Indoor Air Pollution

The environment moves indoors

by Hal Levin

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Exposure to a wide variety of indoor air pollutants is currently believed to present a greater involuntary risk of premature death than exposure to pollutants in outdoor air, drinking water, and food. The risk of death from exposure to indoor pollutants may not be greater than certain voluntary activities such as cigarette smoking, auto accidents, and home accidents; or some occupational hazards such as uranium mining. Writing in the May 1988 issue of *Scientific American*, Anthony Nero of Lawrence Berkeley Lab. states that "the greatest exposure to airborne combustion products, volatile toxic chemicals, and radioactivity typically occurs not outdoors but inside residences, offices, and other nonindustrial buildings—settings that traditionally have been neglected by pollution-control agencies." Nero says the risks posed by inhaling the air at home or work can "substantially exceed" generally applied risk limits used to regulate pollutants in outdoor air or drinking water (Table 1).

The majority of the indoor air related risk of premature death is based on estimates of radon exposure associated lung cancers, but risks from exposures to other chemicals in indoor air are as great as those associated with exposure to chemicals or radiation in industrial settings (Table 1). Biological aerosols such as *Legionella*, which causes the often fatal Legionnaire's disease; mycotoxins; and allergens have recently been recognized as important indoor air contaminants posing significant health risks (Table 2).

The regulation and control of exposure to indoor air pollutants is extremely difficult compared to regulation of industrial workplace exposure or the quality of outdoor air. More than 80 million U.S. buildings cannot feasibly be monitored, nor is government quick to intrude on the privacy of the home or the assumptions of healthy environments in such places as offices, schools, stores, public assembly buildings, or libraries.

Significant but less dramatic indoor air pollution impacts productivity, health, and well-being of nearly all Americans. Respiratory illness attributed to indoor air affects most people an average of more than once per year. Causal or contributory indoor air contaminants range from bacteria and viruses to combustion byproducts, from volatile organic chemicals to allergens. Days of lost work and decreased vitality have a significant effect on the economy and on personal well-being. A recent study found that army recruits in newer, mechanically ventilated barracks were about 1.45 times as likely to suffer respiratory illness as those housed in older, naturally ventilated barracks. Decreased indoor air quality is assumed to be causally related to these excess respiratory cases.

Indoor air pollution sources are manifold and they are integral parts of modern life. Many contaminants are emitted by building materials, furnishings, pesticides, paints, and consumer products. In smoking-permitted environments, exposure to environmental tobacco smoke (ETS) composed mostly of organic aerosols is believed to account for as many premature deaths annually as exposure from working at a chemical plant. Pesticide residues are widely distributed in both residential and nonresidential indoor air. Combustion appliances, particularly those that are not properly adjusted, operated, and vented, can result in substantial build-up of indoor air contaminants to levels well above those found outdoors (Table 3).

Some of the handful of pollutants that are regulated in outdoor air are found at indoor levels exceeding the regulatory limits for outdoor air. Most volatile organic compounds (VOC) found indoors are at concentrations from 1 to 10 times (or more) those found in outdoor air. Biological aerosols become problematic when their air levels outdoors are amplified indoors.

But for most air pollutants found indoors, there simply are no regulatory guidelines or limits. The greatest limitation on understanding indoor air pollutants is the lack of knowledge about the health effects of exposure to most of them at commonly found indoor levels. The list of indoor air contaminants measured to date is quite large; there are over 2,000 compounds found in tobacco smoke alone. Meaningful regulation can be established when health effects are adequately understood.

In an effort to assess the potential health and physiological effects of organic chemicals emitted from building materials, in 1982, Lars Mølhave of Denmark identified 42 commonly used building materials and measured a total of 62 VOCs emitted. The arithmetic average emission rate was 9.5 mg/m^2h while the range of emission rates was extremely large. Three model rooms constructed from the materials contained between 23 and 32 of the compounds at concentrations from 1.6 to 23.6 mg/m^3. When the cancer risks and health effects, including irritation, of the 62 compounds were reviewed, 82 percent were known or suspected mucous membrane irritants and 25 percent were suspected or known animal carcinogens.

Considering that a very high percentage of VOC commonly emitted from building materials are known or suspected mucous membrane irritants, it is reasonable to expect significant numbers of building occupants to experience mucous membrane symptoms in newly constructed, remodeled, or furnished buildings. In 1981, Turiel et al suggested that a number of contaminants acting synergistically may be responsible for an increased symptom incidence in problem buildings,[1] and Hollowell suggested that the composite effect is the reason building occupants complain about what they ought not be able to perceive.[2]

Sick Building Syndrome

Sick Building Syndrome (SBS) may affect as many as 20 percent of U.S. office workers. In a survey of U.S. office workers, symptoms associated by respondents with poor air quality included a tired, sleepy feeling—56 percent; a congested nose—45 percent; eye irritations—41 percent; difficulty in breathing—40 percent; and headaches—39 percent.[3] Efforts to control and abate the causes of SBS in buildings are potentially important to the economy and to public health (Table 4).

Table 1—Lifetime Risk of Premature Death from Selected Indoor Air Pollutants and Other Risks (After Nero 1988)

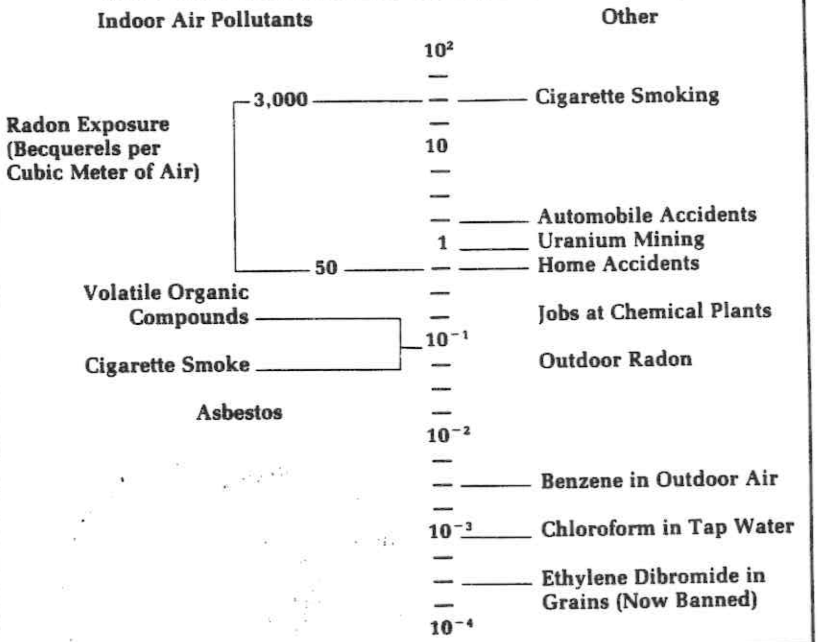

Table 2—Major Indoor Air Pollutants in Approximate Order of Importance

- Radon
- Tobacco Smoke
- Volatile Organic Compounds
- Asbestos
- Carbon Monoxide
- Nitrogen Oxides
- Biological Aerosols
- Particulate Matter
- Carbon Dioxide

The complexity of modern buildings presents significant unmet challenges to designers, operators, and investigators. Problems other than air quality can cause or exacerbate the symptoms of SBS. Psychological and social as well as physical, chemical, and biological factors interact to create occupant physiological and health responses. Detailed, comprehensive investigations of building associated outbreaks are infrequent due to the resources and personnel required to conduct them. Measurement of many contaminants and other environmental factors is expensive and difficult. Even comprehensive monitoring of environmental parameters often fails to produce definitive evidence of causality. Yet epidemiologic evidence strongly supports an association between occupancy of the building and the reported symptoms. Wallace[4] has reviewed findings from SBS studies published during the past four years (Table 5).

Building Related Illness

Many authors explicitly distinguish SBS from Building Related Illness (BRI), which includes allergic respiratory diseases—sinusitis, tracheobronchitis, asthma, hypersensitivity pneumonitis, and humidifier fever; skin diseases—irritant, allergic, and photodermatitides; irritant syndromes—carpet shampoo, formaldehyde; and infections—Legionnaire's disease, Pontiac fever, Q fever.[5-9]

Findings From Major Studies

One large scale British study found an elevated rate of SBS complaints in mechanically ventilated buildings compared with those naturally ventilated. Another large-scale British study of 30 buildings found "few differences in symptom prevalence" between naturally and mechanically ventilated buildings. The definition of mechanical ventilation here was "a ducted system but with no plant for heating and cooling." Higher prevalence rates were found for all symptoms in air-conditioned than in non-air-conditioned buildings and for females than for males. Higher prevalence was found for all symptoms and all ventilation system types in public sector than in private sector buildings.[10]

A group of Danish investigators found no correlation between complaints and building ventilation type. They found a number of factors associated with higher symptom prevalence rates including age of building, sex of occupant, job category, type of work, temperature, the number of occupants, the amount of open shelving, and what they called the amount of "fleecy material."[11] While reported symptom levels were high for mucosal irritation—28 percent; and for general symptoms in the form of headache, abnormal fatigue or malaise—36 percent; the measurements of environmental parameters did not result in elucidation of the epidemiology. Based on findings from the Danish study, some potentially effective preventive measures have been identified (Table 6).

Table 3—Important Sources of Indoor Air Pollutants

Outdoor air
- Vehicular traffic
- Industrial processes
- Dusts, pollens, and microorganisms
- Contaminated soil or water

Building materials
- Composite wood products
- Paints and wood finishes
- Sealants
- Caulking
- Insulations
- Adhesives
- Ceiling tiles

Furnishings
- Partitions
- Furniture
- Carpet

Equipment

Fossil fuel fired appliances

Consumer products

Maintenance materials
- Waxes
- Polishes
- Disinfectants
- Deodorizers
- Pesticides

Table 4—Common Features of Symptoms Reported in Cases of Sick Building Syndrome[16]

- Eye, nose, and throat irritation
- Sensation of dry mucous membranes and skin
- Erythema
- Mental fatigue
- Headaches, high frequency of airway infections, and cough
- Hoarseness, wheezing, itching and unspecific hypersensitivity
- Nausea, dizziness

Limitations of Investigations

There are numerous limitations on investigations of problem buildings that suggest explanations for the frequent failures to identify etiologic agents or contributory building factors. Among these limitations are cost, timeliness, investigatory methods, building complexity, building dynamics, institutional contraints, and insufficient guidance to investigators.

Unsystematic and incomplete investigations result in inadequate diagnoses and unsuccessful remedial efforts. Yet complete, systematic investigations are rare. Expert investigators are usually selected by the occupants or building owner according to their perceptions of the etiology of the problem. Expertise is usually confined to one or a limited number of fields resulting in incomplete investigations in many buildings.[9]

The perseverance of the investigators and the availability of methods can determine whether chemical and biological agents can be eliminated as etiologies of building associated outbreaks.[5] In many instances, ventilation system problems are identified early in the investigation. Modifications to the system equipment, operating schedule, or operational modes such as air flow and temperature, will result in a significant reduction of complaints and symptoms, and the investigation will be terminated before problem causes are defined.

Protocols to guide investigations of problem buildings have not been widely tested, validated, or promulgated by any standards development organization. Standardized sampling and analytical methods for indoor air are limited, and those that exist are not uniformly applied or widely used. Efforts by ASTM to address these shortcomings are under way.[13] However, interbuilding variations limit standardization of investigations and comparability of results.

Even where extensive environmental monitoring is conducted, interpretation of results is limited to guidelines and standards developed in and for different contexts such as the industrial workplace and ambient air. No applicable standards or guidelines are available for most indoor air pollutants.

Comprehensive sampling and analysis to identify airborne contaminants is extremely expensive and rarely definitive in problem building investigations. Monitoring for airborne VOC is expensive and there is a lack of general agreement regarding appropriate monitoring methods. Characterization of total VOC is not expensive, although the methodological problems are significant. But to identify most of the compounds is expensive and time-consuming.

Designer, operator, and occupant perceptions frequently differ from each other and from actual building conditions. Understanding, communicating, and resolving these differences is necessary to improve total building performance and occupant comfort and satisfaction. Investigator interviews with some but not all of these parties can result in biased assumptions or hypotheses.

Building Diagnostics

Building diagnostics is the name given to a set of practices used to assess the current performance and capability of a building and to predict its likely performance in the future.[14] While building diagnostics can be valuable at many stages in the life of a building, it may be most useful in investigations of problem buildings. Four elements are essential to building diagnostics, according to the National Academy of Science (NAS) report; they are as follows:

- knowledge of what to measure,
- availability of appropriate instruments and other measurement tools,
- expertise in interpreting the measurements, and
- capability of predicting the future condition of the building based on that interpretation.

Several authors have proposed phased investigations of problem buildings or in other applications of building diagnostics.[8,14,15] Woods et al (Reference 8) have divided the phases as follows.

- **Consultation**—Scope of the investigation is defined and observations of the building and its systems are made (walk-through survey). Few or no instrumented measurements are made.

Most advocates of phased diagnostic investigations of problem buildings urge extremely limited use of airborne monitoring during the initial phase. They assert that the majority of building problems can be solved or resolved without extensive monitoring. Furthermore, it is argued that monitoring is of limited effectiveness until it can be focused on hypothesized causal agents or factors.

Table 5—Causal Factors Identified in Investigations of SBS[4]*

Multifactorial
Sex of occupant
Hayfever allergens
Smoking
Home-related illness
Carbonless copy paper use
Xeroxing >25 sheets/d
VDT use 1 h/d
Unsatisfied with job
Physical Factors
Ventilation
Ions
Other physical causes (noise, glare, distorted light spectrum)
Chemical Factors
Formaldehyde
Other volatile organic chemicals
Semivolatile organic chemicals
Biological Factors
Molds
Bacteria
Allergens

*The author has compiled this table using his data and that found in Reference 4.

Table 6—Potential Control Measures for SBS*

Smooth Surfaces on Interiors
Lowest Comfortable Air Temperature
Minimize Open Storage Shelving
Low Occupant Density
Maximize Outdoor Air Supply
Increase Worker Control, Privacy
Flexible Work Hours
Minimize Exposure in Stressful Jobs

*These are the author's control measures for the causal factors identified in Reference 11.

• **Qualitative diagnostics**—Hypotheses are formulated through engineering analysis; system performance will be initiated with limited measurements such as airflow and pressure differences. Medical evaluation will be used to identify suspect pollutants and air or bulk samples will be collected for these substances.

• **Quantitative diagnostics**—If further investigation is needed to test hypotheses, samples will be collected and analyzed and other environmental measurements will be made.

Potential Control Measures

There are four major approaches to indoor air quality control. They include the following.

• **Source Control**—Elimination, reduction, isolation, containment, or removal of sources. This includes selection and use of building materials, furnishings, cleaning products, pesticides, equipment, and consumer products. It also involves removal by exhaust ventilation of pollutants generated by processes within the building. This is considered the most effective control method.

• **Outside Air Supply**—Increased outside air supply volume, hours or period of operation—per day and weekends

• **Filtration**—Removal of particulate or gaseous contaminants through entrapment, adsorption, or chemical transformation

• **Space Air Distribution**—Improved supply of air distribution within the occupied spaces through ventilation system design, operation, and maintenance. Effective ventilation avoids short circuiting of supply air to exhausts or stratification resulting in elevated contaminate levels in the occupants' breathing zone.

The following articles provide a more detailed look at some of the major classes of indoor air contaminants. Subcommittee D22.05 on Indoor Air has been developing standard methods for sampling and analysis of these and other indoor air contaminants since 1985. Those with an interest and expertise in indoor air measurements are invited to participate in D22.05 activities. ●

References

[1]Turiel, I.; Hollowell, C.D.; Miksch, R.R.; Rudy, J.V.; Young, R.A.; and Coge, M.J.; 1983, "The Effects of Reduced Ventilation on Indoor Air Quality in an Office Building," *Atmospheric Environment*, Vol. 17 (1) pp. 51–64.

[2]Hollowell, C.D.; and Miksch, R.R.; 1981, "Sources and Concentrations of Organic Compounds in Indoor Environments," *Bull. N.Y. Acad. Med.*, Vol. 57: 962–977.

[3]Woods, J.E.; 1987, Testimony presented before the Subcommittee on Environmental Protection of the Committee on Environment and Public Works, United States Senate. November 20.

[4]Wallace, L.; 1988, "The Sick Building Syndrome: A Review," 81st Annual Meeting of APCA, Dallas, TX, June 19–24, 1988.

[5]Kreiss, K.; and Hodgson, M.; 1984, "Building-Associated Epidemics," in Walsh, P.J.; Dudney, C.S.; and Copenhaver, E. D.; eds., *Indoor Air Quality*, Boca Raton: CRC Press, Inc. 87–106.

[6]Hodgson, M.J.; and Kreiss, K.; 1986, "Building Associated Diseases," proceedings of the ASHRAE Conference IAQ'86: Managing Indoor Air for Health and Energy Conservation, Atlanta, GA, April 20–23, 1986, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

[7]Stolwijk, J.A.J.; 1984, "The 'Sick Building' Syndrome," in Berglund, B.; Berglund V.; Lindvall, T.; and Sundell, J.; *Indoor Air Proceedings of the 3rd International Conference on Indoor Air Quality and Climate," Vol. 7, Recent Advances in the Health Sciences and Technology*, Stockholm: Swedish Council for Building Research, pp. 23–29.

[8]Woods, J.E.; Morey, P.R.; and Stolwijk, J.A.J.; 1988, "Indoor Air Quality and the Sick Building Syndrome: A Diagnostic Approach," *Applied Industrial Hygiene*, in press.

[9]Mølhave, L.; 1987, "The Sick Buildings—A Subpopulation Among the Problem Buildings?" *Indoor Air Proceedings of the 4th International Conference on Indoor Air Quality and Climate*, Vol. 2, Berlin (West) August 17–21, 1987, Institute for Water, Soil and Air Hygiene.

[10]Hedge, A.; Wilson, S.; Burge, P.S.; Robertson, A.S.; Harris-Bass, J.; Matthew, R.; and Johnson-Marshall, 1987, "Indoor Climate and Employee Health in Offices," *Indoor Air '87, Proceedings of the 4th International Conference on Indoor Air Quality and Climate*, Vol. 2, Berlin (West) August 17–24, 1987, Institute for Water, Soil and Air Hygiene, pp. 492–496.

[11]Skov, P.; Valbjorn, 0.; and DISG 1987, "The "Sick" Building Syndrome in the Office Environment: The Danish Town Hall Study," *Env. Intl.*, Vol. 13, 339–349.

[12]Mølhave, L.; 1982, "Indoor Air Pollution Due to Organic Gases and Vapours of Solvents in Building Materials," *Env. Intl.* Vol. 8: 117–127.

[13]Levin, H.; 1988, ASTM Subcommittee D22.05 on Indoor Air: "Progress of Work to Develop Standard Methods for Sampling and Analysis of Indoor Air," (Paper 88-94.5), Presented at APCA Annual Meeting, Dallas, TX, June 20–24, 1988.

[14]NAS 1985. *Building Diagnostics: A Conceptual Framework*, Washington, D.C., National Academy Press.

[15]Sterling, E.; McIntyre, E.; Collett, C.; Meredith, J.; and Sterling, T.; 1987, "Field Measurements for Air Quality in Office Buildings: A Three Phased Approach to Diagnosing Building Performance," in Taylor, J., ed., *ASTM STP 957—Sampling and Calibration for Atmospheric Measurements*, Philadelphia.

[16]WHO, 1983, *Indoor Air Pollutants: Exposure and Health Effects*, EURO Reports and Studies 78, Report on a meeting of the Working Group on Assessment and Monitoring of Exposure to Indoor Pollutants, Copenhagen: World Health Organization, Regional Office for Europe.

[17]NIOSH 1987, *Guidance for Indoor Air Quality Investigations*, Cincinnati: National Institute for Occupational Safety and Health.