can be communicated through personal computers, mobile devices, or other communication technologies. The resulting inputs or an automated analysis of them may be used to control IEQ parameters. Some modern designers have integrated occupant feedback mechanisms into the building environmental control strategy and system. Of course operable windows and adjustable thermostats or manually controlled exhaust fans are long-established examples of enabling occupants to control a building environment based on their own physiological response. After all, thermal comfort is strictly speaking the individual's perception of the effect of the thermal environment on their physiology along with their perception and expectation of the conditions.

While there is abundant scientific evidence that interactive effects can dramatically alter the overall acceptability of an indoor environment, current standards, codes, regulations, and guidelines tend to be limited in focus and to ignore potential important interactions.

Further research

More knowledge is needed to fully inform us about the many important interactions such as between humidity and micro-organisms indoors and the connections of moisture and microbes to occupant symptoms. While the vast majority of individual research projects necessarily have limited scope due to practical considerations of available resources, time, and purpose, an attempt needs to be made to maintain clarity about the interconnectedness of the various aspects of the indoor environment.

IAQ 2013

ASHRAE's 17th IAQ Conference *IAQ 2013* will be held in Vancouver, British Columbia, Canada October 15-18 and will review the state of knowledge on the balance between environmental health and energy efficiency in the pursuit of low energy buildings. Among the topics to be discussed are the IEQ Interactions associated with environmental health in low energy buildings.

The conference will cover a broad range of topics including residential and commercial buildings, new construction and retrofit, active and passive approaches, design and operation; and it is intended to help define future design, education, policy and research directions to re-emphasize the importance of environmental health in buildings. IAQ 2013 will include a track dedicated to IEQ Factor Interactions to highlight the importance of considering the interaction of IEQ factors in low energy building design and operation and to update the state of knowledge on IEQ factor interactions.

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Table 1. Building Processes Linking IEQ, Health, and Building Energy Use (source: Levin and Phillips, 2013)

Process	Link to Energy	Link to IEQ and Health
Outdoor air ventilation	Energy used to transport and thermally condition air	Serves to dilute indoor-generated pollutants, but also brings outdoor pollutants and moisture into the building Higher rates associated with improved symptoms, respiratory health, perceived air quality, and work performance In some climates (and for some systems and approaches): inadequate ventilation leads to increased humidity, condensation, mold, and possibly allergens and vermin in houses. Window opening may bring in noise and pollutants, create drafts, and create a security issue.
Heating	Energy used to heat and transport air	Affects thermal comfort Risk of combustion product entry to indoor air for some systems and installations. Affects emission rates of pollutants, especially VOCs, formaldehyde, and lighter SVOCs Affects occupant response to pollutant exposures
Mechanical cooling	Energy used to cool, dehumidify and transport air	Affects thermal comfort Risk of microbiological contamination of wetted surfaces. Risk of condensation on occupied space surfaces when warm, humid air enters cooled interior. Associated dehumidification may help reduce moisture problems and microbiological contamination Associated with increased health symptoms Can be a source of unwanted noise Can reduce pollutant emissions of VOCs Can reduce moisture content of air and condensation
Particle filtration	Energy used to overcome airflow resistance May save energy by preventing fouling and obstruction of heating and cooling coils and ductwork	Reduces indoor particle concentrations with indoor or outdoor origin Reduces soiling of surfaces Filters can be odor sources Filters, if wet, can be contaminated microbiologically
Humidification	Energy used to evaporate water	Affects comfort Potential source of microbiological and chemical pollutants in the HVAC system May lead to condensation and microbiological growth on occupied space surfaces Linked to respiratory illnesses from humidifier contaminants Possible link to person-to-person respiratory illnesses transmission
Air recirculation	Energy used to transport air	Allows filtration of recirculated air Causes dispersion of indoor pollutants Reduces concentrations of indoor pollutants near sources

Process	Link to Energy	Link to IEQ and Health
		Potential source of noise in occupied space
Building pressure control	Energy used to transport air	Sealing moisture pathways Affects pollutant and moisture transport through building envelope, ductwork, and among rooms May reduce or cause moisture problems in building envelope Affects infiltration-related drafts and comfort problems Can increase likelihood of back drafting of combustion appliances
HVAC maintenance	Improves HVAC system operation, expected to save energy	May improve ventilation, air distribution, thermal comfort, humidity control, and pressure control Lack of maintenance may lead to microbial contamination and combustion safety problems
HVAC cleaning	Cleaning of coils reduces air pressure drops and improves heat transfer, potentially reducing HVAC energy use	May reduce, or temporarily increase, pollutant emissions from HVAC systems Debris, microbiological contamination, and poor draining from cooling coil drain pans are associated with increased respiratory symptoms
Space cleaning	Minor energy use for cleaning	May reduce indoor odors and resuspended particles Cleaning compounds can be indoor pollutant sources Workstation cleanliness has been associated with reduced symptom reports and with lower dust fungal loads.
Water leaks	Degrades thermal performance of building envelopes May increase dehumidification energy	Increases indoor microbiological contamination, including fungi and bacteria Affects presence, survival and pathogenicity of viruses Linked to increase in respiratory symptoms and asthma and other allergy symptoms
Occupant behaviorl	Reducing outdoor air ventilation rates to reduce fan energy and heating or cooling energy use	Reduces potential dilution and removal of pollutants Reduces energy used at power plants, resulting in cleaner outdoor air available for ventilation
Indoor pollutant source removal or reduction	Often energy neutral; except when source or its replacement consumes energy or affects heat transfer from indoors to outdoors. May reduce HVAC and filter maintenance needs May reduce the need for additional ventilation	Reduces indoor pollutant concentrations May improve IEQ by reducing loading on air filters, air cleaners, and interior surfaces

Process	Link to Energy	Link to IEQ and Health
Envelope insulation and tightness	Reduce heat gain and loss	Reduces moisture and pollutant intrusion Changes dew point location; could be beneficial or harmful Reduces infiltration that provides air change where proper means are not in use Reduces garage pollutant intrusion
Crawl space or slab sealing	Reduces heat gain and loss Vapor intrusion	Reduces moisture intrusion Changes dew point location Reduces infiltration that provides air change where proper means are not in use Reduces intrusion of vapor and pollutants
Windows and skylights: ventilation, lighting	Reduces unwanted heat loss, heat gain, and air leakage Reduces need for electric illumination Can be source of unwanted air and water leakage Can be a source of desirable ventilation Back up or replace ventilation for mechanical systems	Dilutes indoor-generated pollutants Associated with improved symptoms, respiratory illness, perceived air quality, and work performance Brings outdoor pollutants and moisture into building In some climates and for some systems: inadequate ventilation leads to increased humidity, condensation, mold, and possibly allergens and vermin Can provide natural lighting and beneficial views to outdoor Can be source of noise intrusion
Gaseous air cleaning	Energy used to overcome airflow resistance Reduced energy when indoor air is recirculated	Reduces indoor gas concentrations with indoor or outdoor origin Reduces SVOCs Filters can be odor sources Filters, if wet, can be contaminated microbiologically Chemical reactions on filters can be sources of cleaner or fouler air

POSSIBLE SIDE BAR ON IAQ 2013

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Besides addressing thermal comfort and other IEQ issues, buildings and other enclosed spaces are increasingly challenged to provide a healthy environment in an energy efficient manner. The complex relationship between indoor and outdoor environmental conditions, coupled with the impacts of climate change, requires a paradigm shift towards creating buildings that are comfortable and healthy for the occupants yet also energy efficient.

Although the goal of improved IAQ and thermal comfort can be achieved by increasing energy consumption, it can also be achieved without significant increase or even with decreased energy consumption. However, there is insufficient information on how to improve energy efficiency in buildings while still ensuring healthy, comfortable and safe indoor environments.

The conference program will include:

- Internationally acclaimed keynote speakers
- Original peer reviewed Conference papers and Extended Abstracts
- Workshops and panels addressing indoor environmental quality in low-energy buildings

Plenary Lectures will be given by four distinguished international authorities:

- William Bahnfleth, Ph.D., P.E., Fel low ASHRAE, ASME Fellow, Pennsylvania State University, 2013–14 ASHRAE president, "Are We Putting Enough Energy into Making Buildings Healthy?"
- Richard Corsi, Ph.D., P.E. University of Texas, Austin, Indoor Air 2011 president, "Building Energy and Reactivity."
- Mark J. Mendell, Ph.D., Lawrence Berkeley National Laboratory and California Department of Public Health, "Do We Know Much about Low Energy Buildings and Health?"
- Pawel Wargocki, Ph.D., Danish Technical University, ISIAQ president, "What Can Europe Teach Us?"

For more information, go to ASHRAE IAQ 2013