the team members need be permanent staff members, but the consultants should be able to ensure the availability and qualifications of specialists in these areas of expertise.

After selecting a firm, schedule a preliminary site visit as soon as possible. The preliminary hypotheses should be reviewed, refined, and made more specific after an initial visit of no more than one day, which should include meetings, interviews, and a walk-through inspection. Then the investigators should be able to refine the hypotheses, the work plan, and cost estimates.

After the site visit, both the consultant and the building operator should feel more prepared to discuss the details of the scope and cost of the investigation. While all of this should be done as quickly as possible, too hasty a selection may result in much time lost eventually. We have been asked to investigate many buildings where other consultants had previously been retained at substantial cost.

Practical Research Briefs

Adaptation to Indoor Air Pollution

Last month we reported on several studies of odors in indoor air by Ole Fanger and his associates (*IAQU* October 1988). Another report by one of Fanger's colleagues, Lars Gunnarsen, has many practical implications for determining and maintaining acceptable odor levels in buildings. This investigation concerned the subjective evaluation of odor and discomfort caused by indoor pollution before, during, and after a period of odor adaptation.

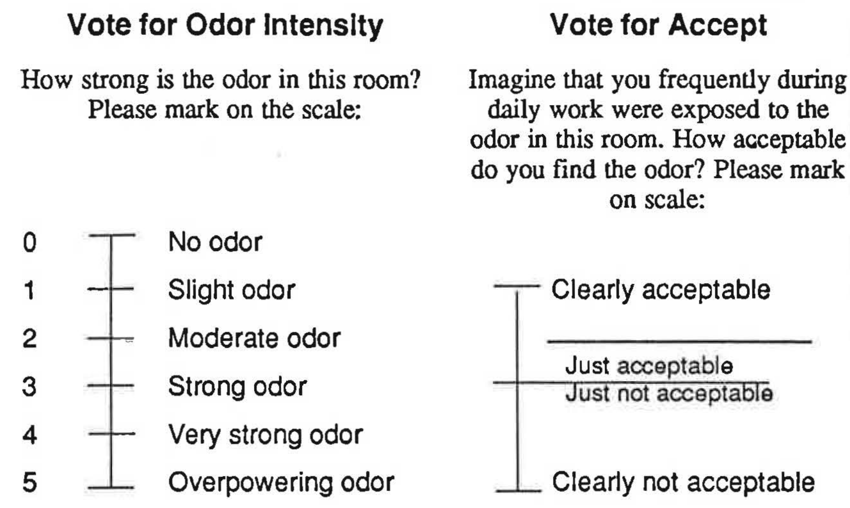

Figure 1. Scales and corresponding questions used in the experiments. For data analysis, the intensity scale ranges from 0 to 5 and the acceptability scale from -1 to +1, where 0 indicated the shift from acceptable to not acceptable.

The odorants Gunnarsen studied were human bioeffluents, tobacco smoke, and emissions from building materials. He found significant variations depending on the source of the odorants. This raises important implications for designing and operating buildings.

Methods of Study

The investigators exposed subjects to odors from the three sources in carefully controlled experiments, conducted in environmental chambers at the Laboratory of Heating and Air Conditioning at the Technical University of Denmark. Upon exposure, the subjects voted on the "acceptability" and perceived odor "intensity," using the scales illustrated in Figure 1.

How They Voted

Figure 2 shows the results of the subjects' evaluations: good correlations between voted "intensity" and "acceptability" and a fairly consistent relationship between "acceptability" and "dissatisfied." ASHRAE bases its standards for thermal comfort on voted "acceptability." It defines acceptable thermal comfort as less than 20% voting "dissatisfied." The actual scale for voting in this study differs somewhat from that used in historical ASHRAE studies. The investigators developed their scale for this study and recommend its use in other research or standard setting.

To understand the scale used by voters in Gunnarsen's study, note that at the point of 20% dissatisfied, subjects found the odors only about one-third of the way from "just acceptable" (0) to "clearly acceptable" (1.0).

In terms of the relationship between "intensity" and "acceptability," and between "dissatisfied" and "acceptability" there were no significant differences among responses to bioeffluents, tobacco smoke, building materials, and adaptational status (whether or not

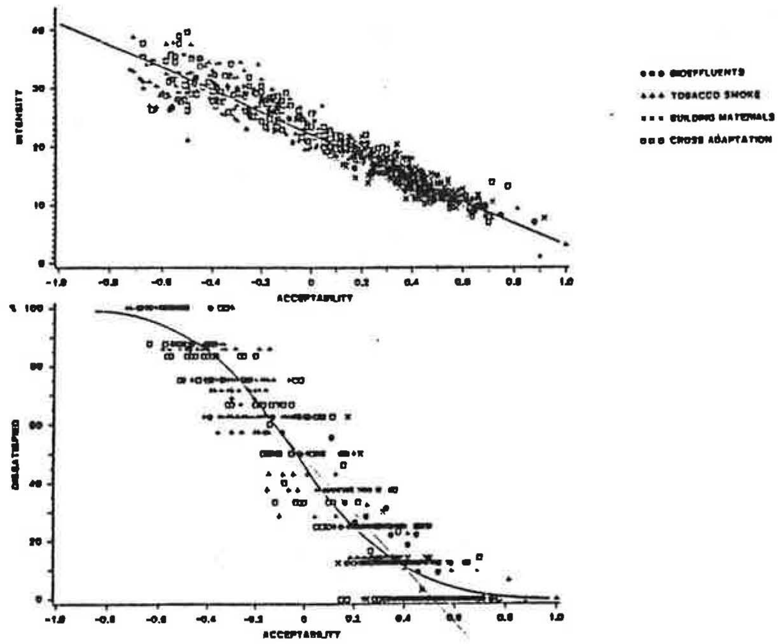

Figure 2. The relation between votes for intensity and acceptability and between percent dissatisfied and votes for acceptability. The dissatisfied are defined as all votes below 0 on the acceptability scale.

In Figure 4, results of the study for adapted and nonadapted subjects are plotted against ventilation rates with an assumed constant CO_2 emission rate of 16.9 l/s. It also shows a plot of Fanger's definition curve for one olf = one standard person for comparison. (Fanger defines the olf, a unit of measure for odor, as the emission rate of bioeffluents from a "standard" person — a person under normal activity, sedentary in thermal comfort, with a hygienic standard equivalent to 0.7 bath/day).

Figure 5 shows intensity and acceptability votes versus CO concentration, which was measured and used as an indicator of tobacco smoke air level. In contrast to votes during exposure to human bioeffluents, the voted "intensity" was higher and voted "acceptability" was lower for both the subjects had been previously exposed to one of the other odorants). This reflects fairly good consistency in the subjects' responses during the various components of the study.

The exposures were for 15 minutes, but 95% of the changes in votes (apparently due to adaptation) occurred in the first six minutes.

Figure 3 shows the votes during exposure to bioeffluents, with the strength of bioeffluent exposure indicated by CO_2 concentration. Note that adapted subjects voted low intensity and high acceptability regardless of pollutant concentration. In contrast, nonadapted subjects voted higher intensity and lower acceptability for increasing levels of air pollution.

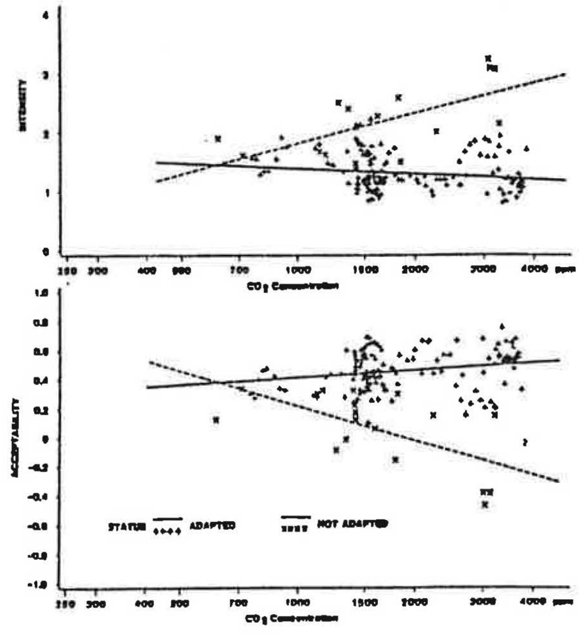

Figure 3. Votes for intensity and acceptability vs. CO_2 concentration for exposure to bioeffluents. Each point on the figure represents the mean of eight votes. the CO_2 concentration is the level above outdoors.

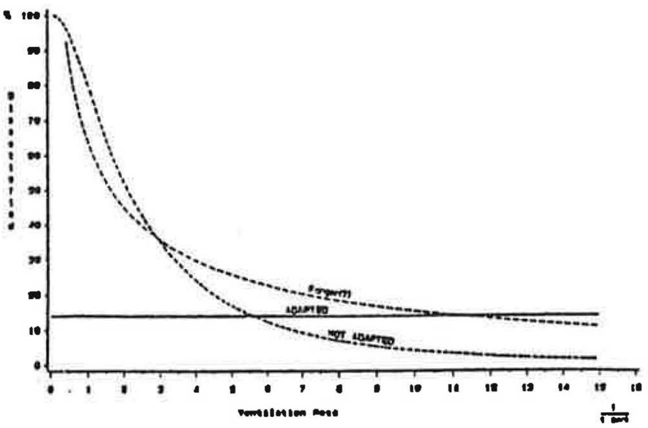

Figure 4. Relation between steady-state ventilation rates and dissatisfaction shown for adapted and nonadapted persons exposed to bioeffluents. Fanger's (7) definition curve for one olf = one standard person is shown for comparison.

The votes for intensity and acceptability of odor from building materials are very similar for adapted and nonadapted subjects. Furthermore, they do not change as pollution levels increase. These results, presented in Figure 7, are hard to interpret other than to suggest that pollution from building materials does not appear to affect people significantly. This seems counter-intuitive and is certainly counter to the experience of many who have found the odor of new carpet or fresh paint unpleasant. The materials used include gypsum board with water-based acrylic paints, stainless steel plates with acrylic sealant and isocyanurate lacquer, chipboard, carpet. However, pollution levels were calculated rather than

adapted and nonadapted subjects during exposure to increasing levels of tobacco smoke. Nonetheless, the adapted subjects voted the concentration less intense and more acceptable than the nonadapted.

Figure 6 illustrates the relationship between steady-state ventilation per cigarette (assuming a CO emission of 44.4 ml/cig.) and percent dissatisfied for adapted and nonadapted persons exposed to cigarette smoke. It also shows the results of work by Bill Cain and his co-workers for comparison. This indicates that the amount of ventilation required for adapted versus nonadapted subjects in order to achieve 80% acceptability is very different. In fact, more than twice as much ventilation per cigarette is required for nonadapted subjects as for adapted subjects.

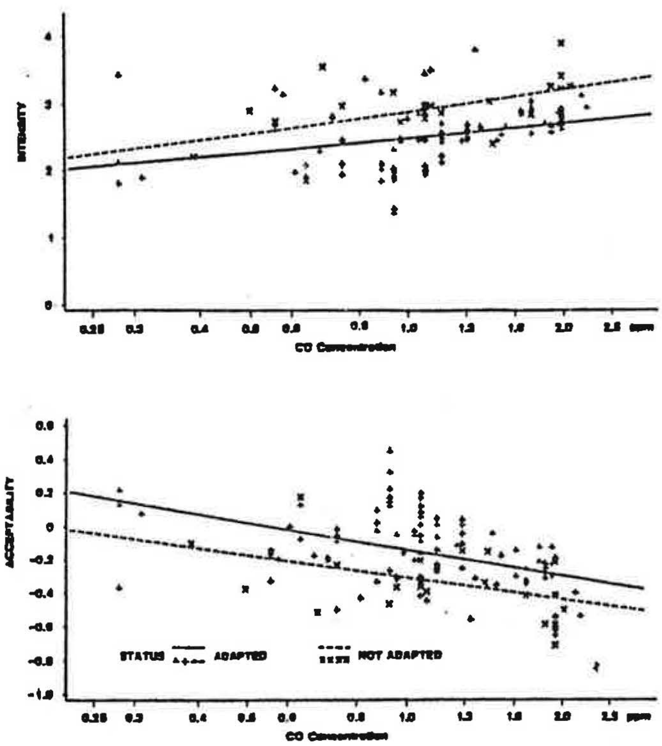

Figure 5. Votes for intensity and acceptability vs. CO concentration above outdoors. Each point on the figure represents the mean of eight votes.

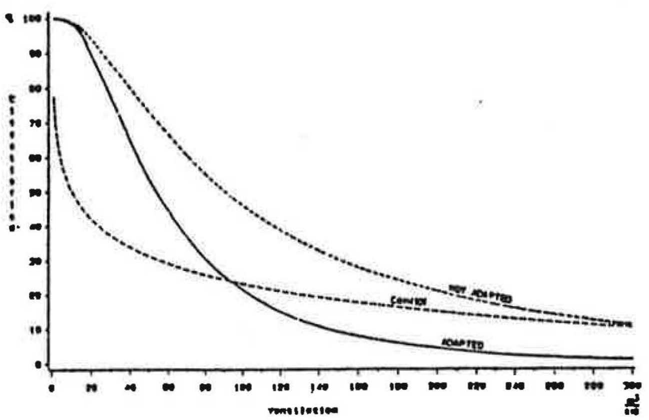

Figure 6 — Relation between steady state ventilation and percent dissatisfied shown for adapted and not adapted persons. Results of Cain et al. (10) are shown for comparison.

not distinguish between smoking and nonsmoking environments, and many criticize it for that reason. Those critics say the absence of the distinction removes some of the presumed or potential health protection and makes the standard strictly an "acceptability" standard. However, Gunnarsen's work shows that it may not even be adequate as an acceptability standard where tobacco smoke is concerned.

Additionally, the adaptation phenomena indicate that we need to consider both initial responses (upon first entering a space or encountering an odor) and longer-

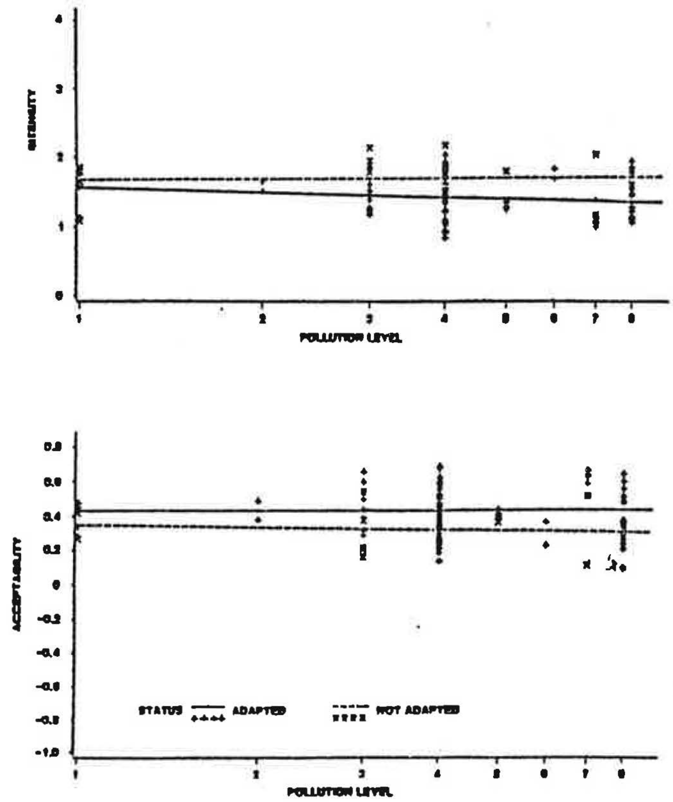

Figure 7 — Votes for intensity and acceptability versus a calculated pollution level. Each point on the figure represent the mean of 8 votes.

measured, and it was assumed that the levels were inversely proportional to ventilation rate. In fact, indoor air levels for volatile organic compounds are usually inversely proportional to the log of the ventilation rate.

Practical Implications

An important finding of the study is that "when people enter a space with air pollutants, the air quality initially perceived is least acceptable." Adaptation takes place during the first few minutes and the air is found to be more acceptable as time passes. If the major pollutant source is human bioeffluents, the air is found to be significantly better after a short period of exposure. If it is tobacco smoke, it is found to be somewhat better after a short period, and if building materials emissions are the major pollutant, it is found to be only slightly better over time.

The study indicates that permitting smoking in buildings significantly increases ventilation requirements. The draft revised ASHRAE ventilation standard (62-1981R) does 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