term responses (more than 15 minutes) to odors when determining acceptability for the purpose of setting ventilation standards. Gunnarsen calls for longer time periods (several hours) to be used in future studies.

In sum, the question of odors and the acceptability of indoor air is a complex one, we need sophisticated techniques and multiple study conditions to clarify the factors which building operators must understand. Until that research is completed, ventilation should be maintained at relatively high levels when the majority of building occupants first enter any space to minimize dissatisfaction and complaints.

For More Information

Gunnarsen, Lars and Ole Fanger, 1988. "Adaptation to Indoor Air Pollution." in ***Healthy Buildings '88***, Vol. 3, Stockholm: Swedish Council for Building Research. pp. 157-167.

For more information on the Fanger approach to odor evaluation and its relation to ventilation requirements, see ***IAQU***, October 1988, and also the November 1988 issue of the ***ASHRAE Journal***.

Productivity and Indoor Air Quality

EPRI Sponsors User-Controlled Workstation Discussion

The Electric Power Research Institute (EPRI), looking for ways to utilize electric power to improve office environments, recently hosted a two-day workshop to explore possible research topics related to user-controlled workstations. A major concern was to find ways in which research, new technology, or designs could provide improved indoor air quality through the user-controlled workstation.

"Improved environmental quality improves office worker productivity" is an assumption that the more than thirty participants discussed at length. There seems to be a strong belief among building designers that productivity increases would easily pay the costs of environmental improvements. However, no evidence of such a relationship could be identified, nor was there any agreement about how to define or measure productivity in office environments.

The participants identified a major research need: to identify indices of office worker productivity and to devise ways to measure these indices. Keystrokes or other quantitative measures that reflect industrial productivity are not widely accepted as adequate indices. Corporate or institutional goals such as profitability, public image, and customer satisfaction are among the multitude of indices which might be considered more important in different organizations.

Only after defining office worker productivity, participants said, could studies of the relationship between air quality and other environmental parameters be systematically studied. They agreed that such studies need to be done, but will be difficult due to the problems of defining and measuring office worker productivity.

For more information or a copy of the workshop report, contact Mort Blatt, EPRI, 3412 Hillview Avenue, Palo Alto, CA 94304; (415)855-2000.

Other Related Efforts

EPRI is not alone in its interest. The Gas Research Institute (GRI) and EPA's Division of Indoor Air have expressed interest in exploring the presumed relationship. These institutions as well as most design professionals assume that if building owners appreciated the economic importance of environmental quality, they would be willing to pay the cost of better buildings.

EPA's report to Congress on indoor air (due out at the end of the year) will explore the economic impact of indoor air quality problems. Since indoor air quality often has rather obvious, although not always very specific, physiological and psychological effects on office workers, it is natural that the rapidly increasing interest in indoor air has invigorated the long-standing impact in the economic interest of environmental quality.

Dr. Irv Billick has indicated a strong interest in the issue of productivity and office environments and says GRI would like to conduct research in this area.

Contact: Irv Billick, Gas Research Institute, 8600 Bryn Mawr, Chicago, Illinois 60631; (312)399-3100.

From the Field

Ozone in Office Buildings?

Depletion of the ozone layer in the Earth's atmosphere and the potential resulting global warming effects have received much media coverage lately, but only modest attention has been paid to the existence of elevated local ozone levels, particularly in urban areas. When we looked into indoor ozone, we were quite surprised by what we discovered.

We were recently challenged to consult on indoor air quality for the design of a new southern California office building, which is to have "model" indoor air quality. We wondered what ozone levels might be found in this area, what was the latest thinking on ozone-related human health effects, and what could be done to control ozone levels indoors.

Indoor Air Ozone Sources

The major identified sources for indoor air ozone are outdoor air, building equipment, and office machines. Indoor devices which cause electrical arcing, including some photocopiers and most electrostatic precipitators, result in elevated ozone levels. Investigators of indoor air quality problems in offices have expressed concern regarding ozone produced by office copiers.

Photocopiers are common in offices, but not all photocopy processes produce ozone. Those that don't usually emit some sort of volatile organic chemicals (see the October 1988 *IAQU*, "Wet Process Photocopiers and VOC").

Electrostatic precipitators are often used in building filtration systems because, when properly maintained and operated, they are effective in removing the small particles that are not well controlled by most in-duct panel filters, even those with very high ASHRAE dust spot efficiency ratings. (But the filter collection surfaces must be cleaned regularly or the removal rate will drop to zero.) The small particles are the ones that penetrate deepest into the respiratory tract, where they can do the greatest health damage (see the October 1988 *IAQU*, "Air Filtration for IAQ Needs More Study").

Outdoor air in some urban areas, especially in southern California, is contaminated by excess ozone during more than half the days of the year, especially during the summer. And the outdoor levels are highest during the work day. Outdoor levels tend to begin rising between 5 and 7 AM and peak at or shortly after solar noon. Then they fall off rather sharply starting between 1 and 3 PM (daylight time) to negligible levels in early or mid-evening.

Ozone level peaks are observed in the afternoon after a series of hot, sunny, windless days. In southern California, the National Ambient Air Quality Standard (NAAQS) is exceeded for at least one hour on 40% of the days per year and ozone reaches peaks levels three times the standard.

Indoor Air Levels

It was believed in the past that "structures protect occupants" from excess ozone levels. This myth prevails today, 15 years after definitive contrary evidence was published in a prominent scientific journal, ***Environmental Science and Technology***.

Researchers found that indoor ozone air levels track outdoor levels and lag behind them by a matter of two to four hours. In one report of measurements from both residences and offices, ozone levels indoors began rising between 9 and 11 AM, peaked at about 60 to 80% of outdoor levels just after solar noon, and closely tracked outdoor levels into early evening. (See Figures 1, 2, and 3.)

These data and measurements made elsewhere suggest that indoor ozone levels generally tend to shadow (resemble but lag behind) outdoor levels and reach indoor/outdoor (I/O) ratios of 0.2 to 0.8. In tightly sealed houses with little outside air ventilation, I/O ratios have been found well below the 0.5 I/O ratio, down to 0.2 and 0.3 times the outdoor level. This is one pollutant where more outdoor ventilation will result in higher pollutant levels and minimal ventilation may keep ozone levels low.

People who do not own air conditioning or other effective home cooling methods are likely to open their homes to the outdoors during warm weather, increasing air movement and air exchange between the home and the outdoors. Office workers in non-air conditioned buildings during hot spells are also likely to be exposed to increased ventilation through open windows. Such increases in air exchange would likely be accompanied by an increased indoor/outdoor (I/O) ozone ratio.

Ozone oxidizes materials made from chemicals with unsaturated bonds (such as neoprene and rubber). This might explain the deterioration of some critical building materials such as gaskets used in glazing systems, roof covering components, or expansion joints.

Ozone-related Human Health Effects

The current NAAQS standard for ozone is 120 ppb for one-hour. Recently reported research suggests that a three-hour, 80-ppb ozone air concentration might be a more appropriate standard based on human health effects. Some

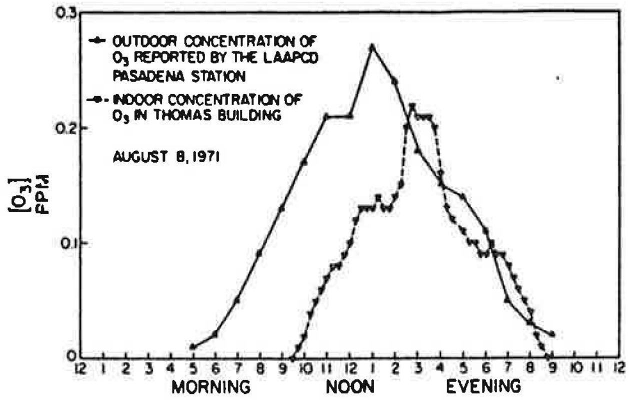


Figure 1. Ozone concentration vs. time of day for Thomas building, August 8, 1971

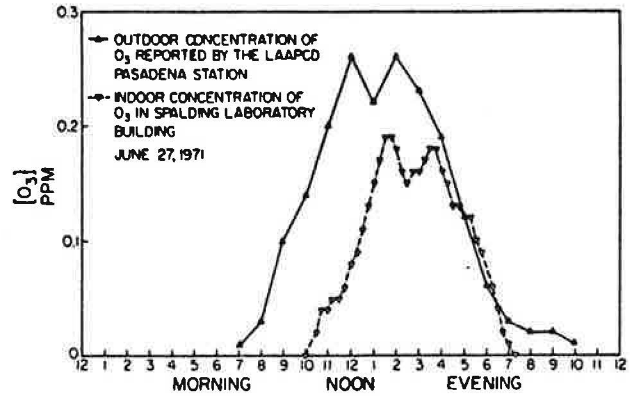


Figure 2. Ozone concentration vs. time of day for Spauling Laboratory Building, June 27, 1971.

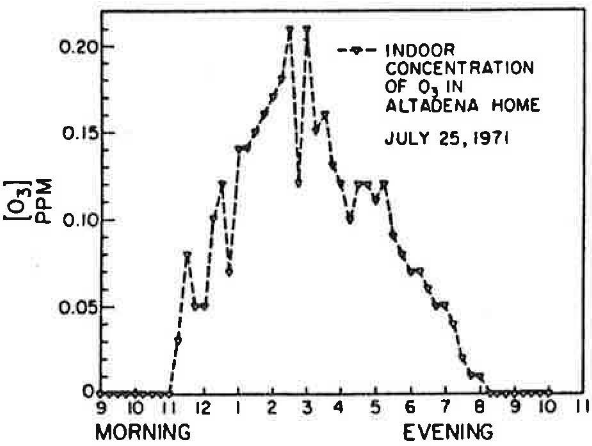


Figure 3. Ozone concentration vs. time of day in private home in Altadena, July 25, 1971.

scientists are urging a lower level over a longer period of time because recent research has shown that human lung functioning is impaired by exposure to lower concentrations over several hours. This was true in studies of children of both sexes at a YMCA camp and for two separate studies of adult, nonsmoking males.

How to Control Ozone Indoors

Some authorities have suggested activated charcoal filters, but surface area and the contact time between ozone and the filter media might have to be quite large to remove the excess ozone present in polluted urban air.

Copper (or other metal) screen coated with a transition metal (such as manganese) as a catalyst is effective for removing ozone, and we are told a similar device is used to filter ozone for aircraft cabin air.

Researchers investigating the removal of ozone by materials found inside buildings discovered that cotton muslin and lamb's wool are the most effective ozone decomposition surfaces, followed closely by neoprene. Plywood and nylon are less than one-third as effective, followed by polyethylene sheet, linen, and lucite. Virtually no decomposition occurs on aluminum or plate glass. We wonder whether the observed ozone decomposition rates for these materials were a function of adsorbed VOC with which the ozone reacted, or whether the reaction was directly with the materials themselves.

The researchers did indicate that a long contact time (perhaps minutes or hours rather than seconds) is required for the decomposition to occur. This might have implications for the rate at which air is circulated in buildings as opposed to the quantity of outside air that is brought indoors.

There is a price to be paid for the decomposition of ozone: the materials involved, particularly rubber, will deteriorate over time. This can be (and is) a problem for some building materials exposed to high ozone levels inside or outside building walls.

Ozone levels can be lowered by a decrease in ventilation rates, especially during periods when outdoor levels are elevated. This reduces intake and also provides a longer residence time, which is required for removal of ozone by materials within the building interior.

Implications

Based on the information we have seen recently, we consider ozone a seriously neglected indoor air pollutant. All the ingredients are there for significant concern: large segments of the population exposed for significant time periods to levels known to cause acute and chronic health effects.

We do not expect the federal ambient air quality ozone standard to be lowered soon; it would simply be impractical for most major metropolitan areas to comply with an 80-ppb, three-hour ozone standard without massive reductions in the use of motor vehicles and some industrial activities. A tighter ozone standard would create major problems for many urban areas around the country, which are not able to comply with the current standard of 120 ppb.

But we do believe it is reasonable to expect some new guidelines for indoor levels. These should be levels that provide reasonable protection for public health and can be achieved with presently available, economically feasible filtration technology.

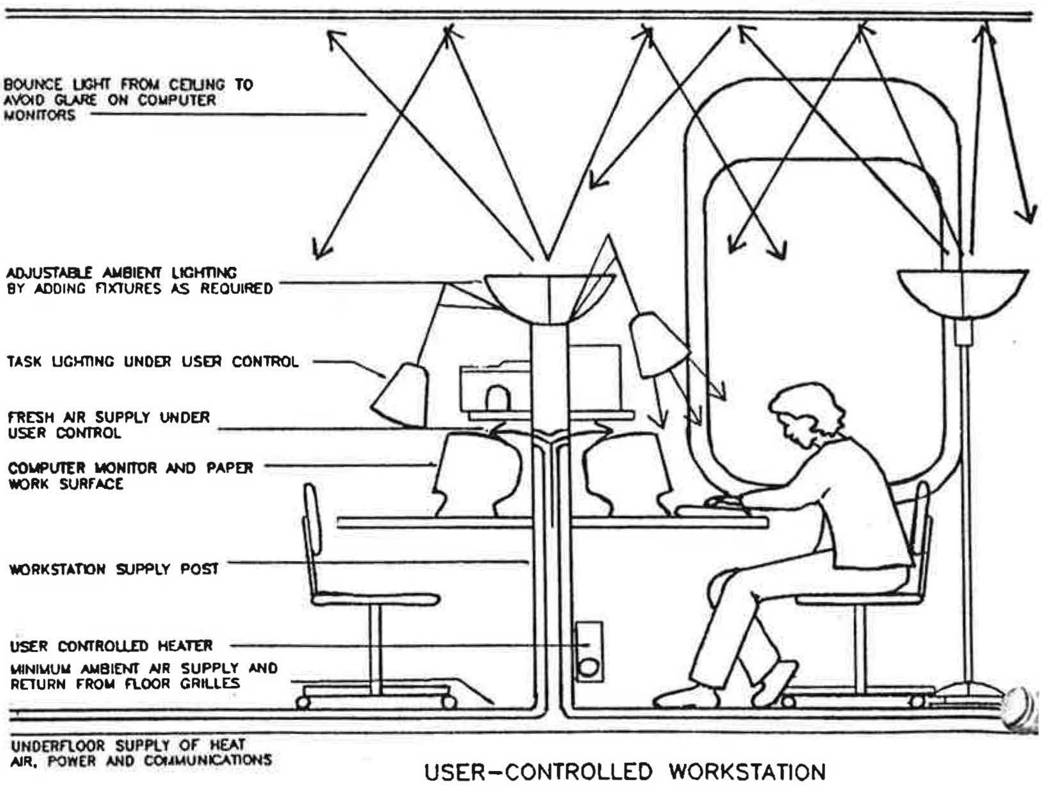
Tools and Techniques

Designing a High-performance Building

On August 25th and 26th, 17 building professionals ranging from architects and engineers to realtors and developers brainstormed the design of a new office building, with an emphasis on air quality, lighting, and energy efficiency. The design charette was sponsored by Energy, Mines and Resources, Canada (EMRC) and hosted by The Iredale Partnership, a Vancouver architectural firm. The EMRC sponsorship was for the purpose of testing "the effectiveness of additional preliminary design effort in improving the environmental quality and energy efficiency of the work environment."

The product of the charette was a design scheme for an 80,000-square-foot office addition to an existing office facility of 52,000-square-feet. The existing space is occupied by a governmental agency; the new space will be offered for lease to high-tech tenants, a restriction imposed by local zoning ordinances.

The design team focused on building materials as pollution sources, air quality problems from tight envelopes and reduced ventilation rates, and poor lighting quality and thermal comfort. The designers tried to solve these problems without generating excessive capital costs, a major client concern. We participated in this exercise and were surprised to see the very sophisticated appreciation of IAQ



USER-CONTROLLED WORKSTATION

issues and solutions shared by the participants.

The resulting solution started with the individual workstation and the site constraints and ended with a conceptual design and schematic for the whole building. The work station concept included user control of the lighting, ventilation, and thermal environment (see Figure 1).

Desk-top air supply outlets are fed through flexible ducts under the raised floor. Illumination is with maximal daylight from perimeter windows and a light shelf, indirect (uplights) for general area illumination, and desk-top task lights.

Several aspects of the design reflect the participants' generally shared concern with IAQ and other work environment concerns:

- User-controlled, individual, desk-top air supply distribution units allow direct supply of air into the breathing zone and allow individuals to regulate the quantity and direction of the flow.
- The general upward flow of supply air to returns means one person is not receiving air supply that is essentially exhaust from the upwind person(s).
- Heating is separated from the air supply system by providing radiant heating units located near the floor, possibly one per work station.

One of the major challenges in developing a building is the coordination of the various specialized technical consultants involved. Bringing the disciplines together at the outset is recommended by many authorities, and we found the exercise a rewarding one. We believe that this practice is worthwhile and should be replicated whenever possible.

For more Information

Rand Iredale, The Iredale Partnership, 1151 West 8th Avenue, Vancouver, British Columbia, Canada V6H 1C5.

Honeywell IAQ Diagnostics Course

In the premier issue of ***IAQU*** (May 1988) we described Honeywell's proposed one-week IAQ Diagnostics course. The course has run twice now, and Jim Woods of Honeywell told us that it was even more successful than he had expected. He was particularly pleased with the mix of professionals who have attended and the degree to which they were willing to consider other disciplinary viewpoints. Woods said, "We're very pleased with the success of the course in integrating the viewpoints of the engineer, the industrial hygienist, and the architect."

The course has two focal points: the first is the principles of diagnostics, with practical resolution of a problem based on examination of construction documents (working drawings). The second is the actual inspection of an occupied space.

One of the requests from participants is for more information on psychrometrics, air movement, and air distribution including ventilation. Woods is pleased with these requests and says Honeywell will respond to them in future offerings.

The program is set up to handle 16 people per course, and it fills up fairly quickly. Four are planned for next year, with the next one probably near the end of February.

For more information, contact IAQ Diagnostics, Honeywell, Golden Valley, MN 55422-3922; (612)542-7043.

Products and Services

Whole House Air Cleaners

Thurmond Air Quality Systems

The Thurmond IAQ-2000 is the only HVAC system we have seen that is designed for the whole house with indoor air quality as a primary objective. It contains a high-efficiency final filter and a carbon module to remove both particles and gases from indoor air. Its three-stage filter train comprises a pre-filter, a carbon module, and a final filter (see Figure 1.)

The pre-filter is a medium-efficiency, pleated disposable unit with an ASHRAE dust spot rating of 25-30%. The carbon module is 2,000 cubic inches of one of four available types. The final filter is a high-efficiency extended surface medium with an average ASHRAE dust spot efficiency of 90-95%. HEPA 99.97% filters are available as an optional final filter where air quality requirements make them necessary.

The carbon modules are available in four different types for various applications. The Type I activated carbon is made from natural grain coconut shell for general purpose odor and gaseous contaminant removal. The manufacturer states the unit is designed to provide one year of removal for space volumes up to 40,000 cubic feet in a standard installation. This would be ten times the volume of a typical 1,250-square-foot house with eight-foot ceilings. The actual life of the filter will depend on the