Indoor Air Quality Update™

A Guide to the Practical Control of Indoor Air Problems, from Cutter Information Corp.

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European Community Releases SBS Report

In August, the European Community (EC) published its fourth IAQ report, *Sick Building Syndrome, A Practical Guide*. The report was prepared under the auspices of the European Community Concerted Action, *Indoor Air Quality and Its Impact on Man*. The title accurately describes this 36-page monograph prepared by four leading European indoor air researchers. Claude Molina (France), Anthony Pickering (United Kingdom), Ole Valbjørn (Denmark), and Maurizio de Bortoli (Italy) collaboratively wrote the guide, which is available from the EC Joint Research Centre, Institute for the Environment, in Ispra, Italy.

The guide is comprehensive, albeit brief, in describing the causes, effects, diagnosis, and investigation of SBS. (See the sidebar on page 2 for a list of contents.)

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Significance of the Report

We think the report is important for several reasons. First, it is a comprehensive review of SBS that includes various professional perspectives. Since we see SBS as a multifaceted problem, we believe the multidisciplinary approach is necessary to adequately and completely assess problem buildings. Second, the report is based on the most recent and reliable European research. Third, the authors and sponsoring agency represent European leadership in indoor air issues.

European nations, especially in the north, have been addressing indoor air issues far longer than the USA and Canada. Numerous European national agencies have considerable IAQ experience and credibility. Europe also has a tradition of multidisciplinary work that is rarely found in the USA.

1. Background

The report authors write that the cause of SBS "... is probably multifactorial, [and that it] is not usually accompanied by any organic lesion or physical sign, and, ...therefore, diagnosed by exclusion." They also state that SBS usually occurs in air conditioned buildings "... although it has been observed in naturally ventilated buildings."

2. Extent of the Problem

After stating that the problem is worldwide, the report authors devote considerable space to the extent of air conditioning use and regulated ventilation. They cite Jim Wood's study of 600 office workers in the USA showing that 20% of employees experience symptoms of SBS. They also refer to WHO reports that estimate that up to 30% of new and refurbished buildings worldwide are affected by the syndrome. Finally, the report cites the large-scale British study (4,373 office workers in 46 buildings) that found 29% of those surveyed reporting five or more SBS symptoms.

3. Cost Effectiveness

In this section of the report, the authors cite hypothetical calculations of the cost of absenteeism due to increased illness versus the savings generated by decreasing heating and ventilation (reducing energy consumption). The calculation (originally presented by Grey Robertson at "Healthy Buildings '88" in Stockholm) showed the cost of a 1% absenteeism to be eight times greater than the potential savings through reduced energy consumption. The report then states that absenteeism due to SBS is "... probably much greater than 1%." This analysis does not consider the cost of reduced working efficiency. The report suggests that building management and personnel management should be more closely linked in institutional organization.

Sick Building Syndrome: A Practical Guide

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Members of the Community — COST Concentration Committee

In some countries (such as France), the authors say, allergic manifestations in office workers in air-conditioned buildings are considered occupational diseases with all the attendant medical and legal implications. The authors suggest that these issues are important in existing buildings but should be primary considerations in the design and construction of new buildings.

4. Symptomatology

There are five symptom complexes encountered regularly in SBS. They may occur singly or in combinations.

1. Nasal manifestations: most frequently, nasal irritation with rhinorrhea (mucous discharge from the nose) and nasal obstruction (stuffiness).

2. Ocular manifestations: dryness, irritation of the mucous membrane of the eye.

3. Oropharyngeal manifestations: dry, irritated throat.

4. Cutaneous manifestations: dry, irritated skin; occasionally with a rash.

5. General manifestations: headaches; generalized lethargy and tiredness leading to poor concentration.

The symptoms characteristically increase in severity during the work shift and resolve rapidly upon exiting the building. Most symptoms (except some cutaneous manifestations) improve over weekends and disappear during longer absences from the building such as vacations. Certain "constitutional" diseases such as eczema and sinusitis may be made worse in some buildings.

5. Diagnosis

According to the authors, the preceding symptoms suggest an SBS diagnosis. Investigators should exclude other causes of building-related illness (for example asthma, hypersensitivity pneumonitis, humidifier fever, or allergic rhinitis) before making an SBS diagnosis. The consequences of SBS are increased job dissatisfaction, reduced working efficiency, and increased absenteeism due to illness.

6. Risk Factors (Causes)

The report discusses four major categories of risk factors: physical, chemical, biological, and psychological.

6.1. Physical factors

Included in physical factors are temperature, relative humidity, ventilation, artificial light, noise and vibrations, ions, and particles and fibers.

6.1.1. Temperature

Temperatures in excess of 24 to 26° C (75 to 79° F) increase the likelihood of SBS, according to several cited reports. Higher temperatures also increase offgassing from materials.

6.1.2. Relative humidity

Humidity can be a problem both directly by affecting occupants and indirectly by promoting biological contamination by microorganisms. High values (70%) are known to cause discomfort and to increase the likelihood of biological contamination. High humidity can also result in structural damage, especially in cold climates.

Very low humidity (<20%) has been associated with drying of the mucous membranes and skin in some individuals. However, in recent studies with very dry air (R.H. = 9%), individuals exposed to clean air for 78 hours had no signs or symptoms. This was true even when the subjects had high metabolic rates. Therefore, low humidity probably does not directly affect SBS symptoms, although indirect effects such as the build-up of static electricity or offgassing vapors could create conditions conducive to SBS reactions.

6.1.3. Ventilation

Insufficient ventilation is widely considered a causal factor. Many countries have established standards, but they vary considerably. The International Energy Agency suggests that eight liters per second per person (16 cfm/p) will be adequate for sedentary activities where smoking is not permitted. The report states that this ventilation rate limits CO_2 to 0.1% (1,000 ppm) and that 20% of occupants entering the room will be dissatisfied with the environment. (This sounds is similar to the ASHRAE standard.) However, if smoking is permitted, a higher ventilation rate is required.

The proper commissioning and operation of ventilation systems is important to avoid problems associated with the ventilation equipment itself. Recirculation of air "which introduces contaminants to working areas should be avoided."

6.1.4. Artificial light

It is possible that visual stress resulting from insufficient contrast, excessive brightness, or glare induces eye irritation and headache. Special attention should be paid to lighting design where there is prolonged use of VDTs. By using solid-state high-frequency ballasts, one investigator reduced the incidence of eye strain and headaches more than 50% in a study of office workers.

6.1.5. Noise and vibrations

Noise at 70 to 80 dB (A-weighted) may cause tiredness. Very-low-frequency sound (infrasound at 0.1 to 20 Hz) can cause dizziness and nausea. Noise in the 20-100 Hz range found in buildings with industrial machinery or ventilation equipment can cause problems. One study, where noise levels were 61 dBA in two different departments, showed more complaints in workers in the department where greater sound pressure existed in the 8-125 Hz range.

The report also describes the work of Michael Hodgson et al., who found increased irritability and dizziness correlated with vibration levels measured on the desks of secretaries. These vibrations were attributed to an adjacent pump room. Certain body organs, specifically the eyes, have characteristic resonance frequencies in the 1 to 20 Hz range, according to a pilot study.

6.1.6. Ions

British researchers studied the effect of increased negative ion concentrations on office workers in an air-conditioned building. They found no effect on the SBS symptoms reported in their double-blind study. The report also mentions the potential airway irritation from ozone produced by negative ion generators.

6.1.7. Particles and fibers

Researchers have reported correlations between airborne man-made mineral fibers (MMMF) and eye irritation and between surface MMMF and skin irritation. MMMF sources identified in the report include acoustic ceilings and other locations where fibers were bound by water-soluble adhesives exposed to water damage. The exposure is through direct hand contact rather than through airborne transmission.

6.2. Chemical factors

The authors say that chemical factors are too numerous to be considered individually. Therefore, they grouped them into six major categories. Industrial workplace threshold limit values are usually far higher than indoor air levels. But two factors should be considered: first, indoor air consists of complex mixtures where synergisms can occur; and, second, workplace limits are for healthy adults working 40 hour shifts. High-risk groups in non-workplace environments, such as children, the elderly, and hypersensitive individuals, are often exposed to pollutants for much longer periods of time.

6.2.1. Environmental tobacco smoke (ETS)

"Generally speaking, this is by far the most important source of chemical pollution in indoor air. It is now generally accepted that ETS may cause cancer of the lung." SBS is statistically more common in smokers. Nonsmokers and ex-smokers exposed to ETS experience an excess of symptoms.

ETS can cause mucous membrane irritation (sidestream smoke contains more irritants than mainstream smoke). ETS contains several hundred compounds, many of which are toxic, and tobacco smoke can be an allergen affecting bronchial and alveolar immune defense mechanisms. The report says smoking should be "prohibited in working environments and indoor spaces open to the public."

6.2.2. Formaldehyde

Formaldehyde indoors may come from wood products, urea-formaldehdye foam, and a variety of disinfectants, cleaners, and paints. Since formaldehyde irritates both the eyes and the upper- and lower-respiratory tract, it has been suggested as the cause of SBS. It may also cause allergic disorders.

Concentrations in building air are rarely high enough to cause SBS symptoms. SBS has also been found where no formaldehyde was found in the air. However, low concentrations of formaldehyde potentiated by other factors may be a contributor to SBS. The World Health Organization (WHO) recently published a concentration limit of 0.1 mg/m^3 for indoor air.

6.2.3. Volatile organic compounds (VOC)

VOC have many sources, varying effects, and often are sources of odors. Direct evidence on the relationship of VOC to SBS is not convincing. However, the work of Lars Mølhave of Denmark has shown detectable effects on subjective sensation, performance of tests, detailed clinical observations, and tear film stability in the eye. He found these effects in chamber tests using total VOC concentrations similar to those that occur in new or refurbished buildings.

Birgitta Berglund of Sweden has reported finding an inverse correlation between concentrations of some VOC and relative humidity. This, the report suggests, would explain why SBS can be more severe in winter than in summer.

The Danish Town Hall Study researchers speculated that VOC dissolution in and re-release from moisture adsorbed on material surfaces increased in buildings with high surface areas (high "shelf factor"). In the same study, Peter Wolkoff found significant spatial and temporal variations in VOC air concentrations. These variations depended on occupant activities. (See ***IAQU***, May 1988, for a detailed discussion of the Danish Town Hall Study.)

In their study of a "healthy" and a "sick" preschool in Sweden, researchers hypothesized that concentration gradients within the schools rather than absolute levels of VOC may trigger SBS (see ***IAQU***, January 1989).

6.2.4. Biocides

Biocides currently used in most cold-water spray humidifiers to control microbial growth are highly irritating in concentrated form. They may cause mucous membrane irritation when dispersed in indoor air at low concentrations, especially in susceptible individuals.

6.2.5. Other gaseous substances

Carbon dioxide concentrations exceeding 0.1% (1,000 ppm) indicate increased likelihood of dissatisfied occupants and inadequate ventilation for the occupant load. The other gases discussed in the report include carbon monoxide and nitrogen dioxide, although the discussion is limited to combustion appliance sources in residential contexts. The report discusses ozone in relation to indoor sources only, although ***IAQU*** has described how high outdoor concentrations affect indoor air levels (***IAQU***, November 1988 and June 1989).

6.2.6. Odors

Odors can cause anxiety and stress, especially when the sources are unidentified, according to the report. The authors discuss the "olf" and the "decipol" introduced by Fanger to quantify odor perception and source strengths (see ***IAQU***, October 1988). No studies have been reported that compare olf levels to SBS incidence.

6.3. Biological factors

The report describes mites as primarily a residential problem and says that molds are a problem mainly for allergic individuals. It says there were no published suggestions of mold proliferation as a cause of SBS. However, the organic dust content of carpets (primarily skin scales, bacteria, and mold spores) had a demonstrated correlation to SBS symptom reports. The authors suggest the need for further investigation of the relationship between the organic contents of dust, their metabolic products, and SBS.

6.4. Psychological factors

Some research has suggested that SBS is the cause of excess stress rather than the effect of it. However, psychological factors may make people more susceptible to SBS; environmental factors may increase stress, lowering individuals' resistance to illness. The "psycho-physical load" at work (for example, long-term exposure to VDTs) may be an additional factor for indoor air complaints.

7. How to Conduct Investigations

The EC report does not depart from the prevailing wisdom about using a phased (or stepwise) investigative approach. Quantitative measurements should be made only after a subjective and qualitative evaluation. The qualitative evaluation should begin with a review of operations and recent changes in the ventilation system.

It should also review the access building occupants have to HVAC system controls.

If operations are considered normal and complaints persist, a technical and hygiene evaluation is in order. This determines the extent and nature of the problems in order to define the required expertise of the investigating team.

The approach recommended in the report is designed for investigating SBS complaints. However, the introductory comments state that it can be used with minor variations to investigate indoor air or climate problems of nearly any type.

The four major phases of the stepwise investigation recommended in the report are shown in Table 1. These are similar to those recommended by many other authorities (see IAQ Diagnostics, ***IAQU*** May 1988; NIOSH, ***IAQU*** January 1989). The major difference is that for the first phase, the EC report recommends a questionnaire. The second phase consists of making the inspection and guiding measurements. The third phase involves detailed climate and ventilation measurements. The final phase involves medical investigation and measurement of specific suspected components (chemical compounds, biological organisms, or physical factors).

Conclusions and Comments

The EC report contains a good bibliography on SBS studies, primarily in Europe. This is followed by four very useful appendixes as listed in the beginning of this article. Included are a valuable guide for diagnosis by medical personnel and a questionnaire prepared by the Environmental Medicine Clinic in Ørebro Hospital, Ørebro, Sweden.

We do not see anything startlingly new in the EC SBS report. However, the report does represent a continuation of the high-quality work that has been coming from the Joint Research Centre in Ispra. Last month, we reviewed an important paper on VOC in indoor air from two Ispra investigators, de Bortoli and Knöppel (see ***IAQU***, October 1989).

The SBS report continues the flow of valuable information from the European Community. More important, it demonstrates the ability of the representatives of the member nations to develop a consensus on difficult indoor air quality issues. This reflects the optimistic and ambitious attitude we saw in many of the individuals involved who attended the SBS course last month in Copenhagen (see article elsewhere in this issue of ***IAQU***) — optimism about the impact of the sweeping changes coming to Europe in 1992,

Table 1 — Summary of stepwise investigations of buildings with problems

Step	Type of investigation	Performed by (proposals)	Actions (examples)
1	Technical survey and use of questionnaire	Industrial physician Safety representative Maintenance engineer	Contact experts for evaluation, organize new actions, inform.
2	Inspection and guiding measurements of climate-indicators	Safety engineer Ventilation engineer	Clean and adjust ventilation, stop humidifiers, (re)move smokers and pollution sources
3	Measurements of ventilation, climate indicators and other implicated factors	Safety engineer Industrial hygienist Ventilation engineer	Increase ventilation, arrange sun-shielding
4	Medical investigation, specific measurements of suspected components	Medical doctor Industrial hygienist	Renew furniture, change ongoing activities or building materials; move staff, mount local exhaust

when many trade barriers will disappear. We look forward to a continuation of the productive efforts at Ispra and the EC.

For More Information

Report No. 4: Sick Building Syndrome, A Practical Guide. European Concerted Action: "Indoor Air Quality and Its Impact on Man;" COST Project 613. Ispra, Italy: Joint Research Centre, Commission of the European Communities. August, 1989, 36 pages. ♦

Tools and Techniques

Measuring Ventilation Rates

Far too little is known about the practical measurement of ventilation effectiveness. This article is the first in a two-part series on ventilation that explores different aspects of ventilation measurement.

Ventilation rates are of enormous importance to indoor air quality; designers, builders, code officials, owners, occupants, and investigators need to know the ventilation rates of the spaces in their buildings. Building designs are based on assumptions about ventilation rates, and indoor air quality control efforts increasingly rely on such assumptions. Measurements of ventilation rates in buildings show that actual rates can be far lower or far higher than design rates.

Building designers, owners, and regulators expect manufacturers to keep product emissions at "acceptable" or "safe" levels. Therefore, product manufacturers must know the ventilation rates in the spaces where clients will use their products. Ventilation rates affect both chemical emission rates and airborne chemical concentrations. Depending on weather and ventilation system operation, ventilation rates within a single building can vary by factors ranging from five to twenty-five. Also depending on ventilation rates, contaminant concentrations can vary by factors as high as ten. Therefore, knowing the actual ventilation rates in any given space is extremely important.

Measuring ventilation rates is neither simple nor easy. We see four important issues regarding the measurement of ventilation rates. One concerns the choice of an inert tracer gas (usually sulfur hexafluoride: SF_6) or carbon dioxide (CO_2). The second concerns the choice of CO_2 measuring devices: the use of detector tubes or a direct reading analyzer. The third issue concerns measuring ventilation rates in individual spaces within a building versus determining a "whole building average ventilation rate." Finally, the fourth issue concerns defining and measuring ventilation efficiency or effectiveness. We explore the first two of these issues in this article and the second two in next month's ***IAQU***. In this article we use data from recent papers by two of the leading authorities in the field, Andy Persily of the National Institute of Standards and Technology, (NIST, formerly the National Bureau of Standards) in Gaithersburg, Maryland, and William Turner of Harriman Associates in Auburn, Maine.

Comparison of CO_2 and SF_6 Measurements

Turner and Persily separately compared CO_2 and SF_6 measurement methods. Turner believes that each method has weaknesses as well as advantages. He feels that the benefits of using the two methods together cancels out the weaknesses of using each method alone. Therefore, wherever possible, he uses them both.

In a paper presented at ASHRAE IAQ '89 (see ***IAQU***, May 1989, for a report on some of the other papers presented there), Turner presented the results of ventilation measurements in two buildings. Turner said that one advantage of the CO_2 measurement method is the relatively few measurements required to determine the ventilation rate. Another advantage is that the occupants themselves are a built-in source of the tracer gas: CO_2.

Occupancy

A drawback of the CO_2 method is that the investigator must know the exact number of people present in the building when the measurements are made and, perhaps, for some time before. This is because the method requires calculating the theoretical concentration based on the number of occupants and the rate at which people generate CO_2. Most investigators assume a generation rate of 5.3×10^{-6} m^3 per second per occupant. Some empirical work has found generation rates slightly lower but close enough to be acceptable.

Counting occupants can be difficult, especially in large buildings or whenever the number of occupants varies considerably during the day. (For small buildings of less than 30 occupants, counting the occupants is not difficult.) Turner addresses this difficulty by counting people in a representative number of offices and multiplying occupancy times appropriate correction factors to estimate the total number of occupants. Other investigators have actually used occupant sensors located at all entries to monitor the number of occupants in the building. Note

Tracer Gas Measurement Costs and Methods

Tracer gas measurements of ventilation can be made by injecting known quantities of an inert gas into an air supply and then measuring its concentration in the building and ventilation system. Calculations are made to determine ventilation rates. Most researchers use the tracer gas method with sulfur hexafluoride (known by its chemical formula, SF_6).

For field investigators, tracer gas measurement equipment is costly: there are relatively few systems in use. When this method is chosen, the equipment is often rented or the measurement is sub-contracted. In order to get an estimate of the costs for contract tracer gas measurements, we talked to Bud Offerman of Indoor Environmental Engineering (IEE) in San Francisco. He said that IEE tracer gas studies cost from $3,000 to $8,000, with an average cost of about $5,000. Using "age of air theory," Offerman computes local ventilation rates at several points (usually six to eight) in the building, total building average ventilation rate, and the percent of outside air coming in to the building.

From these measurements, Offerman determines the effectiveness of the ventilation system in delivering outside air to the occupied zone. He evaluates ventilation system performance efficiency by comparing the percent of outside air (OA) in the supply air stream at the air handling unit to the percent of OA delivered in the occupant breathing zone. Any differences result from losses from duct leakage and from short circuiting within the space.

again that Turner is attempting to obtain a building average, not a single space measurement.

Another disadvantage of the CO_2 method is the need for relatively high occupant densities. While Turner does not give a guideline for minimum densities, he points out that CO_2 measurements simply can't be done when buildings have been evacuated due to indoor air quality problems.

Equilibrium

An additional disadvantage pointed out by Persily is that CO_2 measurements can be made only after the building has been occupied for some time. This is because it takes considerable time for the CO_2 levels to come to equilibrium, a necessary condition to fit the assumptions in the calculation methods. However, building occupancy varies considerably during the day. Persily shows the variability of CO_2 levels during the day in a typical office building (see Figure 1).

Persily calculated the time required for CO_2 levels to achieve steady state at various ventilation rates. He found that at typical occupant densities, it would take almost four hours at one air change per hour (ach) and eight hours at 0.5 ach. Since occupancy usually does not stay constant for more than four hours, in most cases stable equilibrium will not be reached. Therefore, at rates less than one ach (typical of many office buildings, according to Persily), ventilation rates based on CO_2 measurements will underestimate the actual ventilation rate. Persily's calculations are shown in Figure 2, next page.

Infiltration

Air exchange rates depend not only upon mechanical ventilation but also upon infiltration. Infiltration increases with large differen-

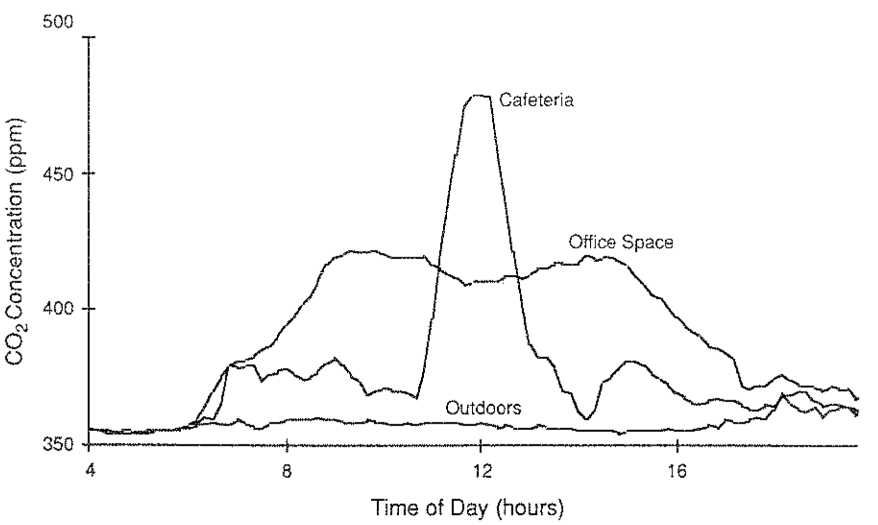

Figure 1 — Example of CO_2 Concentration Data from Building A

ces in indoor-outdoor temperatures. Building mechanical systems also respond to temperature differences, although not in the same way as infiltration. As I/O Delta T (the difference between indoor and outdoor temperatures) increases, mechanical system ventilation rate goes down (in most buildings) and infiltration goes up.

Persily found that in some buildings under minimum mechanical system ventilation conditions, fully half of the air exchange was caused by infiltration. Also, the total ventilation rate under these conditions can be as low as 0.4 ach. When inside-outside temperature differences are minimal, mechanical ventilation will dominate and ventilation rates will be much higher. Figure 3 shows the air exchange rates in one building plotted as a function of inside-outside temperature differences. (See *IAQU*, May 1989, for a detailed discussion of Persily's IAQ '89 paper on ventilation rates.)

Persily plotted two theoretical curves for CO_2 concentrations and ventilation rates: one for a building with a 10-foot ceiling height and one for a building with a 13-foot ceiling height. On the same graph he plotted the measured peak concentrations in three buildings he studied. It is interesting that a very large number of CO_2 measurements were in the 400 ppm to 500 ppm range over a wide range of ventilation rates, from about 0.6 ach up to more than 2.0 ach. This would indicate that the CO_2 measurements are not reliable indicators of ventilation rates. This could be because ventilation rates change relative to occupant density (and the related changes in thermal loads); rates increase as occupancy increases, thus maintaining relatively constant CO_2 concentrations. (See Figure 4, opposite.)

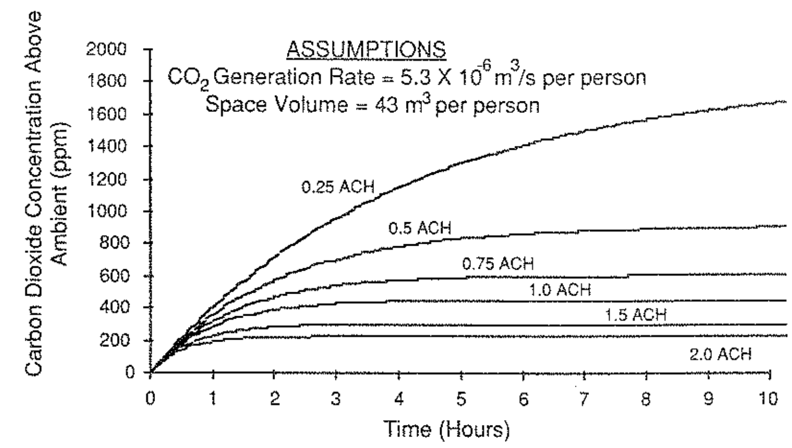

Figure 2 — Calculated Build-Up of Carbon Dioxide

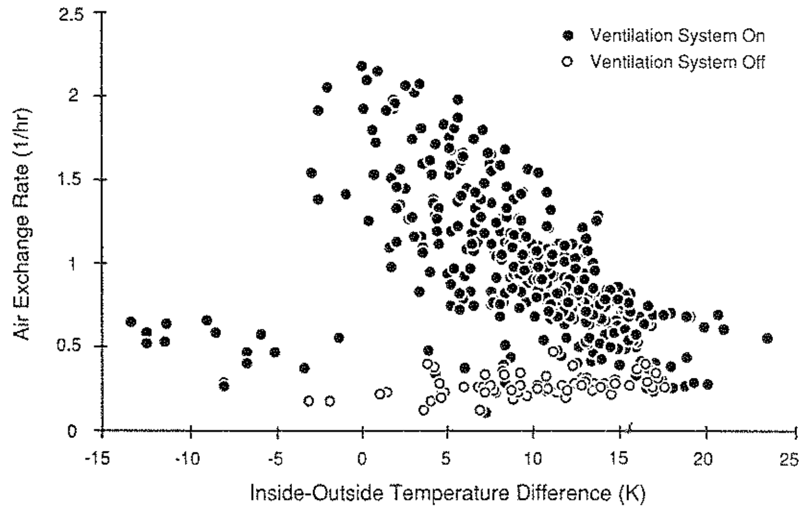

Figure 3 — Air Exchange Rates for Building B

On the other hand, Persily states that the data for Building C alone show a predictable relationship between daily average air exchange rate and peak CO_2 concentration. (See Figure 5, opposite.)

Turner's data are interesting since they demonstrate that neither measurement method alone is definitive. Tracer decay measurements using SF_6 must be corrected for the difference between actual (effective) volume in the building and the theoretical (gross) volume based on building dimensions. Furnishings, building equipment, walls, floors, office equipment, fixtures, and other objects occupy space which reduce the actual volume to something less than the building dimensions. Turner estimates that effective volumes are something on the order of 85% of the gross volume. He uses a range of effective volume estimates for his calculations from 80% to 95% of the gross volume.

When Turner considers the range of accuracy of CO_2 measurements, he arrives at a range of ventilation rates rather than a single value. He then uses the overlap between CO_2-determined rates and SF_6-determined rates to define a smaller range of values. He accepts these as reasonable estimates of the actual air exchange in a building. An example of his work is shown in Table 2, next page.

Comments from the Authors

We asked Turner and Persily what they had learned from their work. Here are some of their observations:

1. They both believe that building envelopes leak, sometimes quite a lot.
2. They also believe that there is considerable air movement in buildings between zones or spaces, and that this movement must be understood to rely on tracer gas or CO_2 measurements. All that is required for air movement is some path between two parts of a building and a pressure difference. This makes measuring ventilation difficult. To check for this, Turner uses tracer gas released in one zone in a building to see if the gas shows up in another zone.
3. Persily warned that when exhaust ventilation is used to control indoor air contaminant sources, it is important to know where the air that will be exhausted is going to come from. Turner said an important part of measuring ventilation or in designing systems is balancing the supply and exhaust (or return) air in each space or zone. Lots of zones Turner has measured are not balanced.
4. Turner said that he has seen buildings which actually had air exchange rates that differed from the designed flow by as much as a factor of two, and in either direction. That is, some were as low as half and other as high as twice the designed air flows. Persily's work (reported in ***IAQU***, May 1989) found similar differences.
5. Persily said that when buildings do leak, it is hard to control the ventilation.

For More Information

Turner and Persily both presented papers at ASHRAE's "IAQ '89; The Human Equation, Health and Comfort." The papers will be in the publication from that conference. ASHRAE has scheduled printing in mid-January. The list price will be $65, ASHRAE members' price will be $44. Contact ASHRAE for more information and to order a copy. ASHRAE Publication Sales, 1791 Tullie Circle, NE, Atlanta, GA 30329; (404)646-8400.

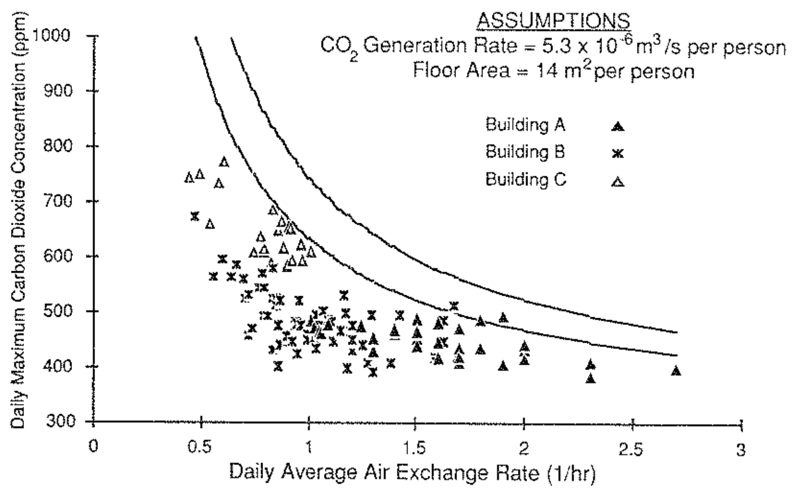

Figure 4 — Peak CO_2 Concentration versus Air Exchange Rate

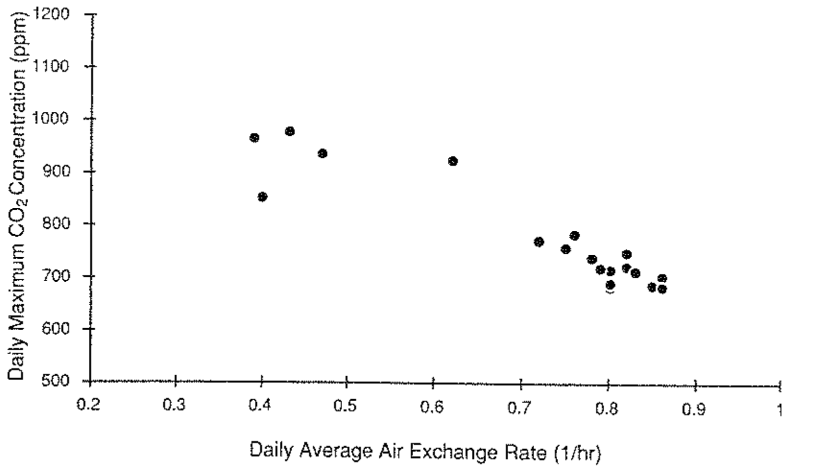

Figure 5 — Peak CO_2 Concentration versus Air Exchange Rate for One Floor of Building C

Table 2 — Comparison of Outdoor Air Quantities from Tracer Testing and CO_2 Testing

Test Zone	cfm from Tracer Decay	cfm from CO_2 Test	cfm from Combination
1	9,340-11,100	10,100-12,000	10,100-11,100
2	3,060-3,630	1,900-3,800	3,060-3,630
3	1,770-2,100	630-840	?
4	1,000-1,700	1,470-1,960	1,470-1,700
5	250-1,100	700-1,050	700-1,050
6	820-960	980-1,180	970
7	1,730-2,050	1,960-2,940	1,960-2,050

CO_2 Measuring Devices

Experts use carbon dioxide measurements when diagnosing indoor air quality problems and determining ventilation rates. Many authorities, and most researchers, recommend using a guideline level of 1,000 ppm CO_2 as an indicator of insufficient ventilation for a given occupant density. The new ASHRAE ventilation standard (62-1989) relies heavily on the 1,000 ppm guideline for establishing outside air supply requirements.

Two devices for measuring CO_2 are detector tubes and direct reading analyzers. Detector tubes are widely used because they are simpler, more economical, and more convenient. Many investigators consider the analyzers more reliable and accurate. Selection of the appropriate device will depend on the purposes of the measurements and the degree of accuracy or reliability required as well as the investigation budget and the availability of the analyzers.

Detector tubes

Detector tube measurements are made by pulling a determined quantity of air through a tube and determining the length of the colored stain. Detector tubes are closed, slender glass cylinders filled with solid chemicals which react with the subject air contaminant, resulting in a color change in the solid material. Tubes for measuring carbon dioxide are available in several concentration ranges. The concentration range of interest for indoor air work is 300 to 1,500 ppm (0.03%-0.15%).

A detector tube setup (pump or syringe and related equipment) costs three to five hundred dollars and the tubes cost $2 to $3 each. One tube is required per measurement. The measurements take two to five minutes each, depending on the type of air sampling device and the tube used. Piston samplers are faster than the squeeze bulb type.

To make a measurement, the ends of the tube are broken and the tube is placed in the manufacturer's holder, fitted with a calibrated squeeze bulb or piston pump. The recommended air volume is drawn through the tube by operating the squeeze bulb or piston pump. After the required amount of air is drawn through the tube, the length of color change is read against the pre-calibrated marks on the glass.

Since the stain fronts are not sharp, some individual operator judgment is required to determine the length of the stain. This judgment can result in large differences in the readings. Acceptable accuracy requires a close reproduction of the flow rate patterns intended by the manufacturer of the tube, and tubes from various manufacturers have produced uneven results when used with other manufacturers' pumps or syringes.

In a just published article, three Swedish researchers found detector tubes completely unacceptable for measuring ventilation rates. They calculated air recirculation based on detector tube and infrared analyzer readings and compared the results.

The calculated air recirculation based on infrared analyzer readings were very close to the settings on the valve controlling the air handler. At settings of 25%, 50%, and 75% recirculation, the three calculated rates were 25%, 50%, and 73%.

They made two sets of detector tube readings. In the first they used three types of tubes with each read by three people. In the second test they compared the results of one person reading two consecutive measurements with each of the three types of tubes.

Table 3 — Comparison between CO_2 measurements with an IR spectrophotometer (Miran 1A) and three types of reactor tubes. The midpoint of the total variation width of reactor tube readings performed independently by three persons is accounted.

	CO_2 Concentrations (µL/L)			Air Recirculation (%)	
Method	Inlet Air (C_3)	Recirculated Air (C_3)	Mixed Air (C_3)	Calculated	Valve Adjustment
Miran	386	596	464	37	33
Auer	250-700 300	200-700 450	200-800 400	67*	33
Dräger	300-350 325	350-450 400	300-450 375	67*	33
Kitagawa	250-260 260	470-500 470	370-390 390	62*	33

* Calculated from the medians

Table 4 — Comparison between CO_2 measurements with an IR spectrophotometer and three types of reactor tubes. The mean of the midpoints of the variation widths of detector tube recordings read by one person on two sets of reactor tubes.

	CO_2 Concentrations (µL/L)			Air Recirculation (%)	
Method	Inlet Air (C_3)	Recirculated Air (C_3)	Mixed Air (C_3)	Calculated	Valve Adjustment
Miran	410	513	479	67	66
Auer	0-500 225	350-1000 575	0-700 375	43	66
Dräger	300-400 325	350-450 380	200-400 290	<0*	66
Kitagawa	300-300 300	350-400 375	375-400 390	>100*	66

* Calculated from the means

Their results are shown in Tables 3 and 4. They show very large deviations among individuals' readings and among each individual's readings of the same tubes.

The trends in the readings reflect the values which the researchers believe are more accurate, but the absolute values are simply too far off to support the use of CO_2 detector tubes for the purpose of calculating ventilation (or recirculation) rates in nonindustrial building settings.

The researchers conclude that "IR spectrophotometers have a high precision for analysis of CO_2." From Tables 3 and 4, it is obvious "... that the air recirculations calculated from the detector tube readings not only demonstrate large spread and unsatisfactory precision, but the results could even be preposterous with values below 0% and above 100% when the air recirculation is calculated from the medians or means of the detector tube readings."

The air drawing device must be checked periodically for leakage at its fittings. The flow rate of the devices should be checked and maintained periodically with a reliable instrument such as a calibrated rotameter to verify proper volumetric sampling.

One investigator has encountered repeated interference from high humidities when using carbon dioxide detector tubes. Therefore, if elevated moisture is present, it might be wise to avoid the use of detector tubes.

If used properly, the detector tubes can be used for screening purposes, where a high degree of precision is not required. The user should consider the range of potential error involved in the use of the device and apply it appropriately.

Direct reading analyzers

Use of infrared analyzers for CO_2 is as uncommon as detector tubes are common. A dedicated CO_2 direct reading instrument costs about $2,000 to $3,000, and more versatile instruments are available at greater cost.

They must be maintained and calibrated carefully and frequently. Although they are bulkier and more costly, they are more accurate and reliable than detector tubes.

Infrared analyzers give a continuous readout of the CO_2 concentration based on the absorption of infrared energy by the CO_2. The device samples air at a set sample flow rate. The devices vary greatly in size and weight, with the smallest weighing in at about 25 pounds and about a cubic foot of volume. They are considered portable instruments, although a cart for their transport is very useful.

For More Information

A detailed discussion of air sampling devices is contained in the American Conference of Governmental Industrial Hygienists' *Air Sampling Instruments for Evaluation of Atmospheric Contaminants*. It is available from ACGIH, P. O. Box 1937, Cincinnati, OH 45201. It is revised periodically and is an indispensable resource for air sampling.

Reference: K. Ancker, et.al., "Evaluation of CO_2 Detector Tubes for Measuring Air Reirculation." *Environment International*, Vol. 15, Nos. 1-6, pp. 605-608.

Contacts: William Turner, PE, Harriman Associates, 292 Court Street, Auburn, ME 04210; (207)784-5728. Andrew Persily, Ph.D., NIST, Gaithersburg, MD 20899 (301)975-6418 ♦

Conference Report

NIVA Course Focuses on SBS

During October 16-20, 1989, forty physicians, industrial hygienists, engineers, architects, and scientists from Scandinavia and other European countries attended a week-long course in Copenhagen on "The Sick Building Syndrome." The course was sponsored by the Nordic Institute of Advanced Occupational Environment Studies (NIVA). NIVA is an association of Scandinavian countries that sponsors courses in occupational health for professionals and scientists.

The course was an in-depth review of the nature and causes of SBS, measurement of indoor air contaminants and climate, and measures to control indoor air quality problems. Speakers included the leading indoor air authorities in Scandinavia and others from Europe. Bill Cain from the John B. Pierce Foundation at Yale and ***IAQU*** Editor Hal Levin from the U.S. represented North America, along with Doug Walkinshaw from Canada, who is the president of "Indoor Air '90."

Swedish Indoor Air Proposals

Thomas Lindvall of the Swedish National Institute of Environmental Medicine presented the opening address and overview lecture. He gave a very thorough introduction to the subject. During his lecture, he presented proposed criteria for ventilation system design. They are listed in Table 5 below.

Lindvall described the Swedish indoor air quality control proposals listed in Table 6 below. While some of these proposals may seem extreme to American readers, the Swedes (and other Scandinavians) have been aware of and dealing with indoor air pollution much

Table 5 — Criteria for HVAC System Design

Occupant Response Factor*	% of occupants
Detect any odor	<50
Detect mucous membrane irritation	<10
Experience discomfort	<20
Experience annoyance	<5

* Judged or perceived by non-adapted visitors/semi-visitors to the space.

Table 6 — Swedish Indoor Air Proposals

1. Declaration by designer/builder.
   a. Chemical content of materials.
   b. Estimated pollutant emissions.
   c. Estimated side effects of use of the materials.
2. Minimum ventilation of 0.5 air changes per hour outside air.
3. Classification of ventilation system.
4. Prohibition of return air systems.
5. Prohibition of general air humidification.

longer than we have. There also seems to be far less ventilation in Scandinavian buildings. This is probably because they are much better at creating tight seals for the purpose of saving energy. However, the price of this effectiveness has been poor indoor air quality.

Odor and Irritation

A full day was devoted to understanding odor and irritation. We were struck by the similarities between the hypothesized mechanisms of odor perception and of irritation. An "odor event" apparently occurs when an active chemical molecule penetrates nonmotile cilia to reach receptor cells. An "irritation event" apparently occurs when an active chemical molecule penetrates a mucous membrane in the upper respiratory tract, for example, or a lipid layer which overlays the aqueous membrane covering the eye. In both cases, the mechanisms are not demonstrated but only hypotheses.

Peder Skov (of Danish Town Hall Study fame) described his work showing that noncomplaining occupants of high-complaint-level buildings exhibit visible physiological changes in the eye; these changes are not found in the eyes of noncomplaining occupants of noncomplaint buildings. Skov's work suggests that studying the eye using his techniques can assist in determining the likelihood of an SBS or problem building.

In the Danish Town Hall Study, Skov found that eye irritation increased proportionally to the amount of fleecy surfaces present in the building. This irritation was also accompanied by unstable tear film as well as epithelial damage.

Bill Cain of Yale presented his hypothesis that nicotine in ETS is responsible for the irritation experienced by those exposed to tobacco smoke. Cain's hypothesis has not been published, but much of his work has built support for this theory. Cain said we have much to learn about irritation and he doesn't think we will understand SBS until we understand irritation.

Sensitivity to odors, Cain said, ranges over concentrations with differences up to 10^{14}. For example, ethane has a detection threshold of 120,000 ppm (1.2×10^5) while 2-methoxy-3-isobutylpyrazine has a detection threshold of 5.4×10^{-8} ppm. The potency and characteristics of odors are quite varied, Cain said.

In relation to SBS, Cain indicated that irritation potential may not be apparent when a chemical is first smelled. Smell decreases over time (with exposure) but irritation increases. He gave the example of ammonia. A sniff of it gives no irritation at first. The odor decreases over time, but the irritation increases if exposure continues. With repeated exposure, odor perception decreases while irritation increases. Cain relates this to the fact that SBS does not usually appear on the first day of exposure but usually occurs after a few days in the new environment. The cumulative exposure leads to the irritation response, he said.

Odor and irritation are mutually inhibitory, according to Cain. The presence of one lessens the perception of the other. Therefore, you could remove an odorant and get increased irritation. This is extremely important in investigations and remedies of SBS complaints. If it is incorrectly assumed that the odorant is causing the irritation (or the complaints), then removal of the odorant might only increase complaints.

Where Will It Lead?

There were many other outstanding presentations. Space limitations do not permit full coverage here. The authors' papers, distributed to the attendees, represent a broad collection of relevant literature. These papers could be the basis of a future publication.

A future offering of the course is also a possibility, although we are aware of no such plans currently. However, we noted a significant difference between this course and others we have attended. The longer time period and comprehensiveness of the program provided an in-depth presentation which we simply have not observed elsewhere.

For More Information:

Contact: Nordic Institute of Advanced Occupational Environment Studies (NIVA), c/o Institute of Occupational Health, Topeliuksenkatu 41 a A SF-00250 Helsinki, Finland, tel 358-0-47471. Or, course organizer: Peter Wolkoff, Arbejdsmiljoinstituttet, Lerso Parkalle 105, DK-2100, Copenhagen Ø, Denmark. ♦

News Briefs

ASHRAE Issues Standard 62 Draft Addendum

On October 26, just one month after publishing Standard 62-1989, ASHRAE issued a Public Review Draft of an addendum to the standard. The purpose of the addendum is to return to the adopted version of the standard those items that were modified in response to procedural objections by appellants. The changes update some of the references and cited authorities for National Primary Ambient Air Quality Standards and indoor air levels.

The Public Review Comment Period begins December 11, 1989, and closes February 9, 1990.

Copies of the draft may be obtained by sending a check for $5 payable to ASHRAE. Send orders and comments to the Manager of Standards, ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329. ♦

Call for Papers: ACEEE 1990 Summer Study

"Indoor Air Quality" and "Occupant Health and Comfort" are among the 15 topics listed in the conference brochure for the ACEEE 1990 Summer Study on Energy Efficiency in Buildings. The conference will be held August 26-September 1, 1990, at the Asilomar Conference Center, Pacific Grove, California. Abstracts, which are due December 4, 1989, should not exceed 250 words, should be typed double-spaced on one page, and should include title and category of submission (refereed paper or poster). Do not include authorship or institutional affiliation on the abstract. On a separate page, include author(s) name and contact information. Send six copies to ACEEE 1990 Summer Study Office, c/o Ed Vine, Building 90H, Lawrence Berkeley Laboratory, Berkeley, CA 94720.

Papers will be selected on the basis of clarity of thought and presentation, relevance of topic to the conference, presentation of new material, and likelihood of stimulating discussion and debate. ♦

Information Exchange

EPA IAQ Publications

EPA has updated its publication, *Current Federal Indoor Air Quality Activities.* The 68-page booklet, prepared with cooperation of the Interagency Committee on Indoor Air Quality (CIAQ), was compiled by the Indoor Air Division, Office of Air and Radiation, at EPA in Washington. Congress mandated the establishment of the CIAQ in the Superfund Amendments and Reauthorization Act (SARA) of 1986. EPA asked each federal agency to submit a list of its indoor air activities. The booklet summarizes the responses to that request.

Their are dozens of activities listed for each of the major IAQ agencies: EPA, CPSC (Consumer Products Safety Commission), DOE (Department of Energy), and the Department of Health and Human Services (HHS), which contains NIOSH. Other Departments such as HUD, Interior, Labor, and Commerce also have activities described in the booklet.

For each activity the booklet lists the issue/major activity, purpose, status, lead agency/office, and contact person with phone numbers. We roughly estimated a total of about 350 to 500 projects contained in the booklet. Although described as current through May 1989, there are a few entries even more current than that. Notable among these is EPA's own Report to Congress, submitted in August just days before the booklet went to press.

Examination of the booklet revealed only 30 publications listed, other than a scattering of technical reports. Most of the listed publications were written for the nontechnical reader. Many of the most important reports published by EPA and other agencies are listed with the description of the particular project rather than in the listing of publications at the rear. This means the reader in search of detailed or technical publications

Table 5 — Publications Available from Federal Agencies

Publication:	Agency/Contact
Report to Congress	EPA/Public Information Center (202)475-8740
Indoor Air Reference Data Base	EPA/Norman Childs (contains over 3,400 citations) (919)541-2229
TEAM Study: Indoor Air in 10 Public Buildings (Vols. 1 and 2)	EPA/Lance Wallace (202)382-5792
IAQ Model (computer model)	EPA/ Leslie Sparks (919)541-2458
IAQ Data Base for Organic Compounds	EPA/James White (919)541-2458
NO_2 Health Research	CPSC/Lori Saltzman (301)492-6477

must peruse the entire booklet. We have scanned the booklet to identify a few publications we think will be of interest to our readers. They are listed in Table 5.

The good news is that the booklet lists the phone number of each project officer. That should make it easy to get a free copy if any extras are still available. If purchased through the National Technical Information Service (NTIS), these reports can be expensive. (We learned the hard way.) ◆

Readers' Forum

Odorless Paint

Dear Hal,

Your article in Vol. 2, No. 4 of IAQ Update brought up the question of whether adding sodium bicarbonate to latex paint made it "healthier." I first heard of this practice from Australians who had been reading American advice books on "healthy" housing. Their ready acceptance of water-based paint as "good" for hypersensitive people was of some concern to me, as inspection of their dwellings revealed a greater incidence of neglected damp problems than I generally saw in domestic architectural practice. As water-based paints were being inappropriately used, and the additive might reduce performance even further, I asked paint chemists for some speculations on its effect. Your readers may find a couple of answers of interest.

One comment was that although visible bubbling reduces, much more air than usual could be entrained in the surface bubbles of the applied paint, giving a poor finish and the likelihood that the paint will wear off the wall much sooner than normal. Another comment was that the paint in the can might be expected to thicken and perhaps become unusable during a period of 2 to 16 hours. Sodium bicarbonate has a low surface tension which is what makes it a good washing agent, but in paint it may have the effect of increasing the sensitivity of the finished surface to humidity, especially if the type of binder used in the paint formulation is itself water sensitive.

All answers suggested possible long-term problems with performance — even if this only meant the need to paint more often, it didn't seem in my opinion a worthwhile risk in exchange for a little less bother during and soon after application. One practical outcome of these enquiries was that in 1983, I specified solvent-based oil paint for a seaside house on a cold, damp site (38 degrees latitude). The paint was applied at the peak of the Australian summer to most of the inner walls of a small, new, unfurnished house which had been designed for easy cross-ventilation. Unexpectedly, there was a positive response from both painter and client. The painter was enthusiastic, preferring the paint to water based as application was easier given the hot, dry weather at the time. The owner, an elderly woman with reduced lung capacity due to surgery, and also many sensitivities, moved in a week later and reported no adverse effects.

This example is but one of many which raises the question of whether materials which are less odourous during application are necessarily "healthier" than others in the long term. It is very tempting to make decisions mainly or wholly on this assumption, because it proves successful so often. The subjective experience of sniffing can be shared with others, and this makes it a rather convincing test. However, the possibility exists that in a few cases taking decisions on this basis may lead to a less healthy building solution — maybe, in the case of hypersensitive individuals, perpetuating rather than alleviating their symptoms. Such individuals may have difficulty seeing any connection — the obvious explanation offered will be "the condition must be getting worse."

Naturally the choice of "safer" materials tends to be what most people focus on first when building healthier — but there seems to be a tendency to oversimplify materials into categories of "good" and "bad." Differences in context and conditions of application are often overlooked. I see sodium bicarbonate as an example of a material found "good" in some contexts such as household management, but not necessarily "good" as a paint additive unless short-term comfort is the major criterion. There may be a good/bad parallel here with casein — a useful ingredient for natural paint, but one of the villains behind sick building complaints associated with some self-levelling screeds in several countries including Sweden. Where the screed's alkalinity and moisture content were both high, irritants formed — the chemistry of the casein was different to what could be expected in other applications.

The debate on what makes "healthy" paint promises to be a long one. In the absence of health-oriented performance data the best we can do is to rely on conjecture and airing procedures — and at worst on a folklore of cut onions and pans of water! It would be interesting to hear of other reader's experiences along these lines.

Yours sincerely,

Heather Robertson
Research Architect
School of Architecture
Royal Institute of Technology
Stockholm, Sweden

Editor's reply:
We are grateful to Ms. Robertson for her informative letter. She has raised many excellent points.

We welcome communication from readers with useful experience and knowledge to pass along. Please send your comments and letters to our editorial office in Santa Cruz. ♦

Calendar

December 4-6. **ASTM Subcommittee D22.05 on Indoor Air.** Orlando, Florida. Contact: George Luciw, ASTM Headquarters, 1916 Race Street, Philadelphia, PA 19103; (215)299-5571.

February 6-8, 1990. **Georgia Tech. Research Institute Indoor Air Quality Symposium.** Atlanta, Georgia. Contact: Ann Harbert, GTRI, O'Keefe Bldg., Rm. 146, Atlanta, GA 30332; (404)894-7430.

February 9, 1990. **Georgia Tech. Research Institute Sampling and Analysis Workshop.** Atlanta, Georgia. Contact: Ann Harbert, GTRI, O'Keefe Bldg., Rm. 146, Atlanta, GA 30332; (404)894-7430.

February 11-14. **ASHRAE Winter Meeting.** Atlanta, Georgia. Contact: Judy Marshall, ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 20239; (404)636-8400.

April 4-6, 1990. **Excellence in Housing '90** — Eighth Annual International Energy Efficient Building Conference and Exposition, Denver, Colorado. Sponsored by Energy Efficient Building Association, University of Southern Maine, Technology Center, Gorham, ME 04038; (207)780-5143, Fax (207)780-5129. *Includes a design competition, exhibits, technical sessions, and case studies. Indoor air quality for health and comfort is one of the four primary topics listed in the conference announcement. Pre-conference workshops (April 4) will include "Ventilation systems for mechanical contractors."*

April 24-26, 1990. **ASTM Subcommittee D22.05 on Indoor Air.** San Francisco, California. Contact: George Luciw, ASTM Headquarters, 1916 Race Street, Philadelphia, PA 19103; (215)299-5571.

April 26-27, 1990. **Blueprint for A Healthy House Conference.** Cleveland, Ohio. Contact: Al Wasco, Housing Resource Center, 1820 W. 48 Street, Cleveland, OH 44102; (216)281-4663.

October 16-19, 1990. **Indoor Radon and Lung Cancer: Reality or Myth?** 29th Hanford Symposium on Health and the Environment. Richland, Washington. Inquiries should be addressed to Fred T. Cross, Symposium Chairman, Battelle PNL, P.O. Box 999, Richland, WA 99352; (509)375-2976.

INTERNATIONAL

April 24-26, 1990. **Indoor Air Quality and Ventilation in Warm Climates.** Lisbon, Portugal. Conference registration: Secretariat International Indoor Air Quality & Ventilation Conference, British Occupational Hygiene Society, 1 St. Andrews Place, London NW1 4LB, UK.

June 13-15, 1990. **Roomvent '90.** Second International Conference on "Engineering Aero- and Thermodynamics of Ventilated Room," Oslo, Norway. Contact: Room Vent, c/o Norsk VVS Teknisk Forening, P.O. Box 5042, Maj N-0301 Oslo, Norway.

July 29-August 3, 1990. **5th International Conference on Indoor Air Quality and Climate.** Toronto, Ontario, Canada. Contact: Dr. Douglas S. Walkinshaw, Canada Mortgage & Housing Corp., 682 Montreal Road, Ottawa, ON K1A OP7, Canada; (613)748-2714.

September 3-6, 1990. **Energy, Moisture, Climate in Buildings.** Rotterdam, The Netherlands. Contact: Mr. G. de Vries, Bouwcentrum, Weena 760, P. O. Box 299, 3000 AG Rotterdam, the Netherlands. *The conference will consider three major topics: Heating, cooling, and ventilating efficiency; condensation and mold growth; and, indoor climate.*

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