Technics | The Myths of Indoor Air Pollution

Architect **Hal Levin** discusses the real and imagined causes of indoor air pollution, and how architects can decrease it.

A popular myth holds that building energy conservation measures, implemented since the oil crises of the 1970s, cause indoor air pollution problems. This myth ignores the fact that most indoor air pollutant sources have little or nothing to do with energy conservation. Air studied inside buildings before 1973 was found to be more polluted than outdoor air even during severe air pollution events. In fact, only two types of conservation measures directly increase indoor air pollutant concentrations: inappropriately reducing ventilation and using sealants and caulks that emit pollutants.

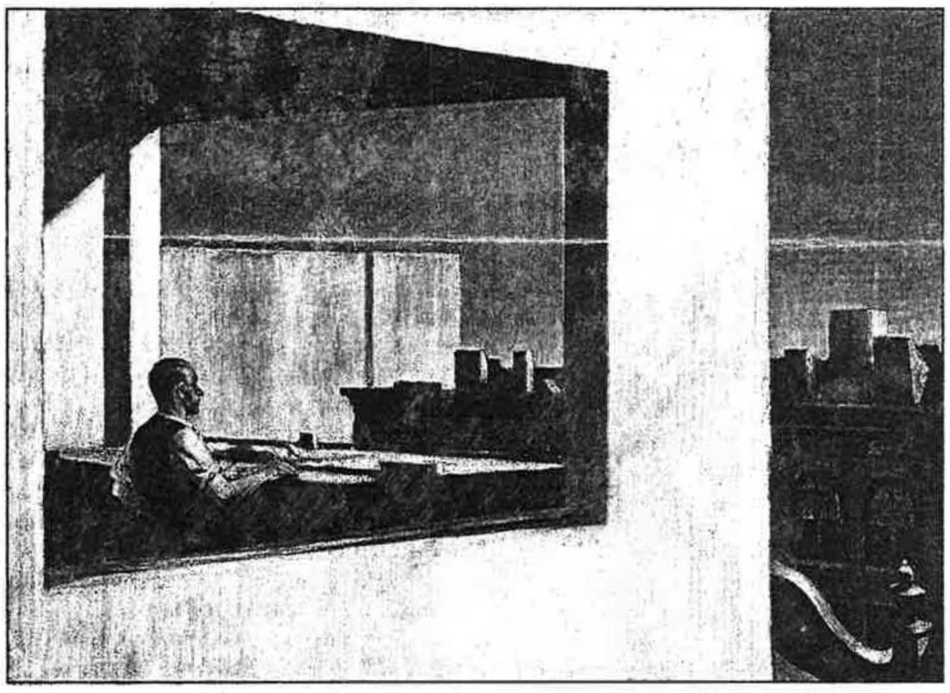
The myth ignores the fundamental responsibility (and ability) of architects, engineers, and building operators to create indoor environments that are both extremely habitable and environmentally responsible. Architects and other building design professionals must provide safe, healthy, and comfortable environments; minimize damage to the environment; and conserve energy and other resources. Achieving good indoor air quality (IAQ) is as essential as providing comfortable, healthy thermal conditions and functional, aesthetically sound lighting and acoustical environments.

Reducing ventilation to conserve energy certainly increases concentrations of pollutants emitted from indoor sources. Adequate ventilation is essential to achieving and maintaining good IAQ. But there are many factors that determine IAQ and their interdependence is strong. Although ventilation is an important way to limit pollutant concentrations, limiting pollutant sources is far more effective. Pollutants from indoor sources that cannot be eliminated should be minimized by careful planning, design, specification, and construction. The preventive approach costs very little and it saves energy.

How Ventilation Affects IAQ

Changes in ventilation rates generally affect IAQ only indirectly; it's the relationship between ventilation and pollutant sources that directly affects IAQ. With the advent of larger buildings and variable air volume (VAV) systems, the role of ventilation has shifted more towards thermal control and away from IAQ concerns. A discussion of these issues follows.

Ventilation rates and IAQ. Reductions in outdoor air ventilation rates are commonly blamed for IAQ problems. However, consider the following three factors. First, there would be no indoor air contamination if there were no pollutant sources. The sources have changed in number and kind during the past 45 years or so; abundant, harmful pollutant sources have resulted from new building materials, furnishings, equipment, and consumer products that will be discussed later in this article.



Office in a Small City, *1953.*
Edward Hopper. Oil, 28" x 40".
Courtesy: The Metropolitan Museum of Art, George A. Hearn Fund, 1953

Second, thermal control has become the dominant driving force in HVAC system design; the need to maintain good IAQ by adequate outdoor air exchange has become incidental. This shift began – long before the oil crises of the 70s – with the advent of VAV systems in the 1950s. The shift towards thermal control became more important as buildings became larger, with more space remote from exterior walls and the concomitant lost access to daylight and ventilation through windows. In fact, ventilation rates sufficient to maintain good IAQ require very modest amounts of total building energy.

Finally, in the majority of buildings with IAQ problems, ventilation systems do not function as designed. Many of these failures result from problems in operation and maintenance. As many as 75 percent stem from design and construction flaws because designers simply did not place enough emphasis on IAQ. The percentage of various deficiencies (1) commonly found in buildings with IAQ problems is revealing.

Ventilation and indoor air pollutant concentrations. Ventilation dilutes and removes indoor air pollu-

1 FREQUENCIES OF OCCURRENCE OF PHYSICAL CAUSES OF PROBLEM BUILDINGS (WOODS, 1988)

Problem Category	Physical Cause	Frequency (%)
Design	**System Problems**	
	Inadequate outdoor air	75
	Inadequate air distribution to occupied spaces (supply and return devices)	75
	Equipment problems	
	Inadequate filtration of supply air	65
	Inadequate drain lines and drain pans	60
	Contaminated ductwork or duct linings	45
	Malfunctioning humidifiers	20
Operations	**Equipment problems**	
	Inappropriate control strategies	90
	Inadequate maintenance	75
	Thermal and contaminant load changes	60

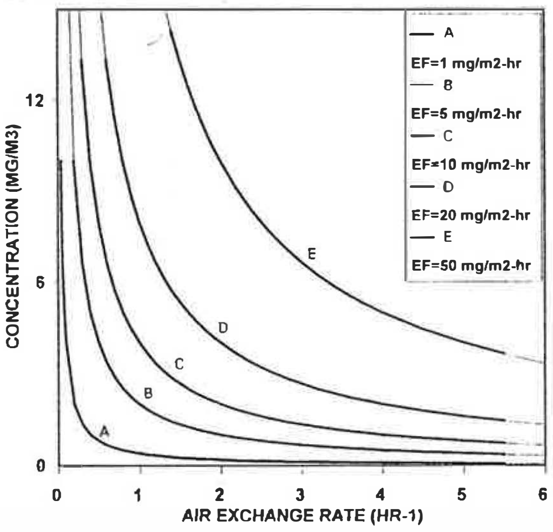
Definition of Terms

VAV: Variable Air Volume, a type of control used in ventilation systems, either at the air handler or at the local distribution point within the building interior.

VOC: Volatile Organic Compounds, chemicals that contain carbon molecules and are volatile enough to evaporate from material surfaces into indoor air at normal temperatures. Typical examples are chemicals used to manufacture solvents, adhesives, preservatives, paints, caulks, sealants, and a host of other building materials and furnishings.

mg/m3: milligrams per cubic meter, refers to the concentration of a substance in the air in units of weight per unit volume. 1 milligram of a typical indoor air contaminant converts to between 1 and 20 parts per million (ppm), depending on the molecular weight of the substance.

2 VOC concentration as a function of source strength and ventilation rate. This relationship illustrates how air quality depends on ventilation. It also shows the importance of pollution sources. The stronger the source, the more ventilation is required to maintain the same concentration. The point at which the curve changes from a vertical to a horizontal slope is known as the "knee" of the curve. The knee of the curve for most buildings falls within the range of ventilation rates found in most buildings.



2 RELATIONSHIPS BETWEEN VENTILATION AND VARIOUS SOURCE STRENGTHS

tants. The amount of ventilation required depends on pollutant source strengths. The relationship is non-linear, best described by an asymptotic curve; a plot of the air concentration as a function of air exchange rate (a measure of building or space ventilation) is a smooth curve that approaches but never reaches either axis. The relationship between IAQ and air exchange rates based on contaminants from sources inside a building (2) is a direct one.

The average air exchange rate in a series of office buildings studied in 1989 by the former National Bureau of Standards, now the National Institute of Standards and Technology (NIST), was about 0.8 air changes per hour (ach). An open office environment with 140 square feet per person, 20 cubic feet of outside air per minute/person, and an effective ceiling height of 10 feet maintains about 0.85 air changes per hour.

The point at which changes in ventilation rates dramatically affect pollutant concentrations from indoor sources is likely to be between 0.5 and 1.0 ach. Most buildings operate within this range during much of the time they are occupied. Therefore, changes in the ventilation rate (2) can have dramatic impacts on actual pollutant concentrations.

Ventilation from mechanical systems depends on the outside air fraction at the air handler, the flow to the distribution point (local diffuser), and the location and number of distribution points in relation to the area and volume of the space and the "design" number of occupants. These relationships can produce a very wide range of values (3).

Thermal control versus air quality. Historically, ventilation requirements were set to maintain air quality. In the 19th Century, before people began to bathe frequently and use personal deodorants, rates were specified to keep human body odor at acceptable levels. Traditionally, architects and engineers designed mechanical or natural building ventilation on the basis of established outside air requirements for assumed occupant loads and activities in the building program. Starting in the 1950s, thermal control objectives came to drive system design; ventilation requirements became minor components. The acceptance of VAV distribution systems, with strong emphasis on thermal control, resulted in outside air supply deficiencies.

However, VAV systems are not the only causes of these deficiencies. Fewer buildings use independent heating and ventilation systems. Thermal loads in large buildings are dominated by cooling requirements because of the ratio between the enclosed volume and the surface area of the building envelope. There is considerable internal heat gain from

3 OUTSIDE AIR EXCHANGE RATE FOR THREE CEILING HEIGHTS AND TWO AIR DISTRIBUTION RATES ACCORDING TO OSA % AT AIR HANDLER

Distribution Air Flow Rate		**0.5 cfm/sf**			**1.0 cfm/sf**		
Clear Ceiling Height		**8 ft**	**10ft**	**12ft**	**8 ft**	**10 ft**	**12 ft**
OSA Fraction %	10	0.05	0.03	0.02	0.09	0.06	0.04
	20	0.09	0.06	0.04	0.19	0.12	0.08
	30	0.14	0.09	0.06	0.28	0.18	0.13
	40	0.19	0.12	0.08	0.38	0.24	0.17
	50	0.23	0.15	0.10	0.47	0.30	0.21
	60	0.28	0.18	0.13	0.56	0.36	0.25
	70	0.33	0.21	0.15	0.66	0.42	0.29
	80	0.38	0.24	0.17	0.75	0.48	0.33
	90	0.42	0.27	0.19	0.84	0.54	0.38
	100	0.47	0.30	0.21	0.94	0.60	0.42

3 *A comparison of ventilation rates in air changes per hour for various outside and distribution air flow rates and ceiling heights. Typical outside air fractions range from around 10 percent up to 100 percent for buildings with air economizers. However, some buildings, most often very large ones, are limited to a maximum outside air fraction of around 10 to 20 percent of total flow. Note that ASHRAE's ventilation standards call for a minimum of 15 cfm/p in all occupied spaces, with 20 cfm/p as the lowest value for most occupancy types.*

lights, occupants, and equipment. The major exceptions exist in small buildings and at the perimeters of large buildings. This size factor and building bulk are what have driven the shift in ventilation design emphasis towards satisfying thermal requirements, which has led to the notion that "energy conservation causes indoor air pollution."

Designing for Good IAQ

Architects can promote good IAQ in the design stage by taking into account expected loads and likely pollutant sources and by establishing effective source control strategies. In the following section, we discuss these topics as well as the energy costs of changing ventilation rates.

Determining loads. Maintaining a healthy, safe, and productive environment requires that ventilation be sufficient to maintain air quality. The amount of ventilation required (2) depends on the pollutant source strengths (from equipment, building materials, and consumer products), the types of activities within the building, and the occupant density. Since these factors can all vary independently, it is difficult to provide universally applicable ventilation rates. Using the ASHRAE standard's recommended minimum ventilation values assumes no "unusual sources" of indoor pollutants. ASHRAE has increased its recommended minimum ventilation air requirements and the new standards are being adopted into model codes and state building regulations. Nevertheless, the burden is on designers to determine the nature of any pollutant sources and whether they require more than the recommended minimums.

It's worth pointing out that the recommended minimums are not intended to provide a high quality environment. They are simply intended to avoid problems in most situations and to result in air quality that will be deemed "acceptable" to no less than 80 percent of a building's occupants. Most building owners want air quality that would be acceptable to more than 80 percent of the occupants.

In designing buildings' structural systems, engineers analyze performance requirements on the basis of assumed and calculated loads, and then select structural systems and components that satisfy those requirements. Lighting design is also "load-based"; it depends on the illumination requirements of the activities for which a space is planned. Acoustic control, too, is designed to support expected occupant activities.

Determining target levels of pollutants is, unfortunately, not an exact science. We know too little about the actual health and comfort effects of most pollutants to be able to set target or "safe" levels with confidence. This is especially true because the effects of most of the individual chemicals found indoors are poorly understood. In indoor air they are typically present in complex mixtures of hundreds of chemicals. It's possible that they act in ways that are independent, additive, synergistic, antagonistic, or even prophylactic.

Ventilation rates and energy costs. ASHRAE promulgates the recommended minimum ventilation rates in its Standard 62, "Ventilation for Acceptable Indoor Air Quality." Some critics claim this standard imposes a large burden because of the increased costs involved in the revision upwards from the 1981 ASHRAE recommended levels to the 1989 levels. In offices and in some other environments where no smoking was permitted, minimum recommended ventilation rates were 5 cfm/p in the 1981 version. Where smoking was permitted the recommended minimum was 20 cfm/p. The 1989 version eliminated the distinction between smoking and non-smoking environments and changed the minimum ventilation rate to 15 cfm/p. In response to the critics, researchers at the University of California's Lawrence Berkeley Laboratory showed that the increased annual energy costs associated with increasing minimum ventilation from 5 to 20 cfm/p in offices is only about 5 percent of the total annual energy cost of operating a typical office building, even in the most severe climates (Eto and Meyer, 1988).

Researchers at the Bonneville Power Administration have studied the increased costs in several climate zones of the Pacific Northwest and have determined that the increases are not larger than 11 percent except for three building types – schools, hotels, and large retail stores – which exceed an additional 11 percent in operating energy. Because of the high occupant densities in schools, the per

Ventilation Measurements

Ventilation is usually measured in terms of the number of complete air turnovers in a space (air changes per hour – ach), flow per unit of area (cubic feet per minute per square foot – cfm/sf), or flow per occupant (cubic feet per person – cfm/p).

Outside air supply and total ventilation air must be distinguished. Ventilation air may include recirculated air. Terms are not used consistently in the industry, so it is always best to state specifically whether ventilation air measurements include recirculated air or not. Air exchange rate usually refers to outside air.

4 AVERAGE ENERGY INCREASE DUE TO INCREASING OUTSIDE AIR SUPPLY VALUES FROM ASHRAE STANDARD 62-1981 TO ASHRAE STANDARD 62-1989 (PERCENT OF TOTAL ENERGY)

Building Type	Seattle	Richland
Grocery	3.2	3.5
Hospital	0.9	1.4
Hotel	31.9	33.6
Small Office	10.3	10.5
Large Office	0.0	0.4
Restaurant	10.4	10.7
Small Retail	11.8	10.9
Large Retail	16.5	15.4
School	42.3	40.8
Warehouse	1.1	1.1

Note: Percent energy increases are averages between new and existing building configurations and are based on the difference between annual energy consumption at Standard 62-cfm/person and the annual energy consumption at 5 cfm/person.

5 SOME REPRESENTATIVE CHANGES IN BUILDING MATERIALS DURING THE LAST 45 YEARS

Old (traditional) material or product	Modern material or product	Emissions from modern materials and products
Masonry or wood flooring	Resilient floor covering, carpet	Plasticizers, solvents, waxes
Plaster walls and ceilings	Painted gypsum board, ceiling tiles	Solvents, drying agents, asbestos plasticizer
	Fabric covered panels	Textile finishes, insulation binders
Full height plaster walls	Office work station panels	Textile finishes, adhesives, solvents, insulation binders

occupant ventilation rates result in significantly larger overall energy costs (Steele and Brown, 1990). The ventilation rates for retail spaces are based on outside air supply per square foot regardless of occupant density (Steele and Brown, 1990). The results of their investigation (4) also factor in building locale.

The energy consumption and associated costs due to increasing ventilation rates can be dramatically reduced by using recovery devices. The more extreme the climate, the greater the potential savings. These devices have been widely used in industry and are becoming increasingly common in large commercial applications. Residential heat exchangers have been popular for several years and are available for installation in individual rooms or for whole-house applications. The use of heat recovery devices will increase first costs, so the usual economic trade offs between first costs and operating costs will govern the decision making process.

Source Control

Ultimately, we must control sources of indoor air pollutants as best we can and use ventilation to limit pollutant concentrations to acceptable levels. The following discussion of pollutant sources presents an overview of the subject and argues for the importance of pollutant source control.

Sources of indoor air pollutants. There are many sources of pollutants in buildings and they vary considerably from building to building. For that reason, addressing these sources effectively must be part of the design process. Simply to use general guidelines for ventilation as a means of controlling pollutants is to choose the default solution; it does not represent the best effort of a good designer.

It is important to understand the relative contributions of various sources and to address the strongest ones. We must address those with the most surface area, the most mass, and the emissions that we know or believe to be most irritating or toxic. Graphing the amounts of dominant materials present in four different buildings (6, 7) shows how different buildings are from each other and how widely the amounts of the major materials vary.

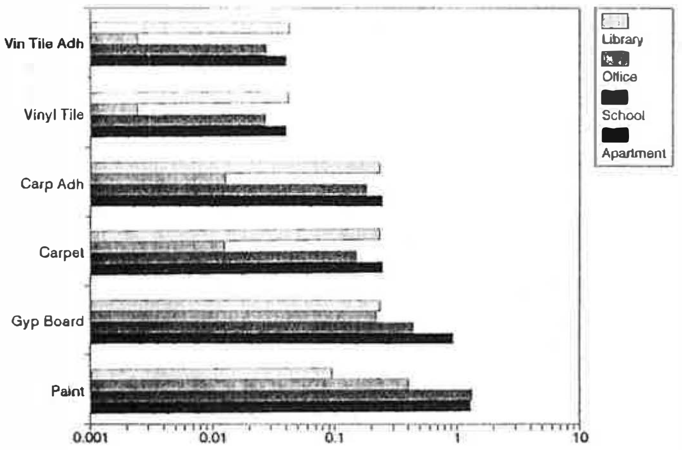
Emissions from new building materials are much greater than from aged materials. However, maintenance, refinishing, and replacement activities result in significant increases in pollutant emissions. Therefore, the durability of a material affects IAQ significantly. It is important to note that "wet" products such as paints, adhesives, caulks, cleaners, waxes, and polishes emit very large fractions of their mass into the building air, usually soon after application. However, even after these products are dry functionally, they continue to emit at low rates for a very long time.

Modern building materials. In the past 40 years, building materials have changed in ways that make them stronger sources of indoor air pollutants than "traditional" materials. For example, composite wood products have replaced solid wood materials, bringing binders, adhesives, and other chemical additives indoors. The best-known and perhaps most widely used examples are particleboard, plywood, and other composite wood products based on urea-formaldehyde resins. Fortunately, these resins are being replaced by the more stable phenol-formaldehyde resins for many indoor applications, and some manufacturers are developing and marketing products that use no formaldehyde-based resins at all.

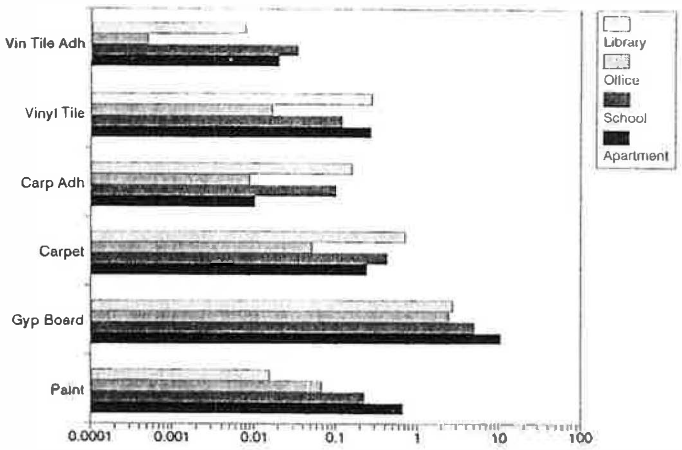
New, low-emitting adhesives are now available for installing flooring products. Paints that use much less organic solvent are also becoming more popular. However, replacing a strong emitter with a non-durable, low-emitting product may result in more maintenance and replacement. This can mean more frequent, short-term emissions. Durability can therefore be a very important determinant of IAQ. Some of the major changes in building materials and furnishings (5) have resulted in more pollutant sources.

A current popular myth is that "natural" materials are healthier than synthetic materials. In fact, many naturally occurring substances are far more toxic or irritating than their synthetic substitutes. Arsenic, lead, formaldehyde, and asbestos are examples of substances found in nature that have been used in building products or processes.

Another problem with many natural materials



6 COMMON BUILDING MATERIALS WEIGHT/VOLUME RATIO (kg/cu.m.)



7 COMMON BUILDING MATERIALS AREA/VOLUME RATIO (sq m /cu m)

6, 7 *Figure 6 shows some of the sources and their relative surface areas compared with the building volume for a school, an office, an apartment house, and a public library. Figure 7 shows the mass of these materials relative to the building volume. Note that both figures show the amount present as a ratio to the volume on a logarithmic scale; the differences are quite significant.*

is that they require chemicals to protect them from deterioration or insect attack. Some of these preservatives and biocides may be toxic to humans as well as to the pests they are intended to control. For example, wool and cotton fibers used in carpets are attractive to pests (unlike nylon fibers) and require pest control with para-Dichlorobenzene (p-DCB), the common substance used in moth crystals that is known to be a carcinogen. Some natural fibers are also less stain resistant and cannot be easily cleaned without using industrial solvents that contaminate their surfaces and the air around them.

The architect's role. Architects can substantially reduce indoor air pollution by pro-actively minimizing its sources. Studies have evaluated the human health and comfort effects of measured mixtures, either in the laboratory or in real buildings, and have established target levels.

Architects can limit chemicals with known toxic effects to levels that will not cause adverse reactions. For example, the California Air Resources Board recommends that formaldehyde levels not exceed 50 parts per billion (ppb). Since it's known that particleboard, plywood, hardboard, fiberglass insulation batts and boards, some textiles, and many other building products emit formaldehyde, architects and designers can try to limit their quantities, select lower-emitting products, or choose substitute materials. They can calculate emissions from these products using test data. Knowing ventilation rates, they can estimate formaldehyde indoor air concentrations and change specifications if necessary.

This approach, although it seems rather unscientific and not very specific, is, in fact, similar to the way we design illumination and acoustic and thermal control. This brings us back to the relationship with energy efficiency. We don't say that energy efficiency causes poor lighting or visibility problems in buildings. We determine what lighting levels are necessary to perform the tasks for which the building is designed and built, then we attempt to achieve those levels in an energy-efficient manner. We must recognize the need to apply the same approach to IAQ.

Conclusions

In the end, the most effective strategy for good, energy-efficient IAQ is to control pollutant sources as much as is feasible and then use ventilation as required to limit pollutant concentrations to reasonable levels. We reduce the energy required for ventilation systems by minimizing the sources of indoor air pollutants in our designs. Sources can be controlled by eliminating polluting products, substituting less polluting products, encapsulating pollutant sources, or by isolating and directly venting emissions. By requiring manufacturers to test emissions from their products and provide architects with reliable, reported results, we can choose the least polluting sources and the products with the lowest overall emissions. We can choose products that do not emit odorous or irritating compounds and we can avoid products with significant emissions of carcinogens, teratogens, and other unacceptable properties. To do less is to abdicate our responsibilities to our clients and to building users. **Hal Levin** ■

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