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The Ambitious European Audit Project: What Does It Tell Us?

The European Audit Project was one of the most ambitious and expensive indoor environment research projects ever completed. Researchers from 16 European institutions in 11 countries participated, and no less than six buildings were studied extensively in each of 9 participating countries. In all, 56 buildings were studied with each country team reporting their results separately. Philomena Bluyssen and several other authors summarized and edited the results in a final report.

The project was funded in part by The Commission of the European Communities' Joule II Programme under the sub-programme "Energy Conservation and Utilization." It was coordinated by Bluyssen and Prof. E. de Oliveira Fernandes of Portugal. It took place over a two-year period during which a manual of procedures was developed and pilot tested and six buildings were selected in each country (except Switzerland, where eight were studied). The project was interesting politically because of the cooperation of researchers from so many countries. The researchers agreed to go forward with a uniform study design and to collaborate on developing a database using standardized measurement methods.

The final report was completed in March of 1995, but several papers have been presented at various conferences giving details of various aspects of the project. Lisbet Groes' Ph.D. dissertation in statistics, the most interesting, complete analysis of the data, was presented in December of 1995 and was the subject of a paper at Indoor Air '96.

Aims of the Study

Project organizers asked investigators in each country to follow a standardized protocol in order to generate comparable results for each country. The main aims of the research were as follows:

- To contribute "...to the European IAQ database of existing European office buildings with respect to symptoms/complaints of occupants, perceived indoor air quality evaluations of a trained panel, pollution sources, ventilation, and energy consumption."
- To develop "...assessment procedures and guidance on ventilation and source control to optimize indoor air quality and energy use in buildings."
- To develop "...a common agreed Europe-wide method to investigate indoor air quality in office buildings."
- To compare "...IAQ-related parameters across several European countries..."

The Study Buildings

The study buildings were of various ages but none were new or newly-renovated. Buildings were served by a variety of ventilation types. Most of the buildings were ventilated with mechanical systems including dual-duct balanced (20%), induction (18%), "simple balanced" (30%), balanced VAV (9%), and various other systems. Over 60% of the buildings had no air

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recirculation. Only 18% were designed for less than 1 air change per hour (ach) and 31% were designed for 3 ach or more. Only 12% were naturally ventilated although 54% had operable windows.

The buildings included smoking permitted (59%), smoking restricted (23%), and smoking not permitted (18%). Building sizes ranged from floor areas of less than 2,500 m^2 (16%), 2,500 to 7,500 m^2 (30%), 7,500 to 15,000 m^2 (29%), and greater than 15,000 m^2 (25%). Occupancy varied from less than 200 to over 1000 office workers. Locations included countryside (14%), suburbs (25%), downtown (54%), and industrial areas (7%).

Building types varied in each country but apparently no strict mix formula was applied for building selection. As a result, the mix of buildings was not uniform in each country nor among countries. This lack of strict selection criteria for the study of a randomly selected sample of buildings raises questions about the overall value of the study results. It certainly makes it harder to interpret the data or draw any conclusions from it. It is difficult to know whether or not to aggregate data from various countries or even from all the buildings within each country. We learned from investigators in three participating countries that the ease of access to buildings was, in fact, the main selection criterion.

Measurement Procedures

Researchers were to make measurements on a single day in five locations in each study building during "normal" occupancy, ventilation, and use. At least 100 occupants per building received questionnaires. Occupants reported their immediate and past-month experiences of symptoms and perceptions. The response rate for the questionnaires varied from 54% to 97% with a mean of 79% for the 56 buildings.

Researchers used the standard protocol to identify and quantify pollution sources in the spaces, the pollution load caused by the occupants, and the pollution load caused by the ventilation systems. Researchers also measured the delivery of outdoor air to the spaces and documented annual energy consumption and weather. In addition to evaluating air quality by instrumented measurements of physical and chemical parameters, trained sensory panels judged the "perceived air quality" of the spaces upon first entering them.

Results and Discussion

The most common building-related symptoms for all the buildings included dry skin (32%), stuffy nose and lethargy (31%), irritated throat (29%), dry eyes (26%), and headache (19%). According to the report, the air was found to be dry in all the buildings with a mean dryness rating of 2.7 on a scale from 1 (dry) to 7 (humid). This is not a surprising finding considering the studies were done in the winter. The report also states that no correlation was found between occupant rating of IAQ and their perception of the thermal environment.

As shown in Figure 1, average reported outdoor airflow supply rates varied significantly from country to country. We suggest that this could indicate either a country-by-country bias in measurement or significant differences in the buildings. The presumed variation between measured and actual ventilation rates (up to a factor of two above and below actual values) interfered with one of the goals of the project, characterizing source strengths. Source strengths are calculated by dividing concentrations by ventilation rate. Without accurate ventilation rate data, the results are not reliable.

Occupants did not perceive the air as smelly, again using a 7-point scale (with 7 being smelly). The mean rating was 2.7. In spite of the rather high reported ventilation rates, the report states that more than half of the buildings were perceived as stuffy. However, the report also states that the ventilation rate measurements may have differed from actual ventilation rates by a factor of two in either direction. This may have been due to a variety of measurement and calculation problems and deviations from standardized protocols.

No correlation was found between the sensory panel evaluations and the Building Symptom Index (BSI). This could be expected since sensory panels judge the air upon first entering a space and do not remain within it for more than a minute or two. Occupants, on the other hand, usually spend a full work day in the space, day after day, year after year.

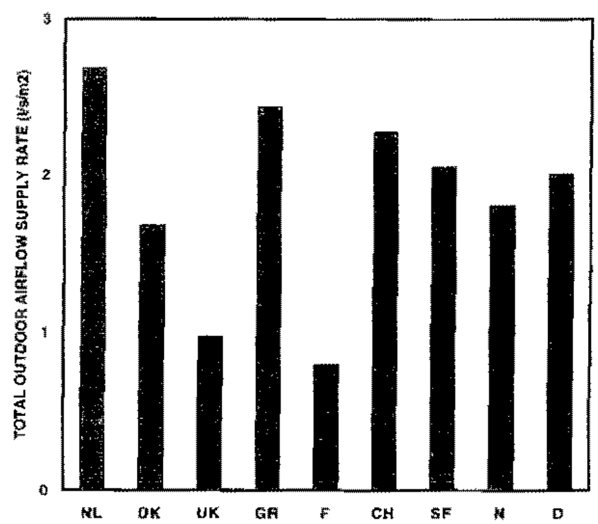

Figure 1 - Mean total outdoor airflow supply rate (L/s/m^2) from 56 European buildings (NL=Netherlands, DK=Denmark, UK=United Kingdom, GR=Greece, F=France, CH=Switzerland, SF=Finland, N=Norway, and D=Germany).

Researchers also found no correlation between energy consumption and outdoor airflow rate. This, the report states, "...indicates that, in general, energy is used for other purposes than ventilation." Presumably these purposes include lights, office equipment, space heating and cooling, and water heating, among others.

A most interesting finding in the Swiss national report was that the BSI was inversely proportional to the degree to which the building actually delivered the designed ventilation rate (Roulet *et al.*, 1994). We speculate that this indicates good communication and execution of design intent from design all the way through construction to occupancy and operation. It may also suggest strong agreement between the relevant parties: designers, constructors, owners, and operators. This finding and our proposed explanation for it provide a logically-consistent basis for creating healthy buildings. This hypothesis should be evaluated by examining the relationships in other data sets.

VOC results were discussed in the ***BULLETIN*** in Vol. 3, No. 5 and again in Vol. 3, No. 7. Here, too, differences in measurement practices may create some difficulties in interpreting the data, according to some ***BULLETIN*** European sources. In general, reported VOC concentrations were nearly all below 1 mg/m^3 and most were below 0.5 mg/m^3 as shown in Figure 2. Note that variations within buildings were significant but could not be related to individual questionnaire responses because the occupants' locations were not identified in the questionnaires. This, in our opinion, decreased considerably the potential power of the study since building average environmental values were used in spite of the variations in environmental measurements in the five locations characterized in each building.

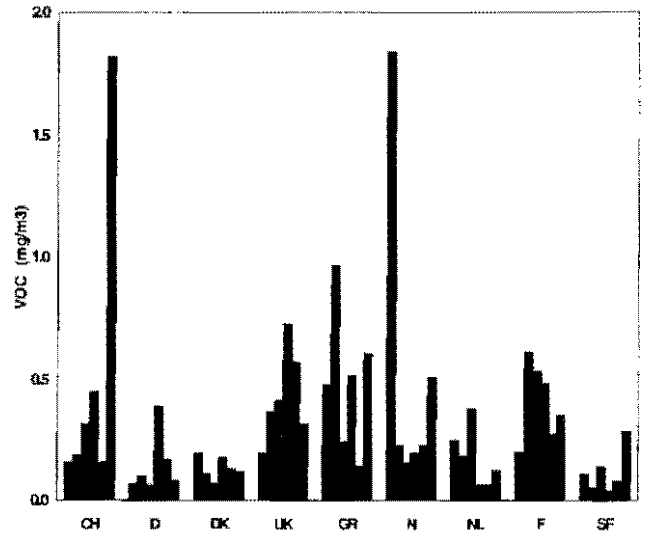

Figure 2 - Average TVOC Concentrations from 56 Buildings in 9 Countries from European Audit Project (Bluyssen *et al.*, 1995).

Lisbet Groes' Analysis of the European Audit Project Data

Lisbet Groes completed and defended her doctoral thesis in statistics by analyzing the results of the European Audit Project. Her analysis, submitted to the Technical University of Denmark in November 1995 and defended in December of that year, is the most useful digest of that enormously important study to date. The major qualitative results of her analysis probably best summarize the overall findings of the study. They were subsequently presented in a paper at Indoor Air '96 co-authored by Jan Pejtersen and Ole Valbjørn, also from Denmark.

Groes performed multiple statistical analyses as logistic regressions based on a model for the causal hierarchy of perceptions and symptoms. Groes incorporated only factors with significance at the $p<0.05$ level into the final model. We show this model in Figure 3.

She conducted the analysis in two steps. First, she delineated perceptions of the indoor environment (acceptability of the IAQ) by building factors, personal factors, and the measured indoor environmental factors. Then, she delineated symptoms by occupants' perceptions of the indoor environment. The model contained 15 building factors, 11 personal factors, 8 indoor environmental factors, 12 perceptions of the indoor environment, and 8 symptom responses. The results are shown in Tables 1 and 2 respectively. These are taken directly from Groes' doctoral thesis.

According to the authors, the results showed significant associations between symptom occurrence and occupants' perceptions of the indoor environment, personal factors, building factors, and measured environmental factors. The analysis revealed that only a limited number of environmental factors were significantly associated with occupant responses. The authors point out that the European Audit Project was not designed to show the effect of environmental factors on symptom prevalence and that within-building variation for some environmental factors was greater than between-building variation. However, the study used a mean building value to describe building environmental levels as discussed earlier in this article.

Among the significant measured environmental factors were noise, relative humidity, and TVOC. The background noise level was attributed to outdoor sources and office-to-office transmission through building construction, which was presumed to be reasonably uniform throughout a building. Relative humidity was

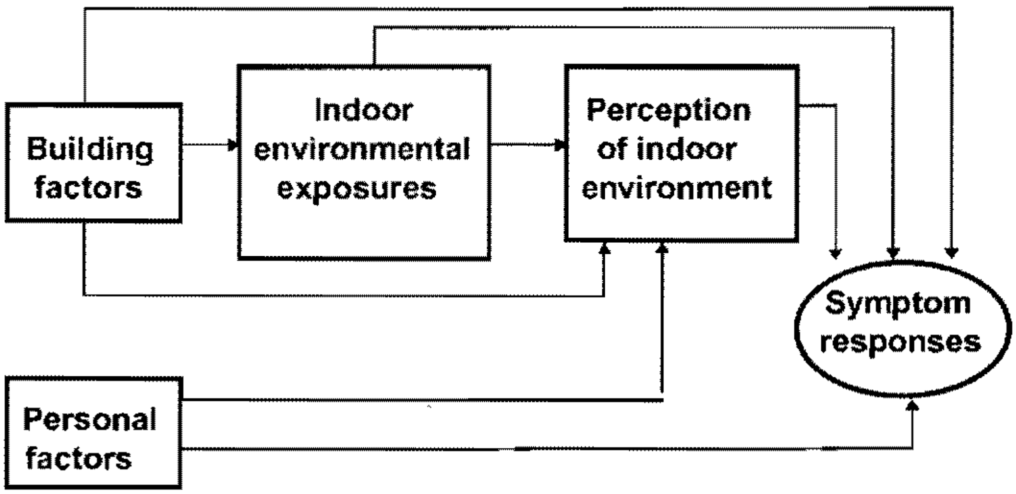

Figure 3 - Groes' model for the causal hierarchy of perceptions and symptoms.

also presumed to be uniform unless spaces were separately humidified. Low TVOC was associated with higher symptom prevalence. The work of Weschler *et al.* was cited regarding the interaction of ozone with VOCs. The authors speculated that the source of the ozone was outdoor traffic but acknowledged that no correlation was found between heavy traffic and low TVOC levels.

Low TVOC Associated with Symptoms

The indoor sources of ozone, such as photocopiers and laser printers typically abundant in offices, could have provided the necessary ozone for the reactions with VOCs. Ozone reactions with indoor VOCs produce hydroxyl radicals resulting in the more rapid transformation of many VOCs into ketones, aldehydes, and organic acids. If that occurred, it is quite likely that these reac-

Table 1 - Factors significant for the perception of the indoor environment.

Group	*Variable*	*Description*
Building factors	Traffic	Occupants in buildings situated in areas with heavy traffic perceived the indoor environment as poorer.
	Size of building	Occupants in buildings with few employees perceived the air quality as poorer.
	Density	Occupants in buildings with less area per person perceived the air quality as poor.
	Ventilation system	The best air quality was perceived by occupants in mechanically ventilated buildings with no recirculation. The occupants in naturally ventilated buildings found that they had more control than those in mechanically ventilated buildings.
	Outdoor air supply	In buildings with less outdoor air supply, the air quality was perceived as worse.
Personal factors	Country	Nationality was a confounding factor for the perception of the indoor environment.
	Sex	Female occupants reported more adverse perceptions compared to male occupants.
	Job	Occupants performing secretarial work reported more adverse perceptions compared to management.
	VDU-work	Occupants working many hours at a video display unit reported more stuffiness and noise compared to others.
	Occupants in room	Occupants in rooms with many employees reported more adverse perceptions than others.
	Tobacco smoke	Occupants in environments with smoke reported more stuffy and odorous indoor air.
Exposures	Noise	Occupants in buildings with a high noise level reported more adverse perceptions than other.

Table 2 - Factors significant for work-related symptoms at the time of the audit.

Group	*Variable*	*Description*
Building factors	Traffic	The highest prevalence of symptoms was found in buildings in areas with heavy traffic.
	Ventilation system	The highest prevalence of symptoms was found in buildings with a humidifying or cooling system.
	Outdoor air supply	The highest prevalence of symptoms was found in buildings with less outdoor air supply
Personal factors	Country	Nationality was a confounding factor for the prevalence of symptoms.
	Sex	Female occupants had a higher prevalence of symptoms compared to male occupants.
	Job	Occupants performing secretarial work had a higher prevalence of symptoms compared to others.
	VDU work	Occupants working many hours at a video display terminal a higher prevalence of headache compared to others.
	Eczema	Occupants with eczema naturally reported more skin symptoms but also more mucosal irritation compared to others.
	Hay fever	Occupants with hay fever had a higher prevalence of mucosal irritation than others.
Exposures	TVOC concentrations	Occupants in buildings with a low level of TVOC had a higher prevalence of mucosal irritation than others.
	Noise	Occupants in buildings with a high noise level reported more adverse perceptions than others.
	Relative humidity	Occupants in buildings with a low relative humidity had a higher prevalence of skin symptoms than others but not a higher prevalence of mucosal irritation.

tions reduced measured TVOC concentrations while increasing the concentrations of formaldehyde and other aldehydes and ketones: compounds that could increase symptom prevalence. These compounds may be important as irritants, especially the higher molecular weight aldehydes and ketones. The aldehydes and ketones were not included in the TVOC values nor were they measured separately. We do not know why not. Surely the evidence for health effects from formaldehyde exposure is strong enough to have warranted investigation, although formaldehyde source strengths and, therefore, concentrations, are much lower than they were ten years ago. Nevertheless, it is plausible that aldehydes are present at concentrations that can cause irritation and health effects. Furthermore, NO_2 concentrations might also have played a role in converting VOCs to aldehydes as shown by Zhang and Lioy (1992).

Low Dust Levels

The authors believed that the measured dust levels were rather low (<0.1 mg/m^3) in nearly all buildings. This made it impossible to determine the effect of dust. CO_2 concentrations were generally below 1000 ppm which indicated generally sufficient ventilation rates to control human bioeffluents. The authors commented that the shelf and fleece factor differences between buildings could not explain variations in symptom prevalence as it had in the Danish Town Hall Study. However, they said, since these are indicators for possible dust reservoirs and absorbed gases, high ventilation rates may minimize the importance of their effects.

The Role of Psychosocial Factors

The association between the occurrence of symptoms and of adverse perceptions with personal factors may be due to psychosocial rather than personal factors, according to the authors. Psychosocial conditions, such as work stress, job security, employee relations with supervisors, job satisfaction, etc. were not characterized in the study. Therefore, they said, the influence of psychosocial factors is included in the personal factors.

We note that in some buildings, psychosocial factors can drive occupant perceptions significantly and strongly affect responses to questionnaires such as those used to obtain the BSI in the European Audit Project. However, studying psychosocial factors is not only difficult when permitted, it is rare that employers are willing to allow researchers to do it. No large-scale study that we know of has done it; it may, however, be far more important than has been acknowledged to date. Michael Hodgson recently reported that work stress was a better predictor of occupant thermal comfort than any of the environmental or personal factors accounted for in the Gagge or Fanger models used for ISO and ASHRAE thermal comfort standards.

Finally, the authors indicated that nationality was a significant factor in the occurrence of symptoms and adverse perceptions. This effect, they believe, "...may be interpreted as an effect of the work environment as well as a difference in style of building." This also begins to suggest the importance of psychosocial factors such as employer-employee relationships, attitudes toward work and supervisors, control of personal space, and worker status which we believe varies among nations participating in the study.

Panel Sensory Evaluations

Dr. Groes divided her thesis into two halves: Part I was "Sensory panel trained to assess perceived air quality;" Part II was "Occupant responses and indoor environment exposures." As stated previously, correlations were not found (and, defenders of the study say, not expected) between the trained panel assessments of IAQ and most occupant responses. Groes, however, made a telling remark at the conclusion of her thesis defense when she said that the original work upon which the decipol method was based should be redone.

Professor Fanger, who sponsored Groes' thesis, has defended the original work and explicitly stated that it does not need to be redone. Meanwhile, the word "decipol" was virtually missing from the oral presentation of his Plenary Lecture in Nagoya. He did, however, explicitly defend the use of the trained panels for determining "percent dissatisfied" among visitors by showing the strong correlation between the results of work in Japan, North America, and Europe. This work is limited to the acceptability only of bioeffluents and only to unadapted persons based on variations in ventilation rates. It cannot be expected to predict the acceptability (or dissatisfaction, if that is the inverse of acceptability) of a mix of sources nor can it predict the acceptability of indoor air to adapted persons in real spaces where normal indoor pollution sources are present.

Chemical measurement and human sensory responses to indoor pollution are different and apparently not colinear. The nature of the relationship is the subject of ongoing research, especially that of Fanger as well as that of Bill Cain and Enrique Cometto-Muñiz. In Denmark, the Netherlands, and elsewhere, more research is being done to better understand the human response to different types of pollution sources and the way in which multiple sources, temperature, and humidity might affect the human response. Until such work is more complete, the disagreements are likely to continue.

Conclusion

The European Audit Project was more important for what it accomplished in the cooperation achieved among various nations than for the study results themselves. However, many Europeans have expressed concern about the very large expenditure of human and financial resources to conduct the study for the limited knowledge gained from it. While Groes' analysis points to many potentially useful ways to reduce the incidence of SBS symptoms (see the following article on the lessons learned from the European Audit Project), we believe there is far more to learn from an open discussion of the study's shortcomings than has occurred to date due to the reluctance of many parties to engage in such a discussion. National pride and diplomacy limit the amount of such discussion that does occur.

More consistent measurements would likely have created a less ambiguous, more useful data set. A representative or systematic selection of the study buildings might also have produced a more useful data set freer from potentially systematic biases. Finally, and perhaps more importantly (even in spite of the study's other limitations), far more statistically reliable associations would likely have been found between symptoms and environmental parameters if the characteristics of the occupants' location within the building rather than average values for the building had been compared to the occupants' symptom responses.

Editor's Note

We had the privilege of attending the defense of Groes' thesis which, like the thesis itself, was in English. David Wyon pointed out at the thesis defense that Dr. Groes had not only written but was also defending her thesis in English, and that few British or American thesis candidates could prepare and defend a thesis in a foreign language. Her performance that day was impressive to say the least. It is a real loss to the indoor environment research community that she has left the field and taken a job directing research at a pharmaceutical company. We thank her for her contribution and wish her success in her new endeavors.

References

Groes, L., Pejtersen, J., and Valbjørn, O., Perceptions and Symptoms as a Function of Indoor Environmental Factors, Personal Factors, and Building Characteristics in Office Buildings. In *Proceedings of Indoor Air '96*, Vol. 4, pp. 237-242.

Groes, L., 1995. "The European Audit Project: A Statistical Analysis of Indoor Environmental Factors." Ph.D. Thesis, Laboratory of Heating, and Air Conditioning, Technical University of Denmark, Nov.

Bluyssen, P., De Oliveira Fernandes, E., Fanger, P. O., Groes, L., Clausen, G., Bernhard, C. A., and Valbjørn, O., 1995. European Audit Project to Optimize Indoor Air Quality and Energy Consumption in Office Buildings, Final Report, March 1995. Copies are available from TNO-Building Construction Research, Department of Indoor Environment, Building Physics and Systems, P. O. Box 29, 2600 AA Delft, The Netherlands.

Roulet, C. A., Foradini, F., Bernhard, C. A., and Carlucci, L., 1994. "European Audit Project to Optimize Indoor Air Quality and Energy Comsumption in Office Buildings, National Report of Switzerland." Laboratoire d'Energie Solaire e de Physique du Bâtiment, Lausanne.

Weschler, C. J., Hodgson, A.T., Wooley, J. D., 1992. "Indoor chemistry: ozone, volatile organic compounds, and carpets," *Environmental Science and Technology*, Vol. 26, pp. 2371-2377.

Zhang, J., and Lioy, P. J., 1994. Ozone in Residential Air Concentrations, I/O Ratios, Indoor Chemistry, and Exposure. *Indoor Air*, Vol. 4, No. 2., pp. 95-105.

Guidance Based on Lessons from the European Audit Project

Even though the results of the European Audit Project raise many questions regarding their interpretation, we believe that many of its results and findings suggest important actions that can and, perhaps, should be taken to avoid or reduce the occurrence of SBS symptoms. Further, because we believe that SBS symptom prevalence rates in buildings may be indicators of the potential for building-related illness, such preventive or corrective actions might be even more valuable in reducing the more serious building-associated diseases.

More definitive evidence of causal relationships is desirable; however, we believe that where statistically strong associations are found and a plausible mechanism is identified, action to control the potential causal factor is warranted.

In this commentary, we interpret three major building factors in terms of the actions that might be warranted in design, operation, or investigation of buildings to reduce SBS symptom prevalence rates.

VOCs and Occupant Health and Comfort

Given the already well-established albeit not-yet-widely accepted understanding of the transformation of some VOCs into potentially irritating aldehydes, ketones, and organic acids, there is no reason to conclude that VOCs are unrelated to SBS symptoms, particularly to eye, skin, and mucous membrane irritation. On the contrary, it is important that at least the aldehydes be measured in any study seeking to find relationships between environmental contaminants and occupant symptoms, particularly where known sources of ozone or hydroxyl radicals exist. Examples of common indoor sources of ozone include not only outdoor air but also electrostatic air cleaners, photocopiers, and laser printers. When ozone interacts with the styrene in the neoprene facing of some air duct liners, not only are compounds of concern formed but the liner facing itself deteriorates and becomes a source of particles that can soil the building surfaces and affect the lungs, eyes, and skin of occupants.

Effective actions to control VOC-related problems:

1. Measure ketones and aldehydes in indoor air investigations and studies.
2. Identify sources of VOCs and reduce or eliminate them. A great deal of literature exists on the control of VOC sources by means including careful selection of building materials, maintenance, and consumer products. Direct exhaust ventilation can be used for point sources of VOCs and general ventilation to dilute and remove VOCs from general sources.
3. Identify sources of ozone and reduce or eliminate ozone formation by design and maintenance of filtration devices.
4. Review occupant complaints for patterns of irritation related to activities presumed linked to VOCs.

Buildings with High Traffic Volumes Nearby

The plausible hypotheses for causal relationships between nearby traffic volumes and occupant symptoms may relate to gaseous or particulate emissions from motor vehicle combustion processes and to creation or re-suspension of particles from friction between vehicle tires and roadway surfaces. Of particular concern are diesel vehicles whose particulate emissions are generally considerably higher than those of gasoline-powered vehicles. Gaseous emissions could include CO_2 and VOCs, and among the VOCs could be aldehydes.

Effective actions to determine the role of vehicle traffic on indoor air quality:

1. Assess the potential entry into a building of vehicle exhaust products and road dust in terms of the following factors: traffic volume, proximity of roadways to building, local wind patterns, air supply intake locations, filter specification, installation, and condition.
2. Look for evidence or indicators of particle contamination: soiling of building air filters or duct and interior surfaces, occupant responses such as skin and eye irritation, and occupant responses such as upper respiratory tract symptoms and complaints.
3. Look for indicators of motor vehicle combustion-associated gases such as irritation of the eyes, skin, or upper-respiratory tract.

Effective actions to protect building occupants from vehicle traffic source pollutants:

1. Locate buildings and building openings as far from roadways as possible.
2. Locate ventilation system inlets for outdoor air as far from roadways as possible.
3. Select filtration and air cleaning appropriate for the contaminant loading and the use of the building.
4. Ensure that filter and air cleaner installations do not permit short-circuiting or bypassing of the air supply stream. Examine the tightness of the filtration units in their frames or racks, the ease of servicing the equipment, etc.
5. Electrostatic precipitator particle collection plates must be cleaned periodically in order to perform properly. They should be easy to remove and replace without damage to the units.

Buildings with Low Outdoor Air Supply

The conclusion that BSI was higher in buildings with less outdoor air supply is consistent with the findings of many other researchers and is also logically quite plausible. Clearly, for a given indoor pollutant source strength, the higher the ventilation rate, the lower the concentration and, for the most part, the resulting occupant exposure.

Effective actions to ensure adequate outdoor air supply:

1. Most mechanically ventilated and cooled buildings in temperate climates can be operated to take advantage of "free" cooling by use of outdoor air when its temperature is lower than the indoor air temperature. The so-called economizer cycle ventilation system designs use outdoor air when such conditions exist. In temperate climates of North America and Europe, this condition occurs during a significant fraction of the year. Thus, increasing the outdoor air fraction can be an important and cost-effective way to reduce occupant exposures at a reasonable cost.
2. Where natural ventilation is used, either alone or in concert with other ventilation strategies, the design should be based on careful analysis of the actual air exchange that will take place. It is not uncommon to find surprisingly low outdoor air supply rates and high contaminant levels in buildings served only by mechanical ventilation. Analytical tools exist to aid designers in creating effective natural ventilation flows. Building operators and users should be well-informed on the outdoor air flow impact of opening windows, doors, skylights, and vents. These are not always obvious, and it is the responsibility of the designers and building managers to educate the users to take advantage of the design features.
3. Changes in building operation and use are typical in many building types. Therefore, it is important periodically to evaluate outdoor air supply rates and the distribution of ventilation air. Particularly in mechanically ventilated buildings, where significant changes in occupancy or interior layout are made, it is essential to determine the adequacy of outdoor air supply for the revised occupancy or layout. A common occurrence is increased occupant density or activity changes that increase pollutant generation without appropriate changes in ventilation system equipment and operation.

Buildings with Low Relative Humidity

Determine the effect of humidity on occupants. Skin symptoms are an indicator of potential low relative humidity, although they may also be caused by numerous other environmental factors. Humidification systems are often sources of IAQ problems, so they should be installed only with careful consideration and an adequate maintenance plan.

<u>Volatile Organic Compounds</u>

VOC and Health Effects

No IAQ subject is more important and less understood than the effect of indoor air contaminants on occupant health and comfort. We have learned a great deal about how to control IAQ and prevent health problems from occurring. However, we still understand poorly the relationships between contaminants and their presumed effects on building occupants: discomfort, irritation, illness, and reduced productivity.

Indoor air contaminants that plausibly might cause health and comfort complaints include microorganisms, VOCs, inorganic chemicals, particles, and fibers. Of these, VOCs are certainly logical culprits. At high concentrations, many are known to be irritating, toxic, or even carcinogenic. The concentrations of individual VOCs found in indoor air are usually at least two or three orders of magnitude lower than the concentrations known to cause irritation and other health problems. However, there are often literally hundreds of individual VOCs in indoor air whose combined effects are practically unknown.

In this article, we discuss what we know about health effects and VOCs in indoor air and why we don't know more. The article presents an overview. A more complete review of health effects is available in Hodgson *et al.* (1994). We conclude that not knowing precise causal relationships does not prevent effective action to protect people from VOC exposures likely to cause or contribute to adverse health effects.

VOC Exposure Symptoms

Typical indoor air concentrations of most VOCs have not generally been believed to be high enough to cause readily observable human health effects (Nielsen *et al.*, 1996a,b) although two studies have shown a significant risk of cancer based on a "no-threshold assumption" and simple additivity of cancer risks from exposure to common indoor air VOCs (Tancrede, 1986, 1987; McCann *et al.*, 1987, 1988).

The uncertainty regarding health effects of most VOCs does not apply to formaldehyde. A great deal of information exists regarding typical indoor air concentrations (Girman, 1989; M. Hodgson *et al.*, 1994), and the health effects associated with exposure are reasonably well understood. Formaldehyde is a mucous membrane irritant, a sensitizer, and a potential carcinogen (CARB, 1991; NAS, 1981; Liu *et al.*, 1991).

VOCs that we know can cause health effects at typical indoor air concentrations are solvents in buildings where construction or renovation activities are occurring or have been recently completed; chemicals emitted by cleaning and maintenance procedures; and, formaldehyde in buildings with large amounts of composite wood products using formaldehyde-based adhesives. Exposure to many solvents and other VOCs commonly found indoors at higher than typical indoor air concentrations is known to cause central nervous system effects (Cain, 1996).

As long ago as 1982, Lars Mølhave of Denmark published a review of 52 compounds commonly found in indoor air and emitted from building materials. He reported that 84% were known or suspected mucous membrane irritants (Mølhave, 1982). So, even if individual VOCs are present at lower concentrations than might cause irritation, it seems logical that together they might be causing some of the SBS symptoms related to eye, skin, and mucous membrane irritation.

Chamber Studies

VOC chamber studies provide conflicting results. Mølhave (1986) described increases in symptoms and decreases in measures of attention and performance at 5 and 25 mg/m^3 of a mixture of 22 VOCs. Kjaergard (1991) repeated the study and demonstrated similar effects to those described by Mølhave. It should be noted that at least one of the compounds in the mixture was a strong irritant and odorant that may have biased the results. Later work by Mølhave (1993) suggests that VOC irritation is associated with a decrease in nasal cross-sectional areas at increasing exposure levels.

Mølhave further investigated the responses of human subjects exposed to controlled concentrations of the 22-VOCs mixture in his laboratory (Mølhave, 1991;1992). The results of these studies showed effects at concentrations of 25 mg/m^{-3} . On the basis of his study results and a review of field studies, Mølhave suggested that at TVOC concentrations from 3 mg/m^{-3} to 25 mg/m^{-3}, those exposed may begin to experience adverse effects in the "multi-factorial" indoor environment (1990). However, those TVOC concentrations are far above typical indoor air TVOC concentrations in occupied buildings. Because Mølhave's chamber studies focused on a particular combination of chemicals, it is not known how applicable the results are to other mixtures or even to different ratios of the same chemicals that he studied (Mølhave, 1992).

Nevertheless, Mølhave's work suggests that the potential for effects does exist for VOCs found in indoor air at plausible indoor concentrations. Mølhave's (1990) classification of exposure to TVOCs in indoor air has been the basis for other authors and is often cited as an authoritative guideline although strong evidence to support its application to an undefined mixture of VOCs is still lacking. Seifert (1990) and Tucker (1990) also presented values that have been used as guidelines for VOC concentrations in indoor air.

Otto (1990) exposed 66 healthy male subjects to Mølhave's 22-compound mixture and reported increased headache and general discomfort but no effects on performance in behavioral tests. Later (1992), Otto documented symptom increases but no changes in performance. Furthermore, Otto reported differences between subjects who had previously reported SBS symptoms and those who had not. Also, all of Otto's subjects were males. Mølhave's studies included females and all of his subjects reported difficulty with indoor air but had no pre-existing medical conditions.

Mølhave delivered Plenary Lectures at Indoor Air '90 in Toronto, Canada, and Indoor Air '96 in Nagoya, Japan. In Toronto, Mølhave provided some "tentative dose-response relations" for TVOC in the section of his paper titled "Tentative guidelines for VOCs in non-industrial environments (toxic)." In Nagoya, he seemed to be qualifying the sense conveyed by these "guidelines" as limited by the measurement method employed and the particular individual VOCs present in any indoor air mixture. The problem is that TVOC is not well defined, and without a definition including the method of measurement, the concept lacks clear meaning. See Vol. 3, No. 8 of the ***BULLETIN*** for an extensive discussion of Mølhave's work, the TVOC concept, and the issues surrounding it.

Field Studies

Results from a review of the major epidemiological studies show that in three of six studies, an association was found between VOC exposure and SBS (Mendell, 1993). Note that most field studies (including at least some of those reviewed by Mendell) have not measured VOCs in the same temporal context and microenvironment as that occupied by the study subjects.

More recent field studies conducted in Sweden and in nine European countries respectively did not find positive correlations between measured indoor air TVOC concentrations and SBS symptom prevalence (Sundell, 1994; Groes, 1995). In fact, they found negative correlations. These negative correlations are counter-intuitive, but they may be explained by the interaction of unsaturated VOCs with ozone, thus reducing the VOC air concentration measured on Tenax™ and forming formaldehyde and other aldehydes (Weschler *et al.*, 1992; Zhang and Lioy, 1994; Weschler and Shields, 1996). Unsaturated VOCs are those having carbon-carbon bonds; they react with ozone significantly faster than saturated VOCs.

Nunes (1993) showed small decreases in verbal learning in subjects with headaches compared to subjects without headaches in four office buildings with VOCs levels commonly encountered in offices. One interpretation of these data is that only subjects who perceive themselves to be susceptible or who have underlying symptoms, like headaches, show decrements in performance on standardized tests. On the other hand, symptoms alone increased as exposure levels increased.

Formaldehyde Effects Are Known

Pressed-wood product emissions and many other indoor sources of formaldehyde have declined since the early 1980's. Nevertheless, there is a wide range of formaldehyde source strengths in commercially available pressed-wood products. Researchers at the California Department of Health Services have found that formaldehyde concentrations approaching 0.1 mg/m^3 are associated with a higher incidence of reported irritation and discomfort in allergic and asthmatic members of the California population studied (Liu *et al.*, 1991).

Why We Don't Know More

Data from field studies over the last ten to fifteen years have not done a lot to clarify the relationships between VOCs in indoor air and occupant responses. There may be many reasons for this, but among them are the following:

- The use of TVOC as an indicator of VOC exposure.
- TVOC measurement issues.
- The transience of airborne VOC species and their concentrations.
- The failure to measure potentially significant reactive VOCs and more or less volatile VOCs.
- The absence of sufficient studies at the low VOC concentrations normally found indoors.
- The effects of VOC mixtures.
- The great variability in individual responses.

The Use of TVOC as an Indicator of VOC Exposure

An important source of difficulty in assessing the results of VOC health effects studies is the fact that TVOC or SumVOC is usually used as the indicator of VOC exposure. Because TVOC is so poorly defined and differs depending on the method used for measurement, it is not likely to be a reasonable indicator of occupant responses.

The report of twelve respected Scandinavian IAQ scientists after their review of TVOC health effects is unequivocal. It says that "...except in extreme cases, there is no scientific basis today for the use of TVOC as a risk index for discomfort or for health effects in buildings."

TVOC Measurement Issues

There are several problems with the ways TVOC are measured. As reported in Vol. 3, No. 8 of the ***BULLETIN***, Hodgson has shown that measured TVOC may vary significantly among methods (*Indoor Air*, Vol. 5, No. 4). Charlie Weschler *et al.* have written several papers, as have others, that show that indoor air chemistry may transform in deceiving ways what is and, perhaps more importantly, isn't measured (Weschler and Shields, 1992; Zhang and Lioy; 1994; Cometto-Muñiz and Cain, 1996). This can be especially true when VOC or higher molecular weight aldehydes (potentially irritating compounds) are not specifically measured.

While accurate VOC or TVOC measurement critically depends on the method, no method can determine the presence or quantity of all VOCs. All VOC measurement methods are inherently selective. Limitations include the boiling point range, the polarity, and the reactivity of the individual compounds that can be collected and detected by a particular measurement method. The relatively high cost of VOC measurements has caused researchers and investigators to choose implicitly partial characterization of the VOCs present in any air sample.

Any actual exposure/response relationships are less likely to be detected using measurements that only approximate relevant personal exposures. Differences that result from spatial variations in concentrations, especially from occupant-activity related sources (Rodes *et al.*, 1991) and from temporal variations in both exposures and responses, will mask the actual relationships. Temporal concentration variations have been shown to be large and potentially significant for occupant responses (Weschler *et al.*, 1992). Hodgson *et al.* (1991) reported a positive association between VOCs measured in study subjects' microenvironment and the prevalence of SBS symptom reports in non-problem buildings studied. However, follow-up studies did not confirm the earlier finding (Hodgson *et al.*, 1991). The relation to sources of oxidants was not evaluated.

The Transience of Airborne VOC Species and Their Concentrations

Weschler *et al.* (1992) indicated that the disappearance of certain VOCs is accompanied by a rise in total measured VOCs and a rise in aldehydes that might be considerably more irritating than the VOCs from which they are formed. Formation of acidic aerosols may also produce irritation while decreasing the measured VOC concentrations (Zhang and Lioy, 1994). Formation of the hydroxyl radical by the interaction of ozone with unsaturated VOCs may produce another, more effective reaction pathway for the removal of VOCs measured by the usual methods and creation of aldehydes and ketones that would not be included in the total VOC measurement by most methods (Weschler and Shields, 1996).

The Failure to Measure Potentially Significant VOCs

Less volatile compounds than those usually measured and reported in indoor air studies and investigations may also have important comfort and irritation implications since they may be more irritating at concentrations observed indoors (Cometto-Muñiz and Cain, 1994; 1995). Equally important, increasing the number of compounds in a complex mixture lowers the thresholds for odor and for eye and nasal irritation. In fact, Cometto-Muñiz and Cain reported that increasing the complexity and lipophilicity of mixtures increased additive effects. Eye irritation showed synergistic effects for the most lipophilic substance tested in a mixture of six components. They concluded that mixtures of chemicals cause human responses even when the individual chemicals are at concentrations far below their individual thresholds.

There is currently considerable discussion among some of the leading indoor air researchers about the compounds that are not being measured by current methods whose health effects might be important. The compounds of interest include reactive species that are known or likely irritants. Some of these are also odorous and can be detected by humans at concentrations far below their measurement detection limits — in the parts per trillion range.

The Absence of Sufficient Studies at the Low VOC Concentrations Normally Found Indoors

A potentially important contributing factor to the uncertainty regarding indoor air VOC health effects is the absence of sufficient studies at the low VOC concentrations normally found indoors. Most of the available data on VOCs' health effects are from higher exposures found more typically in industrial environments, usually where only one or a very limited number of toxic substances are known to be present. Indoor air contains hundreds of identifiable compounds. Most of these are not believed to cause health effects at very low concentrations typical of indoor air, and many are not characterized with respect to health effects.

The Effects of Mixtures

The work of Cometto-Muñiz and Cain (1996) continues to reveal more details about the relationships between specific mixtures of VOCs and odor and irritation responses. This work is leading to a better understanding of fundamental relationships. Finally, it is important to resist the temptation to seek easy answers to the VOC question as well as many others involved in studying occupant symptoms and reports of irritation. The next two or three years are likely to produce a far better understanding than what currently exists.

The Great Variability in Individual Responses

There is great variability in how different individuals respond to environmental stimuli including the same organic compounds. Thus, it requires very large numbers of subjects in studies to reduce the potential confounding effect of individual variability on study results. To date, the numbers of individuals is relatively small in most studies. And, most of these studies have used TVOC or SumVOC as an indicator of VOC exposure. In the largest study populations, the results have been mixed: some showed a positive relationship between TVOC concentrations and SBS symptoms, some showed no relationship, and two showed an inverse relationship.

We Know Enough To Act

In spite of the lack of a complete understanding of the causal relationships between VOCs and occupant responses to them, it is clear that health hazards exist that warrant preventive action.

Preventive measures for important diseases are often available long before causative mechanisms are understood. For example, scurvy was found to be preventable in 1753, but ascorbic acid wasn't identified until 1928. In 1901, Walter Reed found a way to prevent Yellow Fever — but its cause, Flavivirus, wasn't identified until 1928.

According to E. L. Wynder, "Much of this disease burden [diseases related to lifestyle and environmental variables] could be significantly reduced on the basis of existing evidence without much more knowledge than we have now about the specific mechanisms by which these factors induce disease." (Wynder, 1994) This is an important message for IAQ professionals. Arguing by analogy, we believe that preventive measures readily available to those responsible for IAQ are reasonably easily achieved and should be used wherever possible.

Conclusions

At present, the role of VOCs in occupants' responses to indoor air is still an open question. Too little is known to allow the prediction of occupant reactions to undefined mixtures of VOCs. More work is needed, possibly with the contemporaneous administration of questionnaires and personal exposure measurements of air quality parameters. The time course of human responses to VOC exposure probably does vary by compound as well as by individual susceptibility. The time periods of exposure assessment and outcome assessment should be related to the hypothesized relevant time periods for the effect of interest. There is far less certainty about responses to prior exposures. Finally, the presence of a multitude of compounds, the potential for interactions among them, the known health and comfort effects at higher concentrations, and the potential effects of mixtures of VOCs leads to the need for consideration and prudence.

TVOC has become a major measurement point and indicator for IAQ, perhaps only falling behind CO_2 in popularity. Problems with both abound, although there has been far less discussion of the problems with TVOC. While measuring TVOC is not a trivial task, it is the sort of simplified indicator that many indoor air researchers and investigators have hoped would be useful in assessing IAQ. It turns out that oversimplification has occurred and much work has been done that is not very useful. It is time that TVOC *per se* be abandoned as a means of assessing environmental factors and their relationships to problem buildings. A far more detailed analysis of airborne VOCs is required to be useful for problem building assessments and research projects into the causes of occupant symptom reports.

For many years, researchers had difficulty consistently correlating any environmental or personal variables to SBS symptom reporting rates. Then, when they began to break symptoms down into logical groups, they began to find relationships. Maybe it is time to break VOCs down into logical groups in order to find correlations to reported symptoms. Perhaps by identifying important compounds and looking at them individually or in logical groups, investigators might find correlations to symptom reporting rates. In the meantime, it is reasonable to employ readily available source reduction strategies to control concentrations of indoor VOCs.

References:

Bornehag *et al.*, 1996. Report from a Nordic Scientific Consensus Meeting at Långholmen in Stockholm.

Cain, W. S., 1996. "Overview: Odors and Irritation in Indoor Pollution." In R. B. Gammage and B. A. Berven (Eds.) *Indoor Air and Human Health, Second Edition*. Boca Raton: CRC Press - Lewis Publishers, pp. 23-30.

CARB, 1991. Formaldehyde in the Home, Supplement to Indoor Air Quality Guideline No. 1, Sacramento: California Air Resources Board.

Cometto-Muñiz, E., and Cain, W. S., 1996. "Physicochemical Determinants and Functional Properties of the Senses of Irritation and Smell." In R. B. Gammage and B. A. Berven (Eds.) *Indoor Air and Human Health, Second Edition*. Boca Raton: CRC Press - Lewis Publishers. pp. 53-66.

Girman, J., 1989. Volatile Organic Compounds and Building Bake-Out" in J. Cone and M. Hodgson, (Eds.), *Problem Buildings: Building Associated Illness and the Sick Building Syndrome, State of the Art Reviews in Occupational Medicine*, Vol. 4, No. 4, pp. 695-712.

Hodgson M. J., Frohliger J., Permar E., Tidwell C., Traven C., Olenchuk S., Karpf M., Symptoms and microenvironmental measures in non-problem buildings. J Occup Med 1191;33:527-533.

Hodgson, M., Levin, H., and Wolkoff, P., 1994. "Volatile organic compounds in indoor air," *Journal of Allergy and Clinical Immunology*, Vol. 94, pp. 296-303.

Kjaergard, S., Mølhave, L., Pedersen, O.F., 1991. Human reactions to a mixture of indoor pollutants, *Atmospheric Environment*, Vol. 25:1417-1426.

Liu, K.-S, F.-Y. Huang, Hayward, S. B., Wesolowski, J., and Sexton, K., 1991. Irritant Effects of Formaldehyde Exposure in Mobile Homes. *Environmental Health Perspectives*, Vol. 94: 91-94.

McCann, J., Horn, L., Girman, J., and Nero, A. V., 1987. Potential risks from exposure to organic compounds in indoor air. In *Short-term Bioassays in the Analysis of Complex Environmental Mixtures*, New York: Plenum Press, pp. 325-354.

McCann, J., Horn, L., Girman, J., and Nero, A. V., 1988. Potential risks from exposure to organic carcinogens in indoor air. (LBL:-22473).

Mendell, M., 1993. "Non-Specific Symptoms In Office Workers: A Review and Summary of the Epidemiologic Literature." *Indoor Air*, Vol. 3, No. 4, pp. 227-236.

Mølhave, L., Bach, B., and Pedersen, O.F., 1986. Human reactions to low concentrations of volatile organic compounds. *Environment International*, Vol. 12, No. 1-4, pp. 167-176.

Mølhave, L., 1987. "The sick buildings — a subpopulation among the problem buildings?" *Indoor Air '87; Proceedings of the 4th International Conference on Indoor Air Quality and Climate*, Vol. 2. West Berlin, 17-21 August. Berlin: Institute for Water, Soil and Air Hygiene, pp. 469-473.

Mølhave, L., 1990. Volatile organic compounds, indoor air quality, and health. *Proceedings of the 5th International Conference on Indoor Air Quality and Climate Indoor Air '90;* Vol. 5, pp.15-34.

Mølhave, L., 1991. Volatile organic compounds, indoor air quality and health. *Indoor Air*, Vol. 1, No. 4, pp. 357-76.

Mølhave, L., Nielsen, G. D., 1992. Interpretation of the concept "total volatile organic compounds" (TVOC) as an indicator or human responses to exposures of volatile organic compounds in indoor air. *Indoor Air*, Vol. 2, pp. 65-77.

Mølhave, L. *et al.*, 1993. Sensory and physiological effects on humans of combined exposures to air temperatures and volatile organic compounds, *Indoor Air* Vol. 3, No. 3, pp. 155-169.

NAS, 1981. Formaldehyde and Other Aldehydes. Washington, DC: National Academy of Sciences.

Nielsen, G. D, Hansen, L. F., Hammer, M., Vejrup, K. V., and Wolkoff, P., 1996a. "Chemical and Biological Evaluation of Building Material Emissions I; A Screening Procedure Based on a closed Emission System." *Indoor Air* (in press).

Nielsen, G. D, Hansen, L. F., and Wolkoff, P., 1996b. "Chemical and Biological Evaluation of Building Material Emissions II; Approaches for Setting Indoor Air Standards or Guidelines for Chemicals. *Indoor Air* (in press).

Nunes, F., Menzies, R., Tamblyn, R., Boehm, E., Letz, R., 1993. The effect of varying outdoor air supply on neurobehavioral performance function during a study of the sick-building syndrome. *Proceedings of Indoor Air '93*, 1:538-43.

Otto, D., Mølhave, L., Rose, G., Hudnell, H. K., and House, D., 1990. Neurobehavioral and sensory irritant effects of controlled exposure to a complex mixture of volatile organic compounds, *Neurotoxicology and Teratology*, Vol. 12, pp. 649-652.

Otto, D.A., Hudnell, H.K., House, D.E., Mølhave, L., Counts, W., 1992. Exposure of humans to a volatile organic mixture, III. Behavioral assessment. *Archives of Environmental Health*, Vol. 47, pp. 23-30.

Rodes, C. E., Kamens, R. M., and Wiener, R. W., 1991. The significance and characteristics of the personal activity cloud on exposure assessment measurement for indoor contaminants. *Indoor Air*, Vol. 1, No. 2, pp. 123-145.

Seifert, Bernd, 1990. "Regulating Indoor Air," *Proceedings of the Fifth International Conference on Indoor Air Quality and Climate, Indoor Air '90*, Volume 5, pp. 35-49.

Tancrede, M., Wilson, R., Zeise, L., Crouch, E.A.C., 1986. The carcinogenic risk of organic vapors indoors: a survey. Discussion paper series E-86-06, Energy and Environmental Policy Center, John F. Kennedy School of Government, Harvard University.

Tancrede, M., Wilson, R., Zeise, L. Crouch, E.A.C., 1987. The carcinogenic risk of organic vapors indoors: a survey. *Atmospheric Environment*, Vol. 21, No. 10, pp. 2187-2305.

Tucker, W. G., 1990. Building with low-emitting materials and products: where do we stand?" *Proceedings of the Fifth International Conference on Indoor Air Quality and Climate, Indoor Air '90*. Vol. 3, pp. 251-256.

Weschler, C.J., Hodgson, A.T., and Wooley, J.D., 1992. "Indoor chemistry: ozone, volatile organic compounds, and carpets." *Environmental Science and Technology*, Vol. 26, 2371-2377.

Weschler and Shields, 1996. Chemical transformations of indoor air pollutants. *Proceedings of indoor Air '96*, 1:919-924.

Weschler, C. J. and Shields, H.C., 1996. "Production of the Hydroxyl Radical in Indoor Air" *Environmental Science and Technology*, Vol. 30, 3250-3258.

Weschler, C. J., Hodgson, A. T., 1992. "Indoor VOCs: Is What You Measure on Tuesday Night the Same as What You Measure on Wednesday Afternoon?" *IAQ 92: Environments for People*, ASHRAE, pp. 213-219.

Wolkoff, P., Wilkins, C.K., Clausen, P.A., and Larsen, K., 1993. Comparison of Volatile Organic Compounds from Processed Paper and Toners from Office Copiers and Printers: Methods, Emission Rates, and Modeled Concentrations. *Indoor Air*, Vol. 3, No. 2.

Wynder, E. L., 1994. Invited Commentary - Studies in Mechanism and Prevention: Striking a Proper Balance. *American Journal of Epidemiology*, Vol. 139 (6): 547-549.

Zhang, J., and Lioy, P.J., 1994. Ozone in Residential Air Concentrations, I/O Ratios, Indoor Chemistry, and Exposure. *Indoor Air*, Vol. 4, No. 2, 95-105.

Conference Report

CIBSE/ASHRAE Joint National Conference

Members of both ASHRAE and CIBSE (Chartered Institution of Building Service Engineers) met in Harrogate, UK, at the end of September. Three themes caught our attention. One was the breadth of concern over the total indoor environment among CIBSE members in the UK compared to that of ASHRAE members who are primarily in the United States. Second was a related theme, an interest in integrating the various disciplines involved in designing buildings. Finally, there was much discussion about natural ventilation which seems to be gaining more popularity and use in the UK.

By far the most interesting trends we noted there was a shift back to natural ventilation or solutions involving a mix of natural and mechanical ventilation. Some presentations emphasized the environmental benefits of natural ventilation, others emphasized the economic benefits. We are not sure that these are as separate as they might appear. After all, the costs associated with mechanical ventilation involve increased use of natural resources for manufacture and use of the equipment as well as the pollution associated with energy production to operate the equipment.

One paper described a case study where the building budget was reduced by more than 20% by eliminating the all mechanical ventilation system and replacing it with a mixed system dependent primarily on natural ventilation with mechanical exhaust available as required to boost air flow rates. This sort of solution was used in many of the buildings discussed in conference papers. British engineers and architects we spoke with said that the dryness of the climate meant that air conditioning was not required. Therefore, radiant heating systems could be used in association with natural ventilation for climate control in most buildings most of the time.

Publications

Characterizing Sources of Indoor Air Pollution and Related Sink Effects

The proceedings are finally out from "The Symposium on Methods for Characterizing Indoor Sources and Sinks" which took place September 25-28, 1994, in Washington, DC. Organized by Bruce Tichenor (now a consultant since his retirement from the EPA late last year), the symposium brought together about 100 of the leading researchers on emissions from indoor sources. About half the attendees came from Europe, showing the strength of interest in the subject overseas.

The four sessions of the symposium are reflected in the book's organization as follows:

1. Test chambers and facilities.
2. Testing methods and protocols.
3. Models for predicting source and sink behavior.
4. Interpretation and application of test results.

Details of test chamber design and performance were covered for a variety of test facilities. Several papers focused on the effects of sample surface air velocity on emission rates using both chemical and sensory measurement methods. Even emissions of microorganisms were discussed in two papers in the first session.

The discussions of testing methods and protocols in the second session ranged from practical considerations to very theoretical ones. A lot of controversy surrounded Johan Johansson's discussion of gas-to-particle conversion of re-emitted matter from surfaces exposed to sidestream tobacco smoke. A paper from Denmark discussed the oxidative emission process related to linoleum, often considered a "good" IAQ or environmental performer by those unfamiliar with the documentation in the Danish and Swedish literature.

Among the most interesting discussions at the symposium were those during the third and fourth sessions. Several presenters and commentors asserted that it was impossible to do all the testing necessary to provide emissions data for all the products and combinations of products of interest. Instead of trying to keep up with a constantly changing catalogue of products in the marketplace, John Little and Al Hodgson proposed that we study fundamental properties of sources and behavior of chemicals to be able reasonably to predict chemical emissions behavior.

In the fourth session, Peder Wolkoff presented the Danish Indoor Climate Labeling project which appears to be the basic model for an emerging consensus on indoor pollution source labeling — at least in Europe. Also in that session, our own paper, also co-authored by Al Hodgson, proposed screening approaches to materials testing for building design selection processes. Included were appendices outlining the approaches and providing some example guidance on interpreting results.

Copies of the proceedings are available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA,19428-2959, 610 832 9500, Fax 832 9666.

Reference:

Tichenor, B. A., (ed.), 1996. Characterizing Source of Indoor Air Pollution and Related Sink Effects, STP 1287, West Conshohocken, PA: ASTM.

Publications

Indoor Air and Human Health — Just Get It!

One of the most important and least adequately understood topics in indoor air is the relationship between the indoor environment and health. Now, a selective review of important topics is available from the proceedings of the Oak Ridge National Laboratory Life Sciences Symposium, Indoor Air and Human Health, organized by Dick Gammage of Oak Ridge National Laboratory. The symposium was discussed in detail in Vol. 3, No. 3 of the ***BULLETIN***.

Part I of the volume includes in an outstanding overview of the subject of odor and irritation from a session organized by Bill Cain. In his overview, Cain provides an intensive primer on odor and irritation. Cain not only tells us what is known, but shares some of his own questions and concerns regarding odor, irritation, and IAQ.

The chapters in Part I, each by a leading authority, explore the details: The neurobiology of olfaction; Physicochemical determinants and functional properties of the senses of irritation and smell; The potency of gases and vapors; Quantitative structure activity relationships (QSAR), anesthesia, sensory irritation, and odor; Electro-physiologic indices of human chemosensory functioning; and, Human responses to ambient olfactory stimuli.

Part II reviews allergy and respiratory effects with eight detailed chapters. Part III addresses neurotoxicity with an overview and four separate chapters. And Part IV addresses cancer with an overview and four separate chapters. All in all, this is one of the most important and interesting books for the IAQ field that we have seen for quite a while. We say: Just get it!

To order, ask for catalog #L1144, R. Gammage and B. Berven, eds., *Indoor Air and Human Health, Second Edition,* from CRC Press for the list price of $69.95 domestic and $84.00 foreign. You can reach CRC Press at 800-CRC-PRES (800 272 7737). In Florida or outside the continental US, the number is 407 994 0555 ext. 3000. Fax orders to 800 374 3401. In Florida or outside the continental US, the fax number is 407 998 9114. Email orders to orders@crcpress.com.

Correction

Wolkoff on TVOC and the Nordic Consensus Report

In Vol. 3, No. 7 of the **BULLETIN** we reported on the Nordic Scientific Consensus report on TVOC in which twelve leading scientists found "...except in extreme cases, there is no scientific basis today for the use of TVOC as a risk index for discomfort or for health effects in buildings." We incorrectly listed Peder Wolkoff of Denmark as a member of the committee. Wolkoff wrote to us to inform us of our error and to clarify his position on TVOC.

Dear Hal:

I wrote a severe criticism of the whole TVOC concept in my dissertation in Supplement No. 3 in *Indoor Air* (1995). I had not intended to pursue the matter further. Recently, Berglund and Johansson reached the same conclusions as I did, in their TVOC review, published from Stockholm University and Karolinska Institute (Private).

On the other hand, I am sorry to see that in order to achieve personal and political goals, as seen in recent papers and efforts related to TVOC and emission testing, normal scientific practice to recognize important contributions or thoughts by fellow colleagues are disregarded.

I have deliberately not participated in the Nordic consensus work as stated in your latest ***IAB***. I agree in the final conclusion of the work, but a scientific evaluation of TVOC from the point of sampling, analysis, comfort, and health is missing. Indeed, most measured VOCs are considered to be non-reactive, but may be odorous in the concentrations encountered. However, are we sure we have measured the pollutants and their mechanisms causing the effects we are trying to relate to our measurements? I believe the study of reactive VOCs, in particular "reactive species," will be a fruitful approach to identify causative agents of indoor air symptoms, in addition to more research on how odors are formed and what impact they have on the perceived air quality. Some suggestions for refinements on summed VOC measurements can be found in my dissertation.

Regards,
Peder Wolkoff

VOCBASE

VOCBASE is a database created by the National Institute of Occupational Health that contains useful threshold data for over 800 common indoor air VOCs. The database contains chemical formula, molecular weight, boiling point, odor and irritation thresholds, RD50s, occupational exposure limits for Denmark and the United States, and other useful information.

The official price to obtain VOCBASE is 1800 DKr (Danish kroner) which is approximately US$300. VAT will be added.

To purchase VOCBASE, contact the National Institute of Occupational Health, Lersø Parkalle 105, DK-2100, Copenhagen, Denmark, attention: Peder Wolkoff. Fax +45 49270107, email: pwo@ami.dk.

Calendar of IAQ Events

December 8-11, 1996. **Risk Assessment and Risk Management: Partnerships Through Interdisciplinary Initiatives**, sponsored jointly by International Society for Risk Analysis and International Society for Exposure Assessment. Fairmont Hotel, New Orleans, Louisiana. Contact: Society for Risk Analysis, 1313 Dolley Madison Blvd., Suite 402, McLean VA 22101, 703 790 1745.

January 25-29, 1997. **ASHRAE Winter Meeting and Exposition**, Philadelphia, PA. Contact: ASHRAE Meetings Department, 1791 Tullie Circle NE, Atlanta, GA 30329. 404 636 8400, Fax 404 321 5478.

September 27 - October 2, 1997. **Healthy Buildings/IAQ '97: Global Issues and Regional Solutions**, Washington, DC. Organized by ISIAQ, ASHRAE, and Virginia Tech. Contact: Professor James E. Woods, Virginia Tech, Fax 703 698 4729. email: hbiaq.97@vt.edu. *Announcement and Call for Papers have been issued. Abstracts are due November 30, 1996.*

July 21-23, 1997. **Engineering Solutions to Indoor Air Quality Problems**, Research Triangle Park, North Carolina. Sponsored by the US Environmental Protection Agency and the Air and Waste Management Association (A&WMA). Contact: Kelly W. Leovic, US EPA, MD-54, Research Triangle Park, NC 27711, 919 541 7717, Fax 919 541 2157, email: kleovic@engineer.aeerl.epa.gov. *A Call for Papers has been issued. Abstracts of 200 to 300 words are due by January 10, 1997.*

September 27 - October 2 1997. **Healthy Buildings/IAQ '97: Global Issues and Regional Solutions**, Washington, DC. Organized by ISIAQ, ASHRAE, and Virginia Tech. Contact: Professor James E. Woods, Virginia Tech, PO BOX 7430, Falls Church, VA, 22040, 703 698 4725, Fax 703 698 4729, email: hbiaq.97@vt.edu. *Second Announcement and Final Call for Papers has been issued. Abstracts are due November 30, 1996. For updates: http://www.vt.edu:10021/contEd/conted.html.*

International Events

December 4, 1996. **Managing and operating buildings: planning to profit from the future**, Garston, England. Sponsored and organized by the Building Research Establishment (BRE). Contact: BRE, Garston, Watford, Herts., WD2 7JR, United Kingdom, +44 1923 664775, Fax +44 1923 664668.

May 7-11, 1997. **Space design and management for place making; 28th annual conference of the Environmental Design Research Association**, Universite Du Quebec, Montreal, Montreal, Quebec, Canada. Contact: EDRA, Business Office, P. O.Box 7146, Edmond, OK, 73083-7146, 405 330 4863, email: edra@telepath.com.

June 9-12, 1997. **Buildings and the Environment**, Organized by CSTB and CIB T18, Paris, France. Contact: Ms. Angela Ghivasky, International Affairs, CSTB, 4, Avenue du Recteur Poincaré, 75782 - Paris Cedex 16, FRANCE, +33 1 40 50 29 13, Fax +33 1 40 50 28 76, email ghivasky@cstb.fr.

August 30 - September 2, 1997. **Clima 2000**, Brussels. Organized by Belgian Royal Technical Society of Heating, Ventilation, and Related Technology Industry (ATIC), on behalf of Federation of European Heating and Air-conditioning Associations (REHVA). Contact: Clima 2000 '97, c/o SRBII, Ravenstein 3, B-1000 Brussels, Belgium, +32 (0)2 511 7469, Fax +32 (0)2 511 7597. *The conference language will be English.*

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