ARCHITECTS AND THE ENVIRONMENT

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PROGRESSIVE ARCHITECTURE

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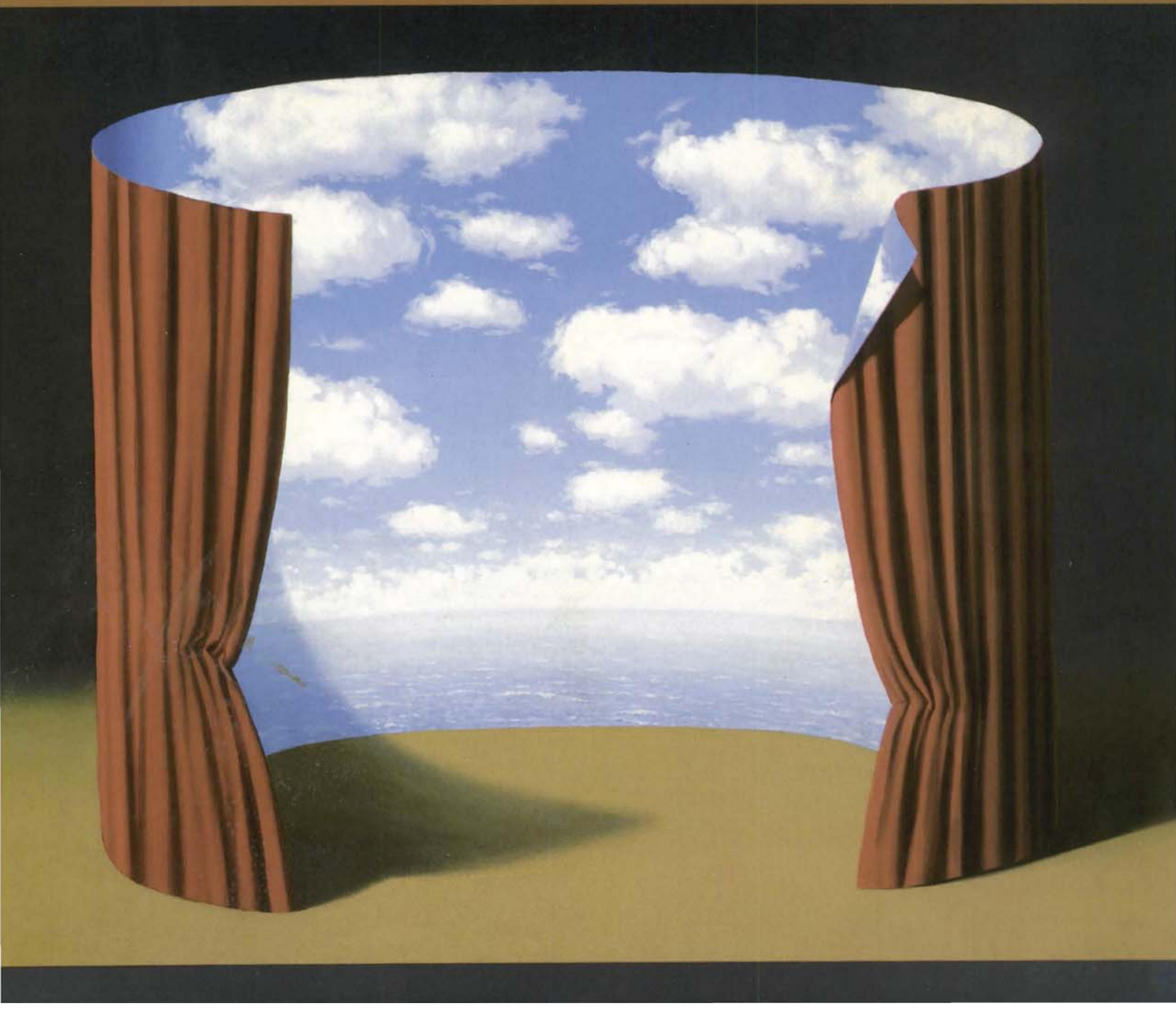

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Executive and editorial offices
600 Summer St., P.O. Box 1361
Stamford, CT 06904
(203-348-7531).
FAX 203 348 4023
For Subscription Inquiry:
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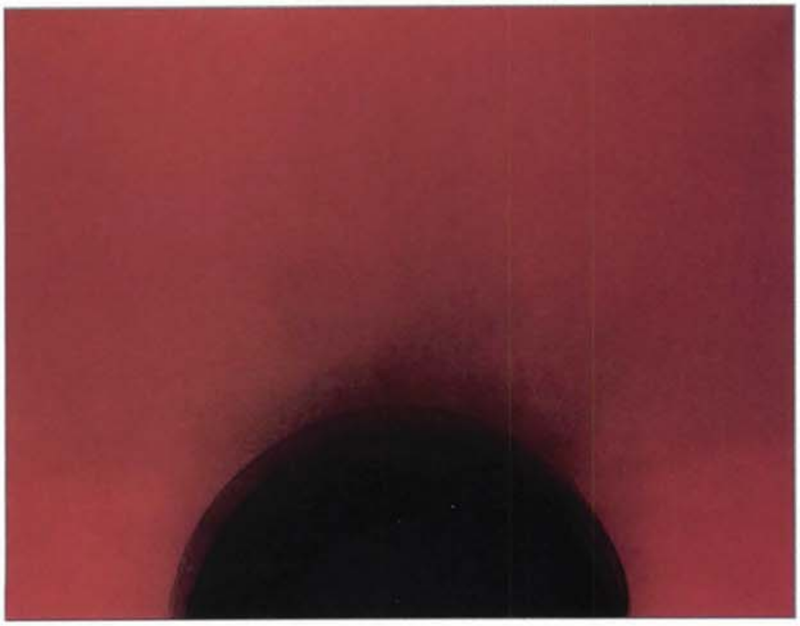
Technics: Here We Go Again?



Otto Piene, The Sun Burns, *1966, Kunstmuseum, Düsseldorf, Germany.*

I suspect that many architects who were either practicing or preparing for the profession during the last "environmental crisis" (which some date from the Santa Barbara oil spill of 1969) may, like me, feel some impatience and some uneasiness with the proclaiming of a new environmental crisis. The impatience comes from broadcasts on television and weekly news magazines that seem too familiar – solid waste disposal, recycling, the greenhouse effect, ozone holes and toxins in the land, sea, and air. Didn't we learn anything from the last one? The uneasiness, I suppose, derives from a sense that, if we didn't, why bother now? And for those of us who have emphasized the "environmental" side of the profession, have our efforts been wasted?

I think not. Most of the discussions about the environment last time around were about large ecological systems and land planning, and were symbolized by Bucky Fuller's catchword, "Spaceship Earth." In the world of practice, environmental concerns got no closer to the building than the site outside, except for a few architects like Malcolm Wells, who challenged us to rate on-site environmental impacts, and to marry architecture with the site by building underground (P/A June 1974, pp. 59–63). It was not until after the 1973 oil embargo/energy crisis that architects found an arena in which they could practice on their own turf – but this was a different crisis, a different agenda, different people, and a different time. By 1978, when the watershed *Second National Passive Solar Conference* was held in Philadelphia, an entire decade had passed since the environment began to make headlines, and the work spawned by the 1960s crisis was already beginning to mature.

In the end, ecological environmentalism meant activism, and the basic principles of ecologically sound site development were codified in wetlands ordinances, soil sedimentation and erosion control requirements, and the stormwater management provisions of land development regulations. These routinely require retention and detention basins and drywells to control runoff from parking lots and roofs – devices that only the most environmentally sensitive architects would have dared advocate to clients two decades ago. Today, these and flexible zoning tools that allow designers to work around steep slopes and woodlots are commonplace. They are part of the legacy of the preceding environmental crisis.

So, I think we did learn from the last crisis. And I think that we're going to learn a lot more this time around, because architects are focusing on the environment inside the building. The catch phrase of the broader sustainable development movement is "think globally, act locally." It's not an expression one hears much in the architectural literature, but it is exactly the ethic of a growing body of architects, whether they are avoiding the use of tropical hardwoods, specifying finishes low in air-polluting volatile organic compounds, or favoring materials that contain recycled constituents. Technics authors Kevin Teichman and Hal Levin remind us that Levin introduced the term "building ecology" in P/A in 1981 (April, pp. 173–175), and that the concept is especially apropos today: A building comprises a complex set of systems, and we all need to learn more about them, and about our relationships and responses to them. **Kenneth Labs** ■

Technics
Indoor Air Quality – for Architects

Indoor Air Bulletin editor **Hal Levin** and **Kevin Teichman**

of the Environmental Protection Agency review the scope of issues, concerns, and measures

that architects can take to improve indoor environmental quality.

1 Phases and Subcategories of Healthy Building Design

Site planning and design
Ambient outdoor air quality
Local source control

Overall architectural design
Vehicle access
Building openings
Operable windows
Pollutant generating activities
Mix of users in building
Envelope and structural materials
Penetration of volumes
Basement dehumidification
Smoking lounges

Ventilation and climate control
Dilution by outside air
Air intake locations
Exhaust locations
Air cleaning options
Space air distribution
Heat recovery
Microbial control
Standards development

Materials and specifications
Low VOC emitting materials
Preventive installation procedures
In-place curing

Construction process and initial occupancy
Design documentation and commissioning
Special ventilation
Initial occupancy period

Indoor air quality (IAQ) has become a major concern because people spend up to 90 percent of their time indoors, where pollutant levels frequently exceed those outdoors. New building materials and energy conservation measures affecting ventilation rates can contribute to elevating indoor pollutant levels and associated exposures. Indoor air quality is also a complex issue, involving multiple pollutants, building types, and sources. There are many confounding factors (for example, thermal comfort and job stressors) and only a limited understanding of the potential health effects associated with low-level exposures to pollutants, both individually and in combination.

Indoor air quality is influenced by energy conservation, product technology, renovation and adaptive reuse, cost of construction, operation and maintenance, and the awareness of building owners, managers, and occupants. For example, building ventilation rates have been reduced, and recommended minimum rates are used more frequently as design maximums. As a result, reduced building ventilation has helped raise pollutant levels from indoor sources.

Buildings with IAQ Problems

Buildings with IAQ problems can cause various health and comfort complaints, and damage building contents and the building fabric itself. Occupant health problems reduce productivity and increase absenteeism, costing building owners, tenants, and occupants valuable time and resources. Contaminants can increase the rate at which building components (for example, sealants, glazing assemblies, and surface coatings) deteriorate, increasing operation, maintenance, and replacement costs.

Health effects resulting from IAQ problems include acute and chronic symptoms such as (1) headache, (2) eye, nose, or throat irritation, (3) dry or itchy skin, (4) dizziness and nausea, (5) difficulty in concentrating, (6) fatigue, (7) cough, and (8) sensitivity to odors. While most building occupants experience one or more of these symptoms occasionally, IAQ problems cause large numbers of building occupants to complain of such symptoms.

If there is no clearly identifiable cause, and symptoms diminish or disappear after occupants leave the building, the problem is often called "sick building syndrome" (SBS). A World Health Organization Committee estimates that up to 30 percent of new and remodeled buildings may have such problems.[1] In fact, almost every building may at some time experience IAQ problems. Frequently, the problems result from the building's being used, operated, maintained, or altered in ways unforeseen by its designers. Specific, clinically-defined illnesses and diseases such as Legionnaire's Disease, Pontiac fever, and hypersensitivity pneumonitis are associated with IAQ problems and are considered "building-related illnesses" (BRI). When BRI occurs, the source of the pollutant must be removed. In some cases, it is necessary to temporarily relocate affected individuals.

Causes and Solutions

Pollutants may be emitted from sources both inside and outside the building. Inadequate ventilation is frequently cited as a factor that may aggravate other complaints, such as inadequate temperature, humidity, or lighting. Indoor pollutants include both chemical and biological contaminants. Volatile organic compounds (VOCs, including formaldehyde and toluene) come from building materials, cleaning solvents and tobacco smoke. Biological contaminants (including mold and fungi) are associated with improperly maintained HVAC systems and wetted building materials. Combustion products (carbon monoxide and particulates) are generated by combustion sources both inside and outside the building, including smoking. Most occupant complaints are associated with acute symptoms. This does not mean, however, that the chronic health effects associated with radon and asbestos do not pose an important potential health risk. Radon and asbestos should be included in any comprehensive effort to evaluate a building's indoor air quality.

Solutions to IAQ problems usually include combinations of the following: (1) pollutant source removal, modification, or substitution, (2) time of use adjustment of a pollutant source, (3) increased ventilation rates, (4) air filtration and purification, and (5) education.[2] Pollutant source removal, modification, or substitution is the most effective way to resolve an IAQ problem. This approach reduces or eliminates the emissions from a pollutant source, and may be used in combination with increased ventilation to dilute the indoor pollutant level. Examples of this method include cleaning or replacing contaminated filters in the HVAC system, removing water-stained ceiling tile and car-

References

1 *Indoor Air Quality Research*, EURO Reports and Studies 103, World Health Organization, Copenhagen, Denmark.

2 "Sick Building Syndrome: Addressing a Real Problem?" K.Y. Teichman, *16th Energy Technology Conference*, 1989.

3 *Ventilation for Acceptable Indoor Air Quality*, Standard 62–1989, ASHRAE, Atlanta (404) 636-8400, 26 pp.

"Dramatic increases in ventilation do not result in correspondingly dramatic increases in total annual energy and initial construction costs."

peting, restricting or prohibiting smoking, and using and storing paints, adhesives, solvents, and pesticides in well-ventilated areas.

Incentives for Healthy Buildings

Rather than focusing on fixing buildings with IAQ problems, we prefer to emphasize the incentives for providing all building owners and occupants with healthy buildings. We define "healthy" buildings as those that address both energy efficiency and environmental concerns (indoors and outdoors) throughout the life of the building, in relation to building design, construction, commissioning, operation, maintenance, renovation, and demolition. The incentives for designing and maintaining healthy buildings include enhanced building occupant health and comfort, energy and cost considerations, and potential liability.

To promote building occupant health and comfort, ASHRAE recently promulgated a new ventilation standard, ASHRAE 62–1989, *Ventilation for Acceptable Indoor Air Quality.*[3] In brief, ASHRAE 62 raised the minimum ventilation rate from 5 to 15 cubic feet per minute per person (20 cfm/person in office spaces). What are the energy costs of providing this increased ventilation to promote acceptable indoor air quality? Using building simulation, researchers at the Lawrence Berkeley Laboratory have shown that the increased annual energy costs associated with increasing the minimum outside air ventilation rate from 5 to 20 cfm/person is only about 5 percent of the total annual energy cost of operating a typical office building.[4] They also showed that the increase in first costs would be of a similar magnitude. This permits us to draw two important conclusions. First, *dramatic increases in ventilation do not result in correspondingly dramatic increases in total annual energy and initial construction costs.* Second, *buildings should be designed, constructed, commissioned, operated, and maintained to optimize energy conservation and indoor air quality.*

Let's examine the benefits of healthy buildings in light of the trade-off between slightly increased energy costs for ventilation and enhanced building occupant health and comfort. Assume that the total energy costs for an office building are $2 per square foot per year, that an average employee salary is $20,000 per year, and that a building occupant density is 100 square feet per person. With these assumptions, an energy conservation measure that saves 25 percent of the building's annual energy costs (i.e., $0.50 per square foot per year) represents only about 1 minute per day or 5 hours per year of the building employee's time. Therefore, we conclude that energy cost savings at the expense of acceptable indoor air quality are less than the resulting costs associated with reduced worker productivity and compromised employee health.

Finally, recent years have seen an increase in the number of indoor air quality cases being litigated. For example, in a recent court case in California, Call et al. versus Prudential Insurance Company of America et al., the plaintiffs claimed that indoor air pollution resulted in personal injury, including temporary and permanent health problems, and business damages involving loss of revenue. After the case went to trial, the parties settled for what some sources believe was a seven figure settlement. Among the many lessons this case offers for architects is that *everyone involved in the design, manufacture, construction, and operation of a building is responsible for ensuring that the building is appropriate for its intended use and meets the expectations of the building occupants.*

Healthy Building Design

Many important building design changes have occurred in recent years that significantly improve indoor air quality. The changes fall in the four major categories: (1) site planning, (2) overall architectural design, (3) ventilation and climate controls, and (4) materials selection and specifications. Additional responsibilities related to commissioning of newly constructed or renovated facilities have also developed.

Not all of the control methods described below are used by even the most air-quality-conscious designers. In fact, some of them are no more than proposals and have not, to our knowledge, yet been used (although each has been developed within the design process of an actual building). More complete description of the critical building design factors for healthy buildings are discussed in the references.[5]

Site Planning and Design

Some sources of indoor air contaminants occur outside the building. They include: (1) gaseous and particulate contaminants generated by motor vehicle, power generation, and industrial process

2 Major Elements of IAQ Control: Site Planning

Pre-design site evaluation

Analyze regional and local air quality
Analyze local pollutant sources:
Vehicular traffic
Industrial sources
Commercial sources
Agricultural sources
Analyze soil and groundwater sources
Radon and other radioactive decay products
Volatile and semi-volatile organic compounds
Determine prevailing weather and wind patterns:
Diurnal variations
Seasonal variations
Microclimate

Site planning

Site selection for suitability
Building location and orientation
Vehicular circulation

Local source control

Landscape and architectural buffers
Soil depressurization
Drainage
Site preparation and imported soil

4 "The HVAC Costs of Increased Fresh Air Ventilation Rates in Office Buildings," J. Eto and C. Meyer, *Transactions*, vol. 94, part 2, ASHRAE, Atlanta (404) 636-8400, 1988.

5 "Critical Building Design Factors for *Indoor Air Quality and Climate," H. Levin, Indoor Air* , c/o University of Minnesota, 330 Wulling Hall, 86 Pleasant Street SE, Minneapolis, MN 55455

6 "Indoor Air Quality Requirements," H. Levin, in *U.S. EPA Pre-Design Master Study, Headquarters Facility,* Viking Systems International and Gruzen, Samton Steinglass, 1988.

"Buildings should be designed, constructed, commissioned, operated, and maintained to optimize energy conservation and indoor air quality."

3 Categories of Overall Architectural Design

Location of vehicle access:
Separate from air entry points

Vehicles in buildings:
Provide air supply ,exhaust removal, negative pressure to building

Building openings facing clean air:
Consider sources, wind, building pressure

Operable windows for backup ventilation:
Occupant-controlled for comfort

Isolate pollutant generating activities:
Separate rooms, negative pressure, no recirculation

Durable envelope and structural materials:
Minimize emissions, maintenance, refinishing

Basement dehumidification, pressurization:
Prevent microbial contamination, pests, soil gas entry

Separate smoking lounges:
Exclude smoking from general space

combustion, (2) particulate matter from agriculture, road dust, and wind-generated soil erosion, and (3) ozone. Soil gas containing radon and organic chemical compounds can enter buildings through joints or cracks in the foundation or by direct migration through semipermeable building materials.

Architectural Designs

The schematic building design embodies basic decisions about building shape and size, orientation, layout of floor plans, location of pollutant-generating activities, envelope and interior materials, fenestration, and general ventilation concepts. Experience shows that many IAQ problems derive from decisions made at this stage of a project. Although such problems can be mitigated by subsequent control measures, it is cost effective to begin consideration during the schematic design phase.

Operable Windows. In a reversal of the trend toward sealed windows that dominated from the 1960s into the 1980s, buildings designed recently often include operable windows. In some instances, operable windows are provided as an "emergency ventilation" system in the event of inadequate ventilation by mechanical means. In many such instances, occupants are not actually permitted to open the windows, which are locked in the closed position.

When mechanical ventilation is operated to create positive pressure inside a building, opening windows may not necessarily provide additional outdoor air. In fact, natural ventilation frequently is not adequate to deliver and distribute outside air to building occupants, even when not competing with mechanical ventilation systems. Moreover, air admitted through windows bypasses the HVAC filtration system.

Some designers provide operable windows to allow occupants psychological benefits. Installation of a sensor "interlock" for window operation and the ventilation system controls can maintain "balance" in the ventilation system while permitting operation of windows. The sensor sends a signal to the ventilation system controls, which then compensate for the change in pressure. Such a system has been proposed for the new U.S. Environmental Protection Agency headquarters.[6]

Envelope and Structural Materials. Designers should specify materials that are known to have low pollutant emissions characteristics. When such materials are not suitable, contamination of air in the completed building should be controlled by temporary ventilation, in-place curing, and encapsulation or isolation of materials from the building occupants' air.

Vehicle Access. Garages, loading docks, and pedestrian drop-off points should be located away from air intakes and building entries. Where openings occur near vehicle access areas, positive building pressure should be maintained inside the opening to keep exhaust fumes out. Spatial relationships of vehicles and occupied building areas must also be considered. This addresses one of the most widely recognized sources of IAQ problems.

Special Provisions for Polluting Activities. Printing, cooking, art and hobby activities, and other common building functions can be sources of indoor pollution. They should be located where their emissions can be isolated and controlled. Dedicated exhaust systems and spaces with direct exhaust ventilation affect the flexibility of interior space planning and require rethinking of the definition of building core. Public awareness and new laws have resulted in the design of separate spaces for smoking in some public buildings. One-pass ventilation with no recirculation is usually provided to eliminate exposure of non-smoking occupants to environmental tobacco smoke (ETS). The strong trend in the United States is to limit smoking to designated areas or prohibit it within the building. Nevertheless, there are still many buildings in which designers have not addressed the issue in planning public spaces.

Ventilation and Climate Control

Many view ventilation as an essential design strategy for IAQ control. They argue that there are too many sources and that the sources are too diverse and change over time, making it impossible to avoid them by design. In particular, contaminants emitted from occupant activities, personal hygiene products, clothing, and other sources are outside the control of the designer. Dilution of contaminants with cleaner air (either outside air or filtered, recirculated air) should be planned for. The quantity of outside air used for this purpose is the subject of much investigation and is a driving criterion of ventilation system design. This is the primary, if not the only, means of controlling indoor air quality in the majority of building

7 "Building Materials and Indoor Air Quality," H. Levin, in *Occupational Medicine: State of the Art Reviews*, J. Cone and M. Hodgson, editors, vol. 4, no. 4, Hanley and Belfast, Phila. (215) 546-7293, 1989, pp. 667–694.

8 "Volatile Organic Compounds and Building Bake-Out," J. Girman, in *Occupational Medicine: State of the Art Reviews*, J. Cone and M. Hodgson, editors, vol. 4, no. 4, Hanley and Belfast, Philadelphia (215) 546-7293, 1989, pp. 695–712.

"The concept of building ecology requires applying a systems approach to designing and operating environmental control systems in buildings."

designs. Even so, delivery of the required quantity and quality of outside air to the occupants' breathing zone as required by ASHRAE 62 has not been addressed explicitly in a majority of projects.

Ventilation standards based on outside air supply per occupant have not been shown to be sufficient to control unusual or strong contaminant sources. Ventilation rates must be based not only on the human occupant density but also on the activities that will occur, the types and strengths of contaminant sources, the ventilation system distribution scheme, and the volumetric dimension of the building's spaces. These are explicit requirements of ASHRAE 62, but they have been vigorously applied in very few buildings. Since it is often difficult to identify most or all of the sources during the early stages of design, a review at the time the actual occupancy is known might be necessary to implement the requirement.

Air intakes. The known sources of potential contaminants for outside air intakes include exhausts from other buildings, motor vehicles, industrial and agricultural processes, and exhausts from the building itself, including plumbing stacks and kitchen and toilet exhaust air vents. In large buildings, cooling towers should be located away from air intakes, to avoid entrainment of drift containing water treatment chemicals or microbial contaminants.

Air Cleaning. Where outdoor air is contaminated, designers should require their engineering consultants to specify air cleaning and filtration as appropriate. While efficient media filters and electronic air cleaners to reduce particulate matter are being used, gaseous contaminants have been largely ignored. There is, nevertheless, growing interest in adsorbents.

When indoor air is recirculated with little outside air introduced, air cleaning and filtration are used to remove contaminants picked up indoors. Particles and gases are removed by the means mentioned above. These air cleaning and filtering devices have been used both in central HVAC components and locally (within or near the occupied space).

Air Distribution. Adequate distribution of air to building occupants requires that air be delivered to supply diffusers and that diffusers and return registers be properly located within occupied zones. Some designers are specifying tighter sealing of supply ductwork to ensure the delivery of supply air to building spaces. This is especially true when the supply ductwork runs through return air plenums.

Many researchers and engineers disagree about the extent to which ventilation supply air distributes itself within building spaces. Some designers have begun introducing supply air through the floor, at desk tops, and from sidewall diffusers to improve space air distribution. Return air registers should be carefully placed to avoid short-circuiting of supply air to the exhaust system. Partial-height partitions in open space offices can block circulation, especially under low volume and velocity flow. Some designers raise partition bottoms above floors to improve air flow and distribution.

Microbial Control. Considerable attention has been focused on reducing potential microbial amplification through selection of HVAC system materials to minimize absorption of dirt and moisture that provide niches for microbial colonization. Control has been achieved by eliminating or reducing the use of exposed fibrous materials for acoustic control, by placing thermal insulation outside of ductwork, and by thoroughly sealing insulation from circulating air.

Drip pans for cooling coils should be designed for positive drainage to eliminate standing water. Ductwork, mixing chambers, and plenums should allow easy inspection and cleaning. Humidifiers can be specified that use "dry steam" rather than cold water sprays to minimize the likelihood of microbial contamination.

Materials Selection and Specifications.

Many designers believe that source control is the most effective strategy for controlling IAQ, and emphasize careful selection and installation of building materials and furnishings. Some data are available for comparison of emissions from various products. No comprehensive set of data exists however, nor is it likely to in the foreseeable future, because of the large number of products and the variations in them over time. Some designers and their consultants have attempted to evaluate the toxic and irritating properties of emissions in order to choose less harmful or irritating chemicals. [7,8] These can be controlled in part through the specifications package.

Some designers are requiring submission of emissions data by manufacturers before specifying or approving the product. This has been done for

4 The Major Ventilation Design Considerations

Dilution by outside air ventilation
Outside air per occupant (cfm)
Outside air exchanges per hour (ach)
Ventilation based on contaminant source strength
Direct exhaust from polluting activities

Air intake locations, design
Avoid plumes from suspected sources
Avoid standing water and cooling tower drift
Prevent bird roosting or animal entry at intakes

Building exhaust locations
Avoid contamination of ventilation air intake by re-entrained exhaust
Increase height/distance from intakes

Air cleaning and filtration
Outside air meets standards for:
Particles (media, electronic filters)
Gases (chemisorption, scrubbers)
Recirculated air meets standards

Space air distribution
Prevent stratification
Ventilate occupant breathing zone
Maintain effective pressurization
Balance supply and return systems

Heat recovery
Energy conserving outside air ventilation/heat recovery devices
Transfer air for high ventilation rate areas

Microbial control
Avoid fleecy materials in airstream
Eliminate standing water in drip pans

9 *Indoor Air Quality Update*, H. Levin, editor, vol. 3, no. 2, Cutter Information, Arlington, MA (617) 648-8700.

10 *Indoor Air Sources: Using Small Environmental Test Chambers to Characterize Organic Emissions from Indoor Materials and Products*, B. Tichenor, Environmental Protection Agency, #PB90-110131, NTIS, Springfield, VA (703) 487-4650.

11 *Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials and Products*, Standard D 5116-90, ASTM, Philadelphia (215) 299-5400.

"Everyone involved in the design, manufacture, construction, and operation of a building is responsible for ensuring that the building is appropriate for its intended use and meets the expectations of the bulding occupants."

5 Material Selection and Specification

Specify IAQ concerns in bid:
Health, safety, and comfort of occupants
Manufacturer's reponsibility for review and assurance

Require manufacturers' submittal of product contents, emissions tests

Select low-emitting materials and products

Criteria for evaluating emissions :
Minimize odorants;
Minimize irritants;
Minimize systemic toxins;
Minimize carcinogens, teratogens.

Minimize required use of adhesives

Minimize use of fleecy materials

Preventive installation procedures:
Ventilation during/after installation
In-place curing: ventilation, bake-out

12 "Regulating Indoor Air," B. Seifert, *Indoor Air 90, the Fifth International Conference on Indoor Air Quality and Climate*, vol. 5, Indoor Air '90, Ottawa (613) 737-2005, 1990, pp. 35–50.

13 "Building with Low-Emitting Materials and Products: Where do We Stand?" W. Tucker, *Indoor Air 90, the Fifth International Conference on Indoor Air Quality and Climate*, vol. 3, Indoor Air '90, Ottawa (613) 737-2005, 1990, pp. 251–256.

several highly "visible" government projects that have stimulated the development of testing in laboratories and the writing of standards for the conduct of such testing.[9,10,11]

Authorities have proposed guidelines for maximum emissions for low-emitting materials and products.[12] Some researchers are now planning to evaluate emissions in terms of various biological responses to them.[13] Others have used sensory responses of the anticipated occupants as a screening technique. In one case, the occupants of a home included two chemically sensitive children. After chemical screening, the children judged the products on the basis of brief exposures.[14]

The maintenance requirements and projected life cycle of materials have important IAQ implications that are seldom considered in design. Cleaning solvents and solutions are an important source of VOCs, and a short service life may mean more frequent replacement of carpets or other finishes with VOC emissions. Attention to these issues can help improve indoor air quality.

Problems remain in adequately characterizing emissions from the thousands of available products. Testing is expensive, time-consuming, and not standardized. Interpretation of results is difficult due to lack of knowledge regarding health effects. Trade-offs between the significance of toxicity and irritation must be determined. Nonetheless, the concern of designers is leading to the development of cleaner products and the elimination of some of the strongest emitters from the market.[7,9]

Controlling Emissions During Installation. Ventilation can be used to reduce the adsorption of VOCs emitted from building materials during installation. These procedures involve one pass, continuous, all-outside-air ventilation during installation of strong emitting materials. This reduces the contamination of "fleecy" materials by adsorption of the solvents and other volatile components of adhesives, caulks, sealants, and plastics. Painting and carpeting should be specified to be done under maximum ventilation conditions.

Construction Process and Initial Occupancy

Designers wishing to control IAQ should document design assumptions thoroughly and provide clear, detailed descriptions of building systems. This documentation is used to evaluate the completed construction during the commissioning phase before occupancy. The building is tested against the design criteria to assure its suitability for occupancy.[15] This procedure is rapidly being adopted by more designers and owners to provide assurance of good IAQ and other building design specifications.

Special Ventilation. Many designers have begun to specify extra ventilation immediately before and during initial occupancy of newly- constructed or renovated buildings. Continuous, outside-air ventilation can be used to minimize occupant exposure to emissions from new materials and furnishings. This might be from three to six or eight weeks after installation. Such extra ventilation also reduces the potential for underventilation by incompletely balanced HVAC systems, which often characterize new buildings with poor indoor air quality. In addition, special ventilation can be used to flush buildings thoroughly before reoccupancy after any period of vacancy and reduction of ventilation (evenings, weekends, holidays).[6]

"Bakeout" has been used in many buildings. This involves raising building temperature for 48 hours or more while maintaining at least minimal ventilation. The elevation of temperature results in more rapid emission of VOCs and a correspondingly reduced contaminant load. The research results indicate that (1) the method has potential to reduce contaminant air concentrations, (2) the process is not a trivial one in terms of technical requirements, and (3) there are some significant additional costs associated with its use. Pretreatment of materials prior to installation appears to be a more efficient approach. However, for adhesives, paints, sealants, and other products applied in the field, it may not be possible to reduce emissions adequately in a reasonable time period without the use of a procedure like the "bakeout."[8]

Construction During Occupancy. Construction during occupancy is common both in newly-completed buildings and during renovation, relocation, or adaptive reuse in older buildings. These situations challenge designers, constructors, and building management to avoid exposing occupants to fumes and dusts from construction. The problem is especially challenging when the construction area cannot be easily isolated from the occupied areas and when contamination migrates directly or is circulated by the ventilation system.

Sources of contamination should be identified and controlled. This can be accomplished, at least in part, by providing temporary ventilation in the construction area while thoroughly isolating it from the occupied zone. Management strategies can reduce occupant exposure by carefully scheduling both construction and occupant activity as well as temporary occupant relocation. Asbestos or lead abatement projects provide examples of the types of barriers, temporary ventilation equipment, and management strategies that can be employed.

The Need for Building Ecology

Most design professionals give little consideration to IAQ issues. Neither codes nor legal actions have created the necessary awareness and changes in practice. Part of the problem originates from the fact that there is inadequate communication between building science researchers and design professionals.

Many actors are involved in the process of making and using buildings. We identify four major groups with different perspectives, needs, and relationships to the buildings they affect (or that affect them): (1) owners and occupants, (2) building managers and operators, (3) designers, product manufacturers, and builders, and (4) institutional interests (codes and standards organizations, lenders, and insurers). Controlling energy consumption, indoor air quality, and other environmental factors involves coordinating their diverse in-puts and resolving differences in their needs and means.

The absence of a useful general body of knowledge, theory, and practice regarding building-environment-occupant interactions impedes developing the necessary design tools and practices to create and operate low-pollution and energy-conserving buildings. Design professionals and facilities operators are not equipped to analyze buildings as dynamic entities with important effects on occupants and a dependence on the outside environment.

Borrowing from the approach of the science of ecology, we suggest that researchers and practitioners develop a systems approach to understanding building-environment-occupant interactions. We reintroduce the term "building ecology" to describe this concept or approach to understanding buildings [P/A, April 1981, pp. 173–175]. The concept of building ecology requires applying a systems approach to designing and operating environmental control systems in buildings. It also requires consideration of the building as a dynamic and complex entity that continually changes in response to external conditions, occupant activities, and operator interventions. Finally, it requires understanding a building's complex chemical, physical, and biological processes that affect occupant health and well-being.

Conclusion

Much progress has been made toward improving environmental quality and energy conservation through building design and operation. Contributions have been made in site planning, architectural design, ventilation, materials selection, and commissioning. Yet many technical problems still challenge researchers and professionals in achieving and maintaining desirable indoor environments.

An overall approach to healthy building design is needed, one that considers the interrelationships between the building, the larger environment, and the building occupants in a complex, dynamic system. This overall approach, called "building ecology," can provide the foundation for needed advancements in the design of healthy buildings and, indeed, the building design professions.

Hal Levin and Kevin Teichman ■

Hal Levin is a research architect in private practice in Santa Cruz, California. For over 12 years he has consulted on indoor air quality to architects and building owners. He also advises the Environmental Protection Agency and other government agencies on the control indoor air quality problems. He edits a new monthly newsletter, Indoor Air Bulletin *(Indoor Air Information Service, Santa Cruz, 408-425-3946), and chairs the Task Group on Indoor Air Quality of the AIA Committee on the Environment.*

Dr. Kevin Teichman is a supervisory environmental engineer in the U.S. Environmental Protection Agency's Office of Research and Development. His responsibilities in this position include serving as the chief of the air team within the Office of Technology transfer and Regulatory Support. In this capacity, Dr. Teichman is responsible for coordinating participation in EPA's policy-making activities related to air and radiation pollution, and helping to develop ORD's research programs in these areas.

6 Construction and Initial Occupancy Considerations

Prepare design documentation and commissioning plan

Document design assumptions
Document systems characteristics and function
Plan commissioning process

Special ventilation

During and after installation of strong sources:
Ventilate continuously with all outside air
Seal return air plenum and ducts

Commissioning process

Complete operation and evaluation of HVAC system
Challenge system under various loads

Initial occupancy period

Ventilate for extended hours with all outside air
Monitor occupant responses to reduced ventilation

14 "Design, Construction, and Ventilation of a Low Pollution Home," V. Salares, G. Allen, and O. Drerup, *Indoor Air 90, the Fifth International Conference on Indoor Air Quality and Climate*, vol. 3, Indoor Air '90, Ottawa (613) 737-2005, 1990, pp. 245–250.

15 *Guideline for Commissioning of HVAC Systems*, Guideline 1–1989, ASHRAE, Atlanta (404) 636-8400, 1989.