Indoor Air Quality Update™

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

Vol. 1, No. 2 | Hal Levin, Editor | October 1988

Radon: How Bad Is It?

In mid-September, EPA stirred the indoor air with its joint announcement with the Office of the Surgeon General that researchers had found elevated radon concentrations in a number of states not previously identified as radon-problem prone. As a result, they have recommended that every home in the country be tested.

We think more comprehensive studies (in more states representing the majority of the country geographically and demographically) should be done before federal officials make such a sweeping recommendation. What is needed right now is sufficient funding for EPA to conduct this type of testing.

Test kits cost from $10 to $35. At an average cost of $15 per home, we are looking at a potential expense of more than $1 billion. Of course this would be privately financed by individuals, not supported by EPA.

If 5 to 15% of all homes require remedial work costing an average of only $500 each (a low estimate, we think), then homeowners will spend another $2 to $6 billion. This does not include the nonquantifiable but real social costs of worry, time lost in real estate transactions, and disruption of people's lives. While the free market or private enterprise aspects of this do not concern us, we would like to see more in the way of safeguards against consumer fraud.

We think EPA has inadequately communicated the intent and meaning of the four picocuries per liter (pCi/l) guideline in the past. EPA needs to make clear that *short-term tests are not sufficient.* How do you tell someone who wants to buy an existing or new home that?

The federal government ought to gear up to monitor the burgeoning radon industry and to advise the public and Congress on the issues involved in selecting testing and remedial methods and firms. EPA has sewn the seeds for fertile business development. Is EPA prepared to play the necessary role to protect American homeowners against fraud and other abuses that usually accompany any rapidly expanding marketing opportunity?

How big is the threat?

Many readers have asked us how serious the threat is and what they should do about it. You should recognize that most (at least 80% by the several estimates available) of the excess lung cancer deaths attributed to radon are expected to occur in smokers.

Smokers are already at serious risk of premature death from lung cancer without exposure to high radon levels indoors. The additional hazard presented by radon does not appear to be large for these people; they are only likely to die a little sooner if they are exposed to elevated radon levels for a significant time period.

There is some question about the magnitude of the increased risk for nonsmokers who live or work in buildings where smoking occurs and that have elevated radon levels. Certainly a higher concentration of airborne particles from environmental tobacco smoke or other sources, which can be attachment sites for radon daughters, increases the risk. How much is not yet fully understood.

In This Issue

House tightness and radon levels
Many people believe that if they are in an energy-efficient home, their radon risk is larger than if they are in an old, leaky home. Myth has it that leaky homes pose no threat. In fact, most authorities agree that there is no correlation between airtightness of a house and the radon levels found inside.

Go ahead and test
If you are worried, go ahead and have your home tested. Get a hold of one of the many informational publications available from state or federal agencies and read it first. Then obtain either a charcoal or electret passive sampler for short-term testing (days) or the track-etch device for longer-term tests.

If the results indicate elevated radon levels, retest with several monitors located in various locations according to the guidance available from EPA or state officials. Do not panic.

First of all, you need multiple samples over a long sampling period to verify the existence of a problem. Unless the levels measured in the short-term test are very high (at least 10 pCi/l, maybe more), don't worry until you have taken samples through winter, preferably for a whole year.

If your short-term levels are high, you should get advice on how to find a qualified, reliable firm to do a thorough investigation — using direct-reading instruments to measure levels and identify potential sources of radon entry into your home.

Nonresidential radon risk
In the September issue of *IAQU* we raised the question of radon risk in nonresidential buildings. We think there needs to be considerably more measurement in such buildings to characterize the potential risk posed by occupancy, particularly in areas where high levels have been found in residences. And we think that schools and other indoor environments where children spend large amounts of time ought to be studied as a class of buildings.

Research needs
We would like to see EPA conduct testing in schools and office buildings, especially on the two or three floors nearest the ground in multistory buildings. And we hope more studies of other nonresidential buildings will be done soon. And we also hope to see more thorough research on the distribution of radon problems in residential buildings throughout the country.

For more information:
Practical Radon Control for Homes. Available from Cutter Information Corp, 1100 Massachusetts Avenue, Arlington, MA 02174; (617)648-8700. $40/copy.

Radon Reduction Techniques for Detached Houses, Technical Guidance (Second Edition). EPA Report 625/5-87/019. Available from state agencies, EPA's regional offices, and EPA's Center for Environmental Research Information, Distribution, 26 W St. Clair Street, Cincinnati, OH 45268.

Feature

Fanger, the olf, and the decipol

Among the highlights of the recent "Healthy Buildings '88" conference (reviewed later in this issue) were the presentations and an exhibit by Professor Ole Fanger of the Technical University of Denmark, whose work has been important in current thermal comfort criteria and ventilation standards promulgated by ASHRAE.

Fanger's latest contributions involve the development of subjective odor evaluation techniques and values that allow comparison of odor acceptability for different sources and in different spaces. Among other things, Professor Fanger and his students have been using his techniques to validate ventilation requirements in current and proposed ASHRAE standards.

Berlin, 1987: The olf unveiled
In August 1987 in West Berlin, at the 4th International Conference on Indoor Air and Climate, Professor Fanger unveiled his olf concept.

Fanger's presentation of his system is as entertaining as it is useful (see Figures 1 through 3). His use of lighthearted drawings and his dramatic and humorous presentation make it difficult to take him completely seriously at first. But his current work provides an extremely valuable research tool with potential for application in standards development as well as in the evaluation of building ventilation performance. Fanger and his coworkers presented a number of papers at the Stockholm conference that illustrate the usefulness of the olf and its companion unit, the decipol. Some of those papers and their implications are discussed below.

What's an olf?
The olf (from olfaction) is a unit of measure for the subjective quantification of odor. One olf is the emission rate of air pollutants (bioeffluents) from a standard person. One standard person is a person under normal activity such as working in an office, sedentary and in thermal comfort, with a hygienic

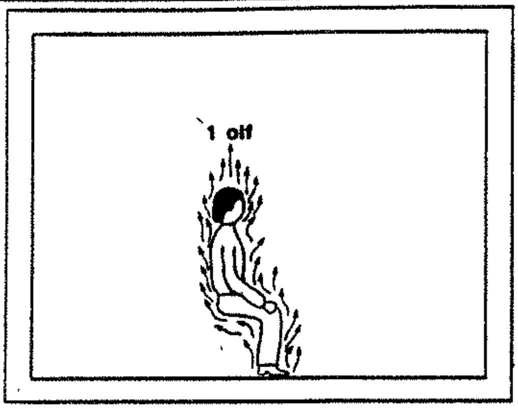

Figure 1 — One olf is the air pollution from one standard person, i.e., from an average adult working in an office or a similar nonindustrial workplace, sedentary, and in thermal comfort with a hygienic standard equivalent to 0.7 bath/day.

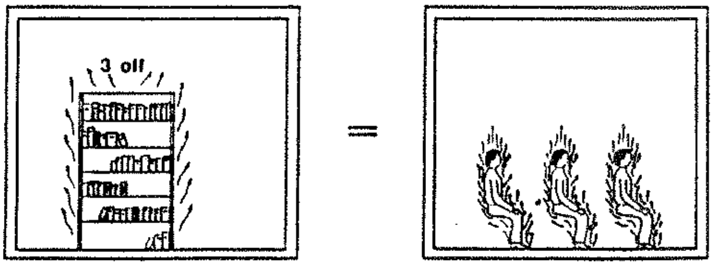

Figure 2 — A pollution source has a strength of three olfs, if the pollution from three standard persons causes the same dissatisfaction as the source.

standard equivalent to 0.7 bath/day. (See Figure 1.)

Other air pollution sources are quantified against that standard measure, the olf, in terms of the number of olfs required to cause the same level of dissatisfaction as the actual pollution source. Note that the measurement is of the level of *dissatisfaction*, not the strength of the odor. It is a measure of source strength (see Figure 2).

What is a decipol?

The decipol is the unit representing the pollution caused by one standard person (one olf), ventilated by 10 liters per second (20 cfm) of unpolluted air (see Figure 3). It is used to quantify human perception of air pollution. The perceived air pollution is the concentration of bioeffluents that would cause the same level of dissatisfaction as the actual air pollution.

Organoleptic techniques

Based on the sense of smell as a measurement instrument, Fanger has adapted the techniques used by coffee, wine, beer, perfume, and other food- and odor-based industries to the measurement of indoor air quality. "Organoleptic" means using the senses. Professional tasters and odor evaluaters make important (economic) judgments based on their sense of smell. Fanger has used this approach to train his "olf busters" (as they call themselves) and develop a useful and practical means of increasing our understanding of the factors affecting indoor air quality and its control.

Panels of trained "olf busters" visit buildings to judge the acceptability of the odor. Evaluations are made in unoccupied spaces with and without the ventilation system operating and in occupied spaces with normal ventilation.

The olf bar

At Healthy Buildings '88, Fanger and his associates operated an "olf bar." This was a booth where visitors had opportunities to sniff various objects in a series of glass jars with small fans blowing air out through a funnel. Standardized olf values were available in four jars ranging from one to 20 olfs. (Many sniffers told us that acetone was used in controlled concentrations for these calibration jars.)

Each day of the conference there was a contest to guess the correct olf value for a mystery jar using the calibration jars for help. Then there was a "cocktail du jour," and a series of "healthy" and "unhealthy" building jars. Using cigarette

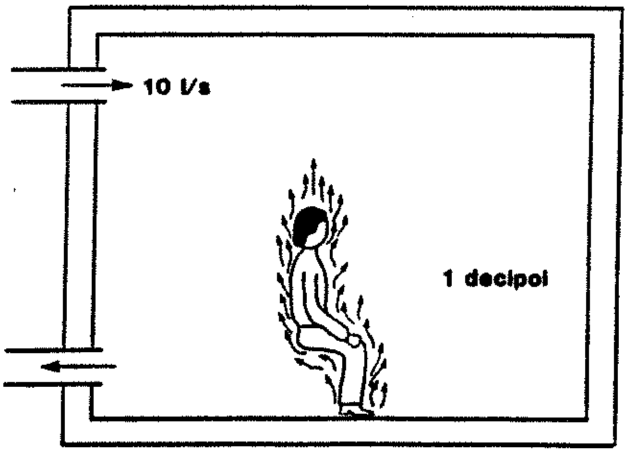

Figure 3 — One decipol is the perceived air pollution in a space with a pollution source of one olf ventilated by 10 l/s (20 cfm) of unpolluted air. Steady-state conditions and complete mixing are assumed.

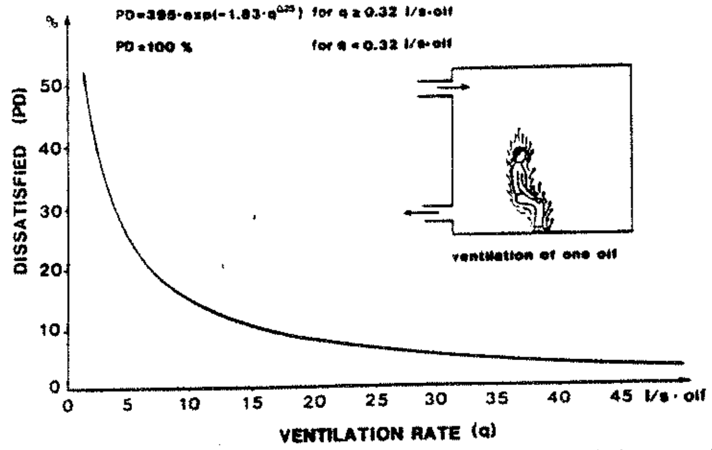

Figure 4 — Dissatisfaction caused by one olf at different ventilation rates. The dissatisfied are the persons who find the air unacceptable when entering the space. The curve is based on bioeffluents from more than one thousand persons, judged by 168 subjects.

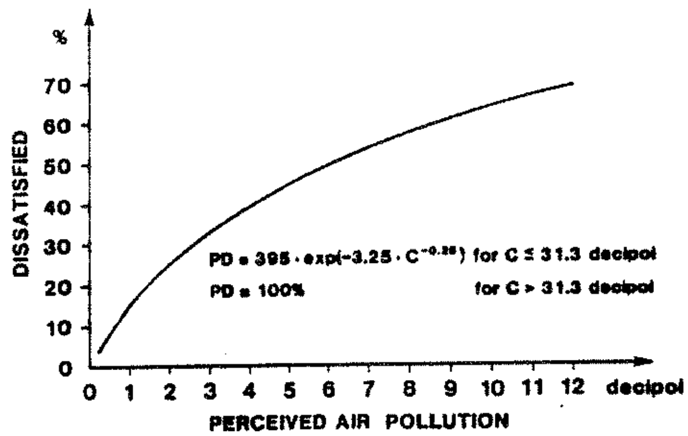

Figure 5 — Percentage of dissatisfied as a function of the perceived air pollution in decipol.

butts or jars with cigarette butts removed, carpeting, and pieces of furnishings, the jars simulated a series of experiences. We actually thought the "healthy building" jar had a rather strong new carpet smell, but maybe some people like that odor.

Use of the olf and decipol

Fanger suggests that the system of measurement using the olf and decipol provides a rational basis for identification of pollution sources, calculation of ventilation requirements, and prediction and measurement of air quality indoors and outdoors. We are convinced by Fanger's track record and the quality of work already done using the olf that he intends to continue developing applications of the olf/decipol system. We do not believe the olf and the decipol are likely to find their way into codes or standards; yet it is certain they will influence research and the development of standards for years to come. Fanger's work on thermal comfort and subjective evaluation from the 1970s are important elements in ASHRAE's standards for thermal comfort and indoor air quality.

The Fanger system has been carefully developed to be consistent with many of the concepts and procedures used in ASHRAE ventilation and thermal comfort standards, including satisfaction and its translation into acceptability. The ASHRAE ventilation standard is based on acceptability and not on health, as some of its critics are quick to point out.

Table 1
Olf Values for Human Pollution Sources

Sedentary persons, 1 met*	1 olf
Active person, 4 met	5 olf
Active person, 6 met	11 olf
Smoker, when smoking	25 olf
Smoker, average	6 olf

* ASHRAE's unit of measure for metabolic rate. One met is 58.2 W/m^2 or 18.4 Btu/hr x ft^2.

Some basic olf relationships

Table 1 gives the olf values for humans at various activity levels and for smokers when smoking and not smoking. Figure 4 shows the relationship of ventilation rate to percent dissatisfied in the presence of one olf. Figure 5 shows the percent dissatisfied as a function of the perceived air pollution in decipols. Note that 20% dissatisfied (or 80% satisfied) is the basis for ASHRAE standards for thermal comfort standard (55-76) and ventilation for indoor air quality (62-1981). Again, remember that these are essentially comfort measures, not health measures.

Tobacco smoke, comfort, and olf values

Geo Clausen, a research associate at the Technical University of Denmark, presented "Comfort and Environmental Tobacco Smoke" at ASHRAE's IAQ '88 (see Information Exchange to obtain the proceedings) and, along with Fanger and Jan Pejtersen, "Olf Values of Spaces Previously Exposed to

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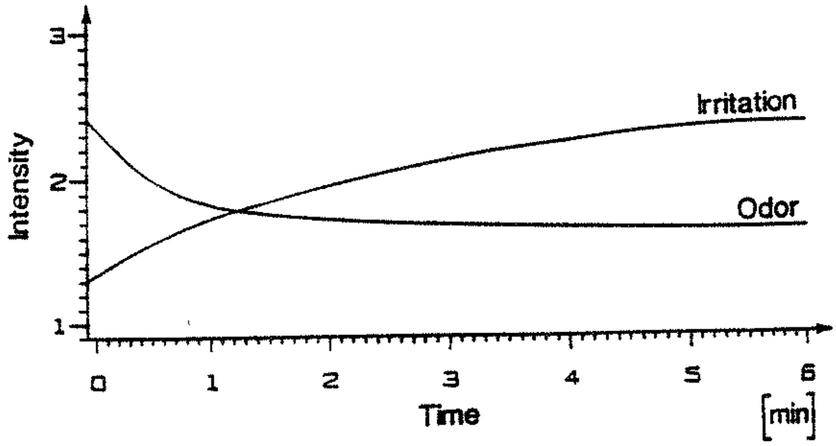

Figure 6 — The intensity of odor and irritation over time (Kerka & Humphreys 1956)

Tobacco Smoke" at Healthy Buildings '88.

In the ASHRAE presentation, Clausen cited research showing that the intensity of irritation increases while the perceived intensity of odor decreases during the first three to six minutes of exposure (see Figure 6).

Clausen found that nonsmokers were more dissatisfied than smokers when exposed to a range of levels of environmental tobacco smoke (ETS). Of course this is not surprising, but it is useful to quantify the relationship, and Clausen has done this (see Figure 7).

Pejtersen, Clausen, and Fanger reported in "Olf Values of Spaces Previously Exposed to Tobacco Smoke" that the indirect effect of ETS adsorbed during previous smoking could have as much effect on air quality as the direct effect of current smoking during the evaluation. During visits to bars and restaurants on various occasions when they were occupied and unoccupied, judges rated the acceptability of the air quality. Measurements of ventilation rates, particulate matter concentrations (an indication of ETS), and of cigarettes smoked were used with the olf and decipol units to compare acceptability of current and prior smoking.

The results indicate that perceived air quality can be significantly affected by outgassing from materials previously polluted by smoking (see Figure 8). Indirect (previous) smoking was found to be of a similar magnitude to direct smoking in its impact on perceived air quality.

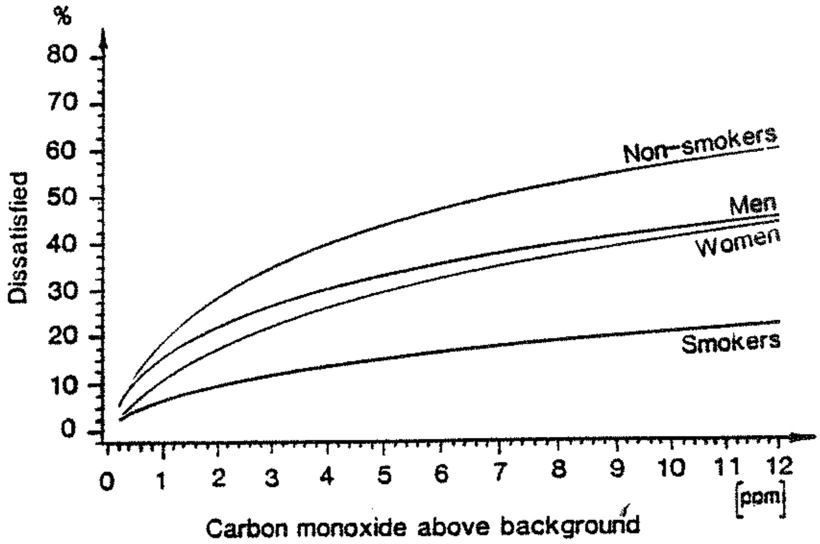

Figure 7 — Percentage of dissatisfied for various concentrations of tobacco smoke expressed by the corresponding concentration of carbon monoxide, as perceived by equally sized groups of men, women, smokers, and nonsmokers (from a study by Clausen et al 1985)

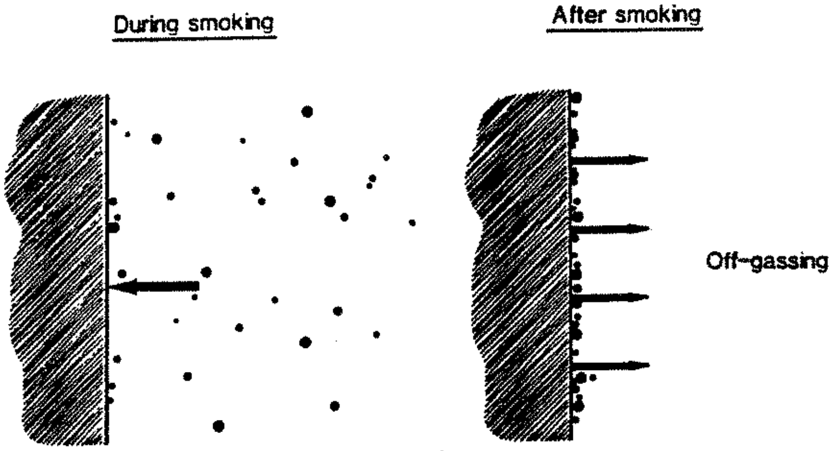

Figure 8 — Background odor from previous tobacco smoking (Clausen et al 1986). During smoking, particulate matter adsorbs on surfaces from which odorous, gaseous components are later remitted to the indoor air.

Adaptation to indoor air pollution
Adaptation to indoor air odors and perception of acceptability depend upon the type of odorant involved, according to another Fanger collaborator, Lars Gunnarsen. Since the sense of smell is likely to adapt while the general chemical sense is not, during the adaptation period the perceived intensity of odor is likely to weaken. But, as Clausen found with tobacco smoke, irritation may persist or increase, depending on the odorant.

Type of pollutant is important
In evaluating the impact on acceptability of human bioeffluents, cigarette smoke, and building materials, Gunnarsen and Fanger found important consequences of the adaptation, odor, and irritation relationships. Their work suggests to us that since human bioeffluents stimulate mainly the sense of smell, while emissions from tobacco smoke and building materials comprise irritants, adaptation to odors may confound acceptability ratings unless the sources of the odors are identified. This raises questions about the olf system's usefulness and requires that further work be done to elucidate the relationships and their consequences. We are confident that Professor Fanger and his colleagues will report such work in the future.

Practical Implications

1. Ventilation is especially required to control odor and IAQ acceptability prior to initial occupancy after:

- new construction;
- remodeling;
- refurnishing;
- floor waxing;
- furniture polishing; and,
- weekends, holidays, and other periods when ventilation has not been operating (even lunch breaks).

2. Continue maximum ventilation as necessary to control IAQ-caused irritation and discomfort (as distinct from perceived odor).
3. Buildings where smoking is permitted require increased ventilation rates for odor and comfort-based acceptability, especially for nonsmokers.

For more information:
The presentations by Fanger *et al* are available in the proceedings of Healthy Buildings '88. See the next article for information on how to obtain them. Fanger's earlier work on olfs and decipols was published in ***Energy and Buildings, Vol. 12.***

Conference Report

"Healthy Buildings '88"
Over 600 participants from 28 countries gathered in Stockholm, Sweden, September 5-8 to discuss healthy buildings. Building planning and design, thermal comfort, acoustics, and illumination were among the topics in addition to indoor air quality. Sponsored by CIB (the International Building Council for Research, Study and Documentation) and the Swedish Building Research Council, the conference was innovative in stressing healthy buildings rather than sick buildings. And the inclusion of the wider range of comfort and health issues beyond indoor air quality was a precedent many of the participants welcomed.

Participants included architects, engineers, builders, developers, and manufacturers, as well as the usual assortment of scientists and government officials. There was considerably more emphasis on the "how-to" aspects of making buildings healthy than in previous international and most U.S. indoor air quality conferences we have attended.

The proceedings have been edited by conference organizers Birgitta Berglund and Thomas Lindvall, and published in four volumes. An additional volume containing summaries of the workshops and symposia will be published soon. Proceedings are available from the Swedish Council for Building Research, Svensk Byggtjanst, Box 7853, S-103 99 Stockholm, Sweden. The four volumes are priced at about SEK 490 (about U.S. $75). Interested readers should write for details.

Experts call for better building maintenance
Speakers and other conference participants stressed repeatedly that maintenance of buildings, particularly of HVAC systems, is a critical element of healthy buildings. While the conference did not extensively explore maintenance issues *per se* in any comprehensive or systematic fashion, various maintenance failures were identified repeatedly as sources of building problems or barriers to healthy buildings. Several of the conference speakers identified correct and adequate maintenance practices and their faithful performance as critical to the creation of healthy buildings.

The building investigations reported by James E. Woods, Jr. (see the premier issue of ***IAQU***), as well as by many other authors, indicate that in many cases problem

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buildings are ones where proper maintenance has been neglected. We will focus on maintenance considerations in future issues of *IAQU*, and we welcome comments and suggestions from our readers.

User control: opinions, recommendations and options

Another theme conferees frequently stressed was increasing user (occupant, tenant, householder, etc.) control in buildings. Systems like heating, cooling, ventilation, and lighting all received attention during the conference, and many speakers stressed the increased satisfaction that accompanies increased user control.

The concept is not a new one by any means. One of the international gurus of housing theory and practice, John F. C. Turner from England, wrote in his 1976 book, ***Housing by People*** (Pantheon Books, New York): "Who decides what for whom is the central issue ...[in] housing and human settlement." In his earlier ***Freedom to Build*** (The Macmillan Company, 1972), Turner wrote that satisfaction in housing increases to the degree that householders control the important (to them) decisions regarding their housing and the resources expended for it.

Jan Stolwijk of Yale, one of the luminaries in the indoor air field for over a decade, frequently argues that providing building occupants with increased control of their environment is likely to reduce complaints and symptoms associated with sick building syndrome.

Evidence to support such a claim is not abundant, and giving occupants increased control runs counter to the inclinations of many engineers. However, there is much evidence from both animal and human subject research that when subjects control or even think they control their environment, they exhibit fewer signs of stress and perform better.

Many studies of building occupants have shown that people express a preference for individual environmental control. We would like to see more applied research on the subject; we tend to believe that user control will increase the user's perception of comfort and sense of satisfaction.

Practical Research Briefs

Controlling Legionellosis — The WHO Report

A report from the World Health Organization — "Environmental Aspects of the Control of Legionellosis" — provides extensive information about the occurrence and control of this disease. Legionellosis is a bacterial infection which can take the form of the sometimes fatal pneumonia-like illness, Legionnaires' disease, or the milder, influenza-like Pontiac fever. The bacterium that causes Legionellosis, *Legionella pneumophila*, thrives in a myriad of environments, especially indoors. It is now believed to be ubiquitous.

Legionella is present in municipal water supplies, in building air, in ventilation system ducts, cooling towers, cold spray vaporizers, and many other locations. Its presence does not mean there will be an outbreak or epidemic, but if control measures are inadequate, building equipment can act to amplify its concentrations. Most of these control measures are matters of building design, operation, or maintenance.

Experts believe that *Legionella* must be inhaled for the illnesses to occur. But researchers consider aerosols from running water, showers, hot tubs, and spas to be probable sources of many past infections.

HVAC systems and cooling towers

Where feasible, Jan Stolwijk suggests dry-type heat rejection units to minimize the risk of *Legionella* growth. This risk is large in wet-type heat rejection units such as cooling towers, which favor bacterial growth and provide opportunities for distribution in the environment through drift.

A recent incident at a BBC building in England has led some public health officials to recommend elimination of all wet-type heat rejection units. This would mean enclosing water in heat exchange devices and using something resembling an oversized automobile radiator as a dry-type system. It would be an expensive and significant change for the HVAC industry, but the potential for major *Legionella* releases and epidemics in urban areas has led to this recommendation. The BBC incident resulted in about 250 cases of illness, but calculations of the potential impact under different wind conditions indicate that as many as 5,000 people could have been affected.

Control methods

If you must use or install conventional wet-type cooling towers, you can employ control measures to reduce or eliminate microbial growth. The most common is chlorination of circulating water. Continuous chlorination to a level of two to four parts per million (ppm) is effective in eliminating microbial growth. However, that level of chlorination is likely to corrode cooling system components if maintained continuously.

Hyperchlorination (higher chlorine levels) at intervals can effectively control *Legionella* and the formation of slime (which can support *Legionella* growth). Use levels of 15 ppm, keep pH below 7, with circulation for two hours followed by draining and refilling. Thoroughly clean all surfaces and components to remove scale and sludge.

The optimal temperature for microbial growth is 36°C (96.8°F). At temperatures above 55°C (131°F) microbial growth is substantially curtailed. Adjusting operating temperatures is not always practical. But knowing what temperature range presents the greatest hazard will allow building operators to selectively monitor their systems for signs of microbial growth.

Designers and contractors should ensure that all cooling tower components are readily accessible for regular surveillance. And effective surveillance should be scheduled and monitored by building operators. This should include thorough inspection at the beginning of the cooling season and throughout its duration.

Domestic or institutional hot water systems

Researchers have realized that hot water systems are more often implicated in outbreaks of Legionellosis than are cooling towers, especially in Western Europe. Many of these outbreaks have been in health care institutions, where there is a large population of people with diminished ability to fight off infections. *Legionella* has been found in samples of a substantial fraction of water distribution systems, especially hot water systems. It is important to note that it only rarely causes Legionellosis.

A special problem exists where solar water heating systems are used and the water temperature does not exceed 131°F (55°C) at least once in the distribution system. Additionally, hot water pipes that stand idle for more than a day or two at a time can be a breeding ground for *Legionella*. Some resort hotels in Southern Europe with solar hot water systems have experienced *Legionella* contamination in recent years.

Energy conservation motives have led many individuals to reduce the setting on water heaters and storage tanks. This is an effective way to conserve energy, but a temperature of 131°F must be exceeded somewhere in the supply system, preferably before the storage phase. No water in the system should be allowed to sit at temperatures of 95-115°F (35-45°C) for long periods of time.

Design guidelines

- Avoid rubber parts and other materials that support microbial activity.
- Make all plumbing runs straight through without loops or stagnant volumes.
- If you use chlorination in hot water systems, 1.5-2 mg/l of chlorine should be present at all times.

If Legionellosis occurs

- *If a single case occurs* in association with a building, the WHO report does not recommend monitoring. However, you should carefully check design and operating conditions, especially with respect to water temperature and chlorination.
- *If more than one case occurs*, monitor to identify possible sources and appropriate control measures. In past cases contamination has been successfully controlled with the following measures:

1. Keep all cold water supply and storage chlorinated so that all water delivered at any outlet contains 1 to 2 ppm free residual chlorine at all times.
2. Cold water storage tanks should be inspected and cleaned at least once a year. Keep temperature below 68°F (20°C) and, if necessary, monitor water temperature near the top of the tank.
3. You can sterilize pressurized vessels by hyperchlorinating at 20 ppm or above for at least two hours, then draining and refilling.
4. Maintain hot water supply and storage tank water temperature limits between 131 and 140°F (55 and 60°C). If scalding is a risk, post signs at outlets. Use mixing valves to avoid scalding temperatures at outlets.
5. Once a year, test all hot and cold water outlets and maintain a log. Test cold water outlets for chlorination; they should demonstrate 1 to 2 ppm free chlorine within two minutes. Hot water supplies should demonstrate temperatures of 131 and 140°F (55 and 60°C) within two minutes. Run all mixing valves, shower heads, and aerating taps hot for one minute, followed by cold for one minute, after which the water should contain between 1 and 2 ppm chlorine.

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6. Run each shower in the building at least once each week — two minutes with hot water followed by three minutes with cold chlorinated water. Unused or seldom used taps and showers should be considered for removal.
7. When any room or part of a building is unused for a period of time, re-occupy only after conducting a full test of hot and cold water systems with satisfactory results.
8. Sterilize water heaters and storage tanks by raising temperatures above 158°F (70°C) and letting cool before draining, or by hyperchlorination at 20-30 ppm free chlorine for 24 hours before draining.

Humidifiers

Only steam humidifiers are thought to be free from risk of disseminating *Legionella*. Air washing (spray type), spinning disc, or ultrasonic humidifiers are capable of efficiently disseminating the bacteria. Use biocides only during cleaning. Evaporative coolers used in dry, hot climates can be a source of aerosolized *Legionella*, especially if their air velocities are high enough to induce aerosolization.

For more information:

Environmental Aspects of the Control of Legionellosis. Regional Office for Europe, World Health Organization, Copenhagen, Denmark. 1986.

Legionnaires' Disease EURO Reports and Studies 72. Regional Office for Europe, World Health Organization, Copenhagen, Denmark. 1982.

Both publications available from WHO Publications Centre, USA, 49 Sheridan Avenue, Albany, NY 12210; (518)436-9686.

Air Filtration for IAQ Needs More Study

Particulate matter found in indoor air presents a significant challenge for designers, product manufacturers, and building operators and users because it includes a wide range of particle sizes, types, health effects, and control measures. Gaseous contaminants also vary in terms of their chemical structure, behavior in indoor air, and effect on human occupants. It is the role of air cleaning to reduce levels or completely remove harmful and annoying contaminants, and no single air cleaning system will work for all of them.

Particles found in indoor air vary considerably in aerodynamic diameter, size, toxicity, and other factors. And the concentration and distribution of particles in a particular environment will vary depending on sources present and the removal mechanisms available.

Particle sources include tobacco smoke, combustion in gas appliances or wood stoves and fireplaces, radon progeny, and cooking by-products. Biological particles, bacteria, and pollen can be present. Other sources of particles include spray propellent products such as antiperspirants, paints, hairsprays, and air fresheners. Office air may contain particles from copying, printing, duplicating, or postage machines.

The size of particles in different indoor environments is important to determine the performance requirements of air cleaners. Table 1 provides some information on particle size and concentration in various indoor environments.

Air cleaner research

Researchers at the Center for Aerosol Technology (Research Triangle Institute) have developed an elaborate system for evaluating the performance of various air filters. The results of their work (reported at ASHRAE's IAQ '88) were not encouraging for those who would like to increase their use of air cleaners to improve indoor air quality. They evaluated several types of air cleaners.

Table 1
Some characteristics of particles found in indoor air

Indoor location or source	Particle size (μm) Median	Range	Typical or Peak Concentrations μg/m³
Offices	0.13	<10μm	
without smokers			20 - 60
with smokers			50 - 130
			200 (peak)
Sports arena			
with smokers			568 (peak)
Radon progeny	0.02	0.01-0.05	
Biological aerosols		1.0	
Spray products		2-9	

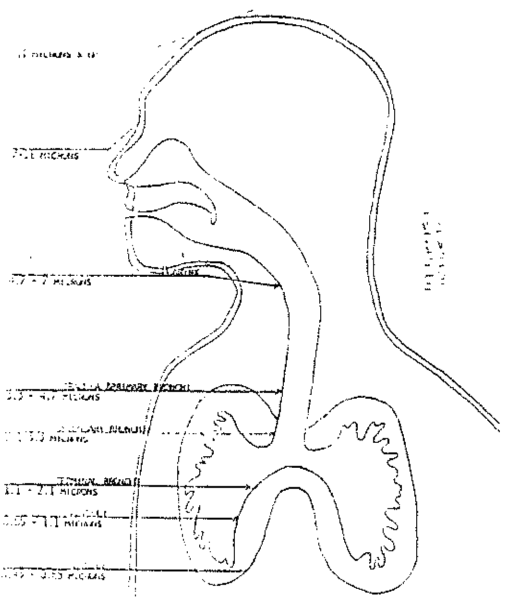

Figure 1 — Respiratory Penetration vs. Particle Size

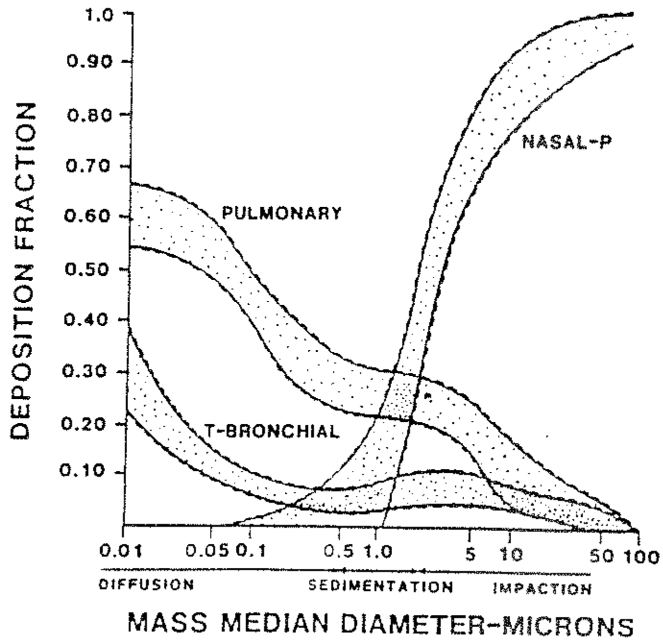

Figure 2 — Predicted Human Deposition

Characteristics of air cleaner performance important to indoor air quality are

- particle-size-dependent removal efficiency,
- behavior of semi-volatile particles after collection,
- secondary emissions such as ozone or particles,
- change in performance with age of filter, and
- energy required for operation.

In-duct filters

The researchers tested four grades of ventilation filters (ASHRAE 40, 65, 85 and 95%) to determine their particle-size-dependent efficiency. This is important because the penetration of particles deep into the respiratory system and into the lungs is a function of particle size — the smaller particles penetrate deeper than larger ones. Figure 1 shows the deposition site in relation to particle size. Figure 2 shows the fraction of total deposition that takes place in the nasal passages, bronchial area, and pulmonary area of the respiratory system.

The results of the filter tests show that all four filters, even those with ASHRAE efficiency ratings of 85% and 95% (by ASHRAE Standard 52-76 dust spot test), are least effective in removing the 0.1-0.5 micrometer particles, the size particles which tend to penetrate deepest into the respiratory tract and reach the alveoli where they can cause great health harm. Even the rated 95% efficient filters remove less than 60% of the particles in this critical particle diameter range (see Figure 3).

Filters rated at less than 85% efficiency are not very effective in removing particles in the 0.1 micrometer range. This raises serious

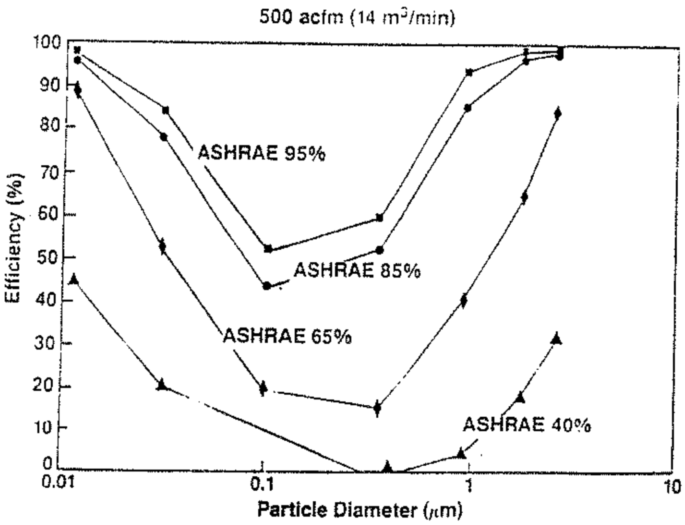

Figure 3 — Particle-size dependent efficiency for various grades of ventilation filters.

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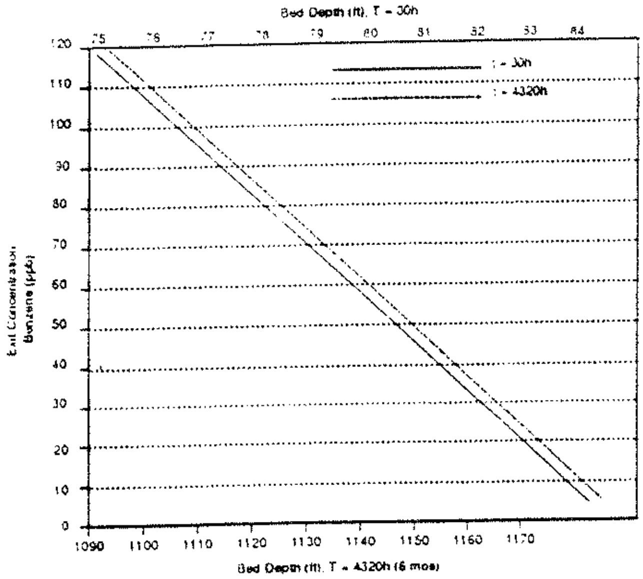

Figure 5 — Variation of exit concentration of benzene with bed depth (150 ppb challenge concentration, 25 ft/min superficial velocity, 0.12 inch particle size, and Barnaby Cheney type activated carbon).

questions about the adequacy of traditional building ventilation filters for protecting human health.

This work also raises questions about the adequacy of the ASHRAE test method, which uses particles larger than one micron for rating filters. While it is important to know the performance of filters in this size range for health and other considerations, the test does not result in filter selection related to the potentially most significant health effects.

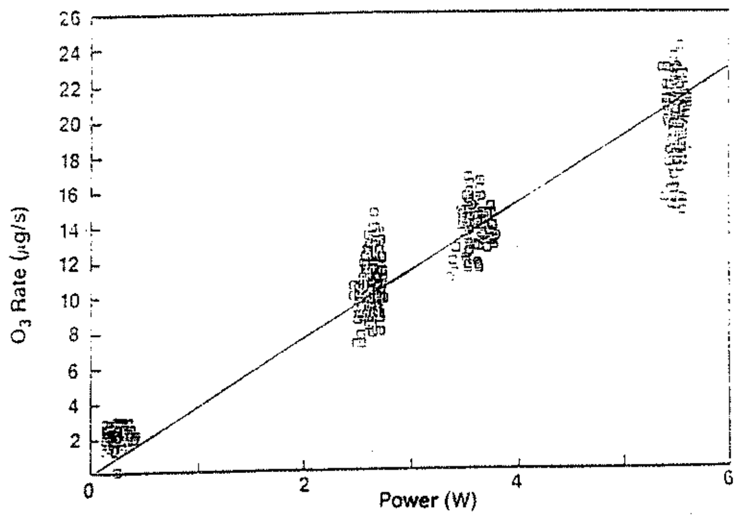

Figure 4 — Relationship of ozone production to power consumption in electrostatic precipitators.

Electrostatic air cleaners

Electrostatic precipitators produce ozone, and the quantity of ozone production seems to correlate with the energy consumed by the device (see Figure 4).

Concern about ozone relates to its direct effects on humans as well as its potential to transform organic chemical substances with which it readily reacts. Control of ozone production from electrostatic precipitators is possible through a variety of design approaches, including the use of a two-stage design separating charging and collection functions; use of positive (rather than negative) polarity corona; use of smallest possible diameter smooth round wire; use of lowest possible corona current and maximum airflow compatible with satisfactory collection efficiency; and elimination of stray discharges.

Sorption

Sorption filters (activated carbon) are not very effective in removing relatively low (ppb) concentrations of volatile organic compounds. Large bed depths would be required to provide a reasonable lifetime for the filter media. Figure 5 shows that the removal rate for benzene with a beginning concentration of 150 ppb is fairly predictable based on the beginning concentration, air flow rate, and depth of the sorption bed of activated carbon.

The researchers suggested that sorption might be useful for short-term, high concentrations found during chemical releases. But such situations are not normally encountered in nonindustrial buildings, and they would generally be difficult to predict or anticipate. The value of providing such a filter for unpredictable and sporadic use is questionable at best.

Practical recommendations

1. The research reported here raises important questions about the adequacy of common forms of building HVAC filtration to protect human health. It demonstrates that 85% or 95% filters should be used to provide at least some level of practical protection. Yet this protection is least effective for particles of greatest health significance.

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2. Electrostatic precipitators can produce ozone if not properly designed. Careful design and selection of the electrodes is critical to minimizing ozone production. However, to control small particles, electrostatic precipitators are the most practical currently available technology.

3. The research results do not provide a great deal of encouragement for control of typical indoor concentrations of VOC with sorption devices. They reinforce the generally held view that these sources must be controlled by elimination, confinement, local exhaust, or treatment.

Comments

Electrostatic precipitators (ESP) must be properly maintained to perform well over time. This means regular cleaning of the collection surfaces. Failure to maintain ESP devices may cause greater IAQ problems than failure to maintain normal in-duct filters if microbial growth is not a problem.

Levels of ozone exceeding EPA's ambient air quality standard of 120 ppb have recently been found in office buildings, and some scientists are calling for an 80-ppb standard because of recent evidence that significant health effects occur at 120 ppb. We will expand on this in our next issue of ***IAQU***.

For more information:

Contact David Ensor, Research Triangle Institute, Research Triangle Park, NC 27711; (919)541-6000.

D. S. Ensor et al. Air Cleaner Technologies for Indoor Air Pollution. ***Engineering Solutions to Indoor Air Problems***. Proceedings of the IAQ '88 Conference. (See Information Exchange for availability.)

Ultrasonic Humidifiers and Airborne Contaminants

Field tests by EPA's Environmental Monitoring Systems Laboratory on various types of portable humidifiers show that indoor airborne particle levels can reach levels many times the national standard when tap water with typical mineral content is used. Using tap water and distilled water, the researchers tested steam, impeller, and ultrasonic humidifiers.

In single-room experiments, the ultrasonic type humidifier using tap water resulted in airborne particle levels of 7,500 $\mu g/m^3$, 50 times the EPA's new PM_{10} primary standard for ambient air of 150 $\mu g/m^3$ for a 24-hour period. (PM_{10} refers to particulate matter less than 10 micrometers in diameter.)

In whole-house tests using tap water, PM_{10} air levels averaged 582 $\mu g/m^3$, and using demineralized water, 43 $\mu g/m^3$.

These levels compare to a background level of 19 $\mu g/m^3$ for the house. The PM_{10} air levels were found to correlate well with the total dissolved solid content of the water used in the ultrasonic humidifiers. In comparison, two impeller type humidifiers resulted in air levels of 191 and 56 $\mu g/m^3$ respectively but with far lower water consumption rates than for the ultrasonic models. The steam humidifier produced an air level of 41 $\mu g/m^3$, also with a lower water consumption rate.

Even using purchased distilled water in the ultrasonic humidifier as per the manufacturer's recommendations, the researchers calculated that airborne particle concentrations would exceed 300 $\mu g/m^3$, or twice the EPA standard, in a single-room experiment. They also found that the impeller and steam type humidifiers resulted in higher airborne concentrations of coarse particles compared to fine particles.

It's the water

Virtually all municipal water supplies contain dissolved minerals and organic gases. The testing was done in Boise, Idaho, where the municipal water was found to contain an average of about 303 milligrams per liter (mg/l) total dissolved solids (TDS) and a hardness of 145 mg/l. Commercially available distilled water used in the experiment contained TDS of 24 mg/l, typical of commercially distilled water.

Health considerations

Fine particles are those with diameters less than 2.5 microns. The steam humidifiers produced mostly fine particles (90% and 89% respectively), while the two impeller types produced 76% and 59% respectively and the steam humidifier produced 39% fine particles. From a health perspective, the fine particles are of greatest concern due to their more likely deposition deeper in the respiratory tract. (See the previous story on air filtration.)

Although manufacturers recommend the use of demineralized-water, the researchers report that "Most homeowners appear to be ignoring these warnings because [of] the added costs and inconvenience."

The ultrasonic type humidifiers have been quickly growing in popularity due to their quiet operation and ability to humidify large areas. They may also reduce mold and bacteria problems associated with the steam and impeller type humidifiers. The concern is with potential acute or chronic health hazards from exposure to elevated particle levels, and the chemical composition of the exposure will depend on the nature of the dissolved minerals. The researchers cited asbestos, lead, aluminum, and dissolved organic gases among the common water contaminants that could be aerosolized by the ultrasonic humidifiers.

For more Information:
Contact V. Ross Highsmith, Environmental Monitoring Systems Laboratory, U. S. Environmental Protection Agency, Research Triangle Park, NC 27711; (919)541-7828.

"Indoor Particle Concentrations Associated with Use of Tap Water in Portable Humidifiers," V. Ross Highsmith, Charles E. Rodes, and Richard J. Hardy. ***Environmental Science and Technology***, Vol. 22 (September 1988), pp. 1109-1112.

From the Field

Wet Process Photocopiers and VOC

Canadian researchers have found that in three of four buildings they studied, exhaust vapors from photocopiers using a wet process proved to be a major source of volatile organic compounds (VOC). And copier exhaust VOC were found on newspapers and books taken from from one of the buildings and placed in a test chamber. Researchers believe the VOC were adsorbed on the surfaces of the printed matter. They say it is likely the copier exhaust VOC adsorbed on surfaces of printed materials and upholstery can subsequently be re-emitted over a period of time even when the VOC source is no longer present.

Table 1
Total VOCs

Sample location	TVOC (mg/m^3)
Bldg. #3, library	0.13
Bldg. #2, library	1.58
Bldg. #1, 1st Fl., SE	1.77
Bldg. #1, 1st Fl., GF stair	1.18
Bldg. #1, GF SE	2.36
Bldg. #1, 1st Fl., NW	0.90
Bldg. #1, 6th Fl., office	64.0
Model A copier exhaust	4,150.0
Model A copier liquid	107,000.0
Bldg. #4, 2nd Fl., 2F Model D copier exhaust	1.42

The majority of the VOC detected were essentially hydrocarbons. The results of the total volatile organic compound (TVOC) tests are listed in Table 1.

For More Information
Yoshio Tsuchiya, M.J. Clermont, and D.S. Walkinshaw, 1988, "Wet Process Copying Machines: A Source of Volatile Organic Compound Emissions in Buildings." ***Environmental Toxicology and Chemistry, Vol. 7***, pp.15-18.

Tools & Techniques

Underfloor Supply Air for Flexibility and Good IAQ

Floor-based ventilation systems are growing in popularity as raised floors become more common in office buildings. The requirements of building owners and tenants for flexibility in office furnishing layouts and access to wiring for communications and computer systems are leading to a rapid increase in the use of raised floor systems, which make underfloor air supply distribution more practical.

Even speculative office developers are installing raised floors because of the growing demand. The raised floor was developed for computer rooms, but as the open office increasingly becomes a collection of computer work stations, the raised floor is finding wider application. One project leader at a major U. S. office design firm told us that the extra cost of raised floors is easily paid for in a short period of time.

The increased use of raised floors creates an excellent opportunity for the introduction of underfloor air supply. Outlets can be at the desk top, in the floor, in a column or partition, or on a pod. Occupant control becomes a more realistic option as distribution becomes localized to the point of one outlet per worker. The hardware to achieve individual, desktop distribution and control has been developed and utilized extensively in Europe and is beginning to penetrate North American markets.

One of the benefits of localized air supply close to the occupant's breathing zone is greater potential ventilation efficiency. This means that less outside air needs to be conditioned and cleaned to provide a given amount to the breathing zone of the occupants. This has both first-cost and operating-cost implications, which should make this approach even more attractive as data begins to be gathered on the actual savings.

Figure 1 illustrates an underfloor air supply with desk-top outlets. The individual air supply is comparable to the desk-top task lighting: Light is largely controlled by the occupant. It is efficiently delivered where it is required, when it is required. And its being under the control of the user gives a psychological advantage.

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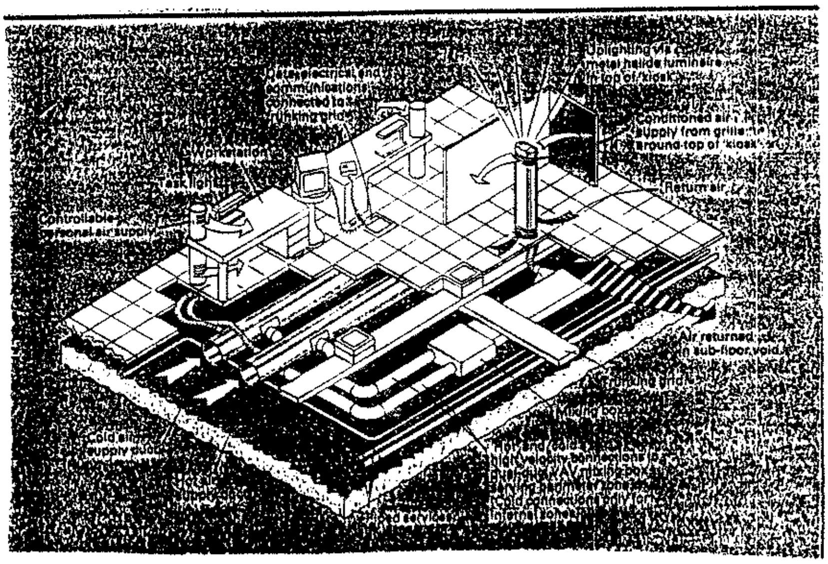

Figure 1 — Initial concept of floor-based services distribution.

Another benefit is flexibility in air distribution similar to the flexibility that underfloor distribution of wiring provides. When work stations or partitions are relocated, supply air outlets (and even return air inlets) can also be easily moved. Many indoor air quality problems come from changes in interior layout and use without commensurate changes in the ventilation system.

In some offices where workers are away from their desks a significant portion of the work day, supply air can be cut off when the work station is unoccupied. This could be done manually or with sensors. Some of the sensor technology will have to be developed, but parallels exist in local lighting control.

The intangible but important benefit of occupant control also has significant value to the occupants themselves and to their employers, who will benefit from the increased health, well-being, and satisfaction that are expected to follow from increased occupant control.

From Our Readers

Are There Any "Safe" Carpets?

The question most frequently asked of us goes something like this: "My company is moving into a new office, and I was wondering if there is anything we can do about the carpets. Do you know of a 'safe' carpet? Are there any?"

Recently we were asked this question by officials at EPA in Washington and at California's Department of Health Services, who were looking for better carpets for their own offices.

Some of our corporate facilities management and design clients are aggressively seeking "cleaner" office carpeting. And we know the carpet industry is beginning to respond to this important market force.

Carpet problems are of three sorts:

1. Odor, especially from new carpets.
2. VOC emissions from carpet, pad or backing, and adhesive; these break into two subgoups — short-term and long-term emissions.
3. Accumulation of particles and growth of microorganisms over time.

Each of these problems involves many issues, and there really aren't any easy answers. We do not know of some particular type of carpet that is problem free. Products are changed over time and carpet varies from one manufacturing run to another.

Odor

Odor frequently associated with new carpet (new carpet odor) has recently been attributed to a chemical which results from the combination of ingredients in the latex backing found on most commercial (office) and many residential carpets. This chemical, referred to as 4-PC (4 phenylcyclohexene) has been found in tests of new carpet and in the air of recently carpeted buildings.

Researchers in Arizona have measured 4-PC in concentrations of 30 ppb when carpet is first installed, and it diminishes to around three ppb after 30 days. However, the odor threshold is in the 1 to 3 ppb range. Once people smell it and associate the odor with the carpet, they may continue to identify that odor upon re-entering the newly carpeted environment.

We advise those looking for acceptable carpeting to do several things. Not all of them are practical in any given situation, but doing as many as possible has been effective in yielding the most satisfactory installations.

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VOC
4-PC is a volatile organic chemical, and while it is thought to be the characteristic new carpet odor, it is not the only VOC we might expect to come from carpet. We have found formaldehyde emitted from new office carpeting, although the levels declined by nearly a factor of ten in the first three weeks of exposure to the environment, and another factor of ten in the next three weeks. We think at least some of the formaldehyde comes from the fiberglass matt used between the carpet fibers and the backing. One carpet manufacturer whose carpet we had found emitting formaldehyde told us there was no formaldehyde added to the product itself.

Plasticizers used to make the backing flexible may also be emitted. Our lab found about 95% of the VOC emitted from some office carpet samples were dioctyl phthalate, a plasticizer.

The best advice we can give about control of VOC is to use the various measures described below to limit the amount that will end up in building air.

Particles and microorganisms
The accumulation of small particles and the growth of microorganisms in carpets are two of the long-term carpet problems of greatest concern from an IAQ perspective. Really removing fine particles is extremely difficult with normal cleaning procedures. Particles get ground up by foot traffic and reduced in size until they are too small to be effectively removed by even good-quality commercial vacuum cleaners. And the enormous amount of material and surface area available to serve as substrata and nutrients for microorganism growth make this problem especially important.

Good housekeeping practices are essential to minimize the problem. Do not allow moistened carpet to go untreated; it will surely support mold growth if not cleaned and dried quickly.

Minimize conditions that result in significant quantities of dust or mud being tracked in by those entering the building. Provide doormats or other mechanisms for collecting debris likely to be on the shoes of people entering the building.

Selecting and Installing Carpet

1. Acquire samples

Acquire samples of the carpets you are considering installing. The samples should be from carpeting which is as identical as possible to the carpeting you will actually purchase. This means that the sample must be manufactured, wrapped, shipped, and stored the same way as the carpeting you will install. Our own testing and that of others has shown that carpeting quickly ages when exposed to air circulation and normal temperatures. We stress the importance of acquiring *representative* samples.

2. Conduct "sniff tests"

Place the samples from each product in separate, *clean* glass jars. Seal the jars with a piece of aluminum foil, dull side facing the sample. Leave the samples at least over night. Moderate heating (not more than 100°F) for a few hours might be helpful. Then open the jars in an odor-neutral environment with good ventilation and do a sniff test. Rate the samples for strength of odor, degree of pleasantness or unpleasantness, and any irritation or other physiological effects you might experience. You can have several people participate, and you can repeat the process two or three times. You might try doing the test "blind," that is, without the person(s) doing the sniffing knowing which sample they are sniffing.

Of course all of this effort is only as useful as the reliability of your samples, so know what you are getting, where it is coming from, and how representative it is. Don't take showroom samples. Get pieces cut from rolls, or from the middle of a box for carpet tiles.

3. Minimize adhesive problems

After you have narrowed your choices to one or two carpets, call the manufacturer's technical representatives. Tell them you want a specification for adhesive that involves the minimum quantity of adhesive that will work. Tell them why you are concerned — health, odor, comfort, irritation, whatever it might be. Tell them you want an adhesive with a minimum of harmful chemicals, one that will dry quickly, but preferably one without any petroleum distillates or other petrochemical solvents. Ask them for the MSDS (Manufacturers' Safety Data Sheet) for the adhesives they recommend. And ask them to provide you with a written specification for installation including the type of adhesive and application instructions, including density.

4. Condition carpet

See if the carpet can be aired out or treated prior to installation. Discuss the possibility with the manufacturer's representative on a big order; you might be surprised what they will do to get the job. On a smaller job, you will have to arrange for this yourself. This means finding a place where the carpet can be un-

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rolled for at least 24 hours, preferably a week, with very good ventilation and temperatures no lower than what will be encountered in the building. This could be a warehouse or vacant space indoors, a garage or storage building, or even the roof of your building. Exposure to sunlight will be helpful in baking out the volatile chemicals.

Ventilation and air temperature are critical to an effective curing process. If the carpet can be supported off the ground so that both the top and back are exposed, that is even better.

5. Install with maximum ventilation

Install only when 100% outside air can be used in HVAC systems. Ideally, no return air should be run through the ducts or in a concealed ceiling plenum. Use windows, doors, stair towers, or whatever other temporary exhaust can be arranged to avoid running fumes from carpet, pad and adhesive through the ventilation system. Cover and seal return air inlets, if possible.

Continue to run 100% outside air ventilation for at least twenty-four hours, preferably a week or longer after installation. Try to plan ahead so that this can be accomplished in a fashion compatible with the schedule for installation of furnishings and fixtures.

Readers: If you have questions, comments, or suggestions for *IAQU*, please send them to our editor, Hal Levin, at 2548 Empire Grade, Santa Cruz, CA 95060.

Information Exchange

Engineering Solutions to Indoor Air Problems

This volume of proceedings from ASHRAE's IAQ '88 conference in Atlanta contains authors' papers from the third in this ongoing series of annual conferences. There are many interesting and valuable papers in the volume, ranging from general and theoretical considerations to practical solutions and case studies. The volume is divided into five sections: Pollutants, Design Concepts, Filtration/Controls, Simulation/Modeling, and Case Studies. Some of the papers are summarized elsewhere in this issue.

Available from ASHRAE, 1791 Tullie Circle NE, Atlanta, GA (404)636-8400. Price $39.00 (ASHRAE Members Price $27.00).

Ecological Illness Law Report

The masthead says: "The Ecological Illness Law Report (EILR) is an independent news-journal addressing the legal aspects of 'ecological illness,' a growing constellation of illnesses caused or exacerbated by chemical pollutants in indoor, outdoor, and workplace environments. These illnesses, probably attributable to chemically induced neuro-immune disorders, may produce a wide range of disabling disease symptoms. EILR is published quarterly. Subscriptions are $30 per volume/year."

Be sure to get the recent Volume V, Numbers 1 and 2, June 1988. It contains a wealth of information for lawyers and other interested professionals.

Published by Earon S. Davis, J.D., M.P.H. Available from the editor, P.O. Box 6099, Wilmette, IL 60691.

Asbestos Directory

This directory includes asbestos abatement information, 700 pages of listings of contractors involved in asbestos abatement, contract volume figures, legislative requirements, listings of important contracts, and glossaries of legal, scientific and trade terms.

Available for $150 from NICA, 1025 Vermont Avenue, NW, Washington, DC 20005.

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