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Indoor Air Quality Update™

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

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Ventilation Requirements Based on Subjective Responses

When Professor P. Ole Fanger presented the concept of the "olf" unit at the Fourth International Conference on Indoor Air Quality and Climate (Berlin, August 1987), there was much laughter in the hall. Fanger, ever dramatic, titled his talk "A Solution to the Sick Building Mystery." He presented humorously illustrated slides and concepts in a plenary lecture, and the large audience found it quite entertaining.

At the time, we thought he was simply using humor to make the point that subjective responses to IAQ should be taken more seriously. Little did we suspect that he was presenting an evolving, serious, and systematic approach to subjectively evaluating IAQ.

In January 1988, Fanger published a more detailed exposition of his concept and some research results in two articles in *Energy and Buildings* (see references at the end of this article). In September of that year, Fanger presented his concept again at the Healthy Buildings '88 Conference in Stockholm. This time it was clear that he was serious, although his presentation continued to be humorous and entertaining (see *IAQU*, October 1988).

The Olf- and Decipol-Units

The word olf was derived from "olfactory." (Fanger has established the convention of not capitalizing the "o" in olf.) Fanger's idea was to quantify indoor air pollution sources by comparing them to the odor from a well-known pollution source: the human body. Researchers working with Fanger had previously quantified the dissatisfaction caused by human bioeffluents with various ventilation rates. More than 200 male and female judges had evaluated the odor of bioeffluents from more than one thousand sedentary male and female building occupants.

Fanger wanted to be able to express any other pollution source by the olf-unit — to determine "the number of sedentary, standard persons that would cause the same dissatisfaction as the actual pollution source." The baseline pollution source was a "standard person": someone who was thermally comfortable, bathed every 1.6 days, and changed outerwear every day.

The data from the earlier studies were adjusted from the original experiment to "correct for the olf value of the space where the experiments took place. The figure applies when human beings are the only source of pollution."

Fanger used the curve in Figure 1 to quantify the strengths of pollution sources. At any outdoor air supply rate to a space where the source is located, and at a specific percent of dissatisfied judges among a panel, "the number of standard persons that would cause the same dissatisfaction can be calculated. This number is the olf value of the pollution source," Fanger wrote. Figure 1 shows this relationship.

Fanger applied the olf-unit concept to data from studies where panels of trained olf judges visited twenty random, non-complaint buildings

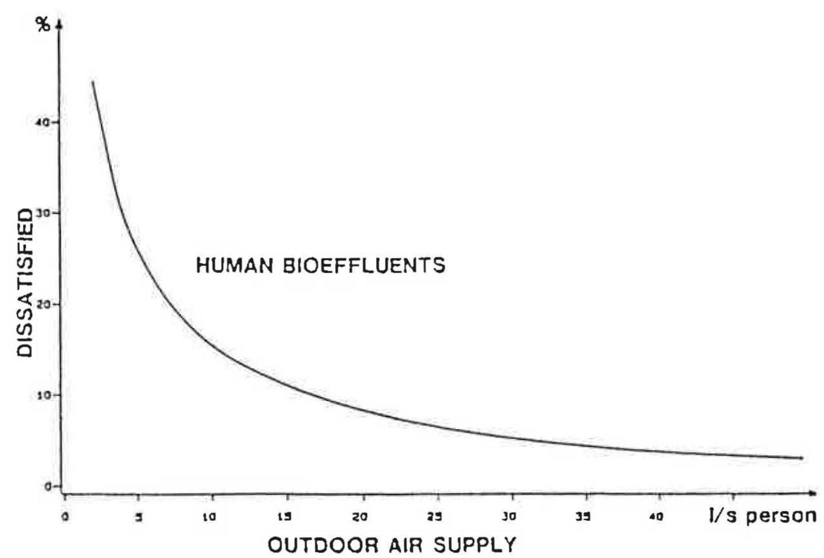

Figure 1— The percentage of persons finding the air quality unacceptable when entering a space with a given ventilation rate (air supply per occupant in liters per second, 1 l/s ≈ 2 cfm).

thermal comfort. (Fanger's work done in the 1970s is still among the most important bases for ASHRAE's Standard 55-1981, "Thermal Environmental Conditions for Human Occupancy.")

How to Use Olfs and Decipols

The olf-decipol system is used to evaluate odors from building materials in small containers (such as a two-liter glass jar) using a tiny fan to deliver a controlled amount of air to the sniffer's nose. This system was demonstrated at a booth called the "olf bar" in the exhibition area of the 1988 conference. By using a known quantity of a specific chemical, the system allows "calibration" of sniffers' responses. According to Fanger and his co-workers, trained judges using his system can generate reasonably reproducible results.

The approach is also used to evaluate material emissions in test chambers and air quality in actual building environments. Fanger and his collaborators have now reported on a substantial number

under three conditions: unoccupied and unventilated; unoccupied and ventilated; and occupied and ventilated. By comparing the results from the three visits, Fanger calculated the olf values of the visited spaces, the ventilation systems, and the occupants. The results are shown in Figure 2.

The mean values from Figure 2 show HVAC systems as the strongest single sources of olfs. The 62 olfs from the systems were slightly more than the 58 olfs from the spaces. The occupants contributed only 42 olfs to the total olf load of 162 olfs. Note that the olf levels were averages; Fanger says "there were large differences in the pollution sources from space to space."

At the Healthy Buildings '88 conference, Fanger added the decipol unit: the "perceived air pollution in a space with a pollution source of one olf ventilated by 10 liters per second (l/s) of unpolluted air." Thus, the olf was a measure of source strength, and the decipol provided a basis for evaluating its perceived level. He compared this to light (source strength in lumens, perceived level in lux) and noise (source strength in watts, perceived level in decibels). He presented a proposal that future ventilation standards could be based on a comfort equation such as that used to set standards for

QUANTIFIED POLLUTION SOURCES

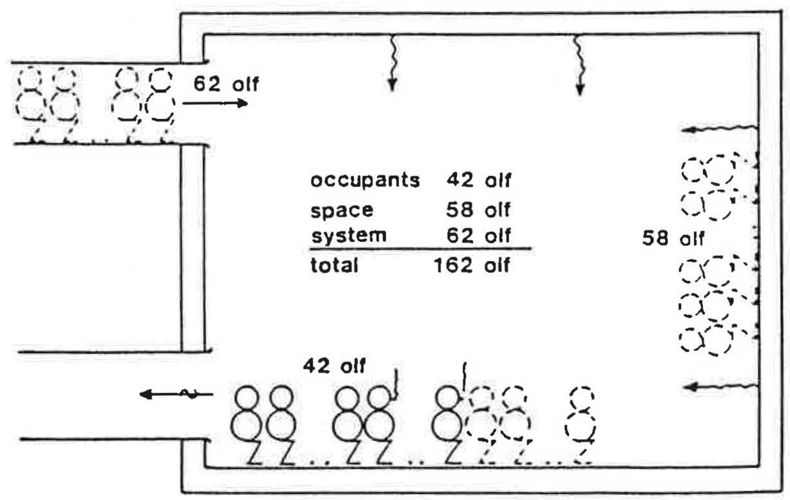

Figure 2 — Mean values of pollution sources quantified in twenty offices and assembly halls in Copenhagen.

of such evaluations, and they are compiling an impressive record of research and publication. They can be counted on to present new information at nearly every major indoor air conference.

They have shown that, using Fanger's method, acceptability of IAQ can be predicted on the basis of source strengths of odorants. He has an agreement with the American Industrial Hygiene Association to train industrial hygienists how to use the olf-decipol technique for evaluating IAQ. We hope they will keep in mind that the system evaluates the subjective acceptability rather than the objective health effects of IAQ. (See "An Important Limitation" below.)

Acceptability of IAQ is a central concept in ASHRAE standards affecting indoor environments and in ASHRAE research and committee work. The concept is prominent in the establishment of thermal comfort parameters (Standard 55-1981) and IAQ parameters (Standard 62-1989). The basic concept says that the design criteria for indoor environments should result in no more than 20% dissatisfaction by the occupants in the space. Currently there is some discussion in ASHRAE committees about reducing the 20% rate to a lower value.

An Important Limitation

Fanger's olf-decipol approach is effective for evaluating subjective effects for occupants first entering a space. However, he indicates that other means must be used to measure the effectiveness of control measures to avoid adverse health effects such as toxicity or carcinogenicity. This is an important point and one that is often overlooked by those who wish to use Fanger's system.

Also, some research shows that the approach might have only limited usefulness for predicting irritation effects. That is because adaptation to odor and adaptation to irritants do not change in the same way over the first few minutes after entering a space. Furthermore, the changes vary depending on the pollutant source. Since irritation is considered a health effect, then Fanger has addressed this concern, albeit by saying that other means must be used to evaluate it. The work of one of his former students, Lars Gunnarsen, has been quite illuminating on this subject.

"Adaptation and Ventilation Requirements"

Lars Gunnarsen of Carl Bro als, in Glostrup, Denmark, is Fanger's former student and collaborator. He is a frequent contributor of articles on his own odor perception research. We met Gunnarsen at Healthy Buildings '88 where Fanger introduced us, and we were impressed with his work, which has focused on adaptation to odors and irritants (see *IAQU*, November 1988).

Gunnarsen presented the results of his most recent research at the Indoor Air '90 conference in Toronto this summer. His paper, titled "Adaptation and Ventilation Requirements," analyzes reported results of a number of experiments conducted by Fanger, Gunnarsen, and others using the Fanger odor evaluation system. It presents convincing evidence that the ventilation required for various types of contaminants varies over time and with the type of contaminant involved, not simply with its source strengths as evaluated by Fanger's system.

One of the important implications of Gunnarsen's work is that ventilation may be reduced after occupants have been in a space long enough to adapt to some types of odorants.

Another important implication of Gunnarsen's work is that odors from building materials have a more lasting impact on occupant acceptance of IAQ than odors emitted from people (bioeffluents) or even from cigarette smoke (environmental tobacco smoke).

Gunnarsen's work focused on the impact of adaptation on the odor perception experience. The purpose of the work was to study "the change of dissatisfaction caused by typical indoor air pollution" during the first few minutes of exposure. From that, Gunnarsen hoped to provide a "rational basis for the design of ventilation for rooms where people become adapted to the air pollution for most of their stay."

Different Rates of Adaptation

In his paper, Gunnarsen reported his and other studies of the time course of adaptation to indoor air pollutants and the effect of the adaptation on acceptability. He found some adaptation occurring, but at different rates for the three classes of contaminants studied. The results have implications for the operation of building ventilation by building engineers and for the emphasis on control of emissions from various sources to achieve acceptable IAQ.

Gunnarsen tells us that the influence of adaptation varies from one class of pollutant to another. Dissatisfaction from air polluted by human bioeffluents disappears

Table 1 — Building materials used in the experiment

1. Brown carpet	32.4 m^2
2. Red carpet	32.4 m^2
3. Striped carpet	32.4 m^2
4. Acrylic paint on stainless steel plates	36.0 m^2
5. Rubber floor material	8.0 m^2
6. Mixture of 7.2 m^2 of 1, 2, and 3 plus 5	7.2 m^2 each 2.0 m^2

"after some minutes at all realistic concentrations of bioeffluents." However, adaptation only modifies the perception for environmental tobacco smoke (ETS), resulting in a 50% reduction in ventilation requirements at moderate levels of ETS (defined by a CO concentration of 0-2 ppm).

The time required for adaptation also varies by pollutant. Measured dissatisfaction decays at an exponential rate. For bioeffluents, 95% of the adaptation takes place in the first 10 minutes of exposure, and a little faster for ETS at lower levels of satisfaction.

Since previous research had shown that from an odor/dissatisfaction perspective, building materials were more important sources of pollution than people, Gunnarsen examined the rate of adaptation to odors from building materials.

The Study

Panels of trained judges evaluated six sets of air-cured building materials. The building materials used are listed in Table 1.

Figure 3 shows the results from the study. Each point in the figure represents the arithmetic mean of the votes from each of the eleven judges. Note that the ranking of materials after adaptation is different from the ranking before adaptation. This may result from the differential composition of emissions for irritants and odorants among the materials, allowing less adaptation to some than others.

Also note that most adaptation takes place during the first eight minutes, but that there still were some position changes after that time. Earlier work by Clausen shows that for ETS odor perception decreases and irritation increases until they cross at about one and one-half minutes after initial exposure. Figure 4 shows this relationship in abstract form; it is an extremely important concept to keep in mind when applying the olf-decipol system to the design of ventilation strategies.

Figures 5, 6, and 7 show the calculated, generalized adaptation

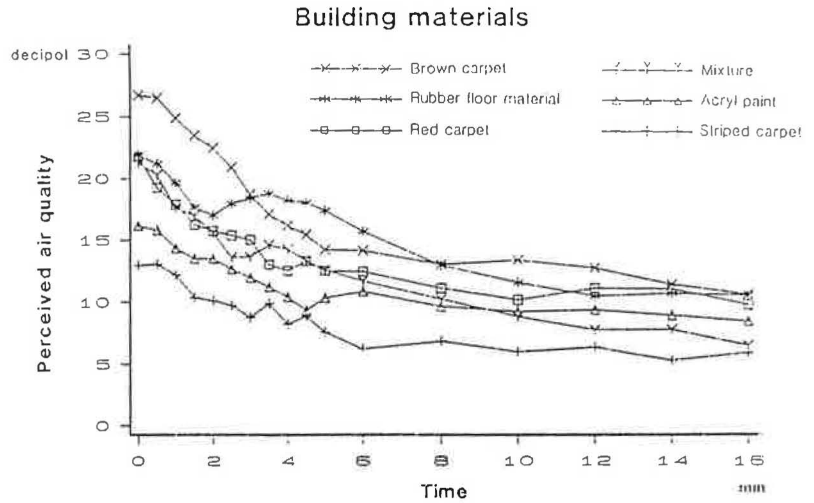

Figure 3 — Mean perceived air quality from odors from building materials.

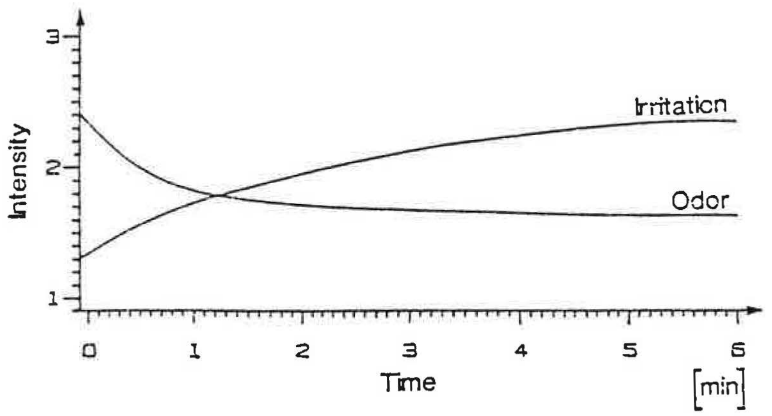

Figure 4 — The intensity of odor and irritation from ETSover time. (Source: Geo Clausen)

model for the pollutants from the three classes of sources: building materials, ETS, and human bioeffluents. Figure 5 is based on an assumed exponential decay of dissatisfaction for all materials.

The figures show that adaptation occurs in every case, except where it is 100% for ETS. The rate and extent of adaptation depends not only on the pollutant source but also on the degree of dissatisfaction at the outset. Note that the model for human bioeffluents shows that after 15 minutes, no more than 20% of judges will be dissatisfied with odors from human bioeffluents (assuming reasonable ventilation).

Gunnarsen's Conclusions

Gunnarsen points out that the acceptability of typical indoor air pollutants improves through adaptation. The improvement is a function of the type and number of contaminants present. The more irritants present, the less adaptation.

He also points out that "Based on the present results, it may be assumed that building materials often emit a high fraction of irritants, tobacco smoke a smaller fraction, while the familiar bioeffluents are hardly irritative at all."

A few of his conclusions:

- Air quality is least acceptable immediately after entering a room with air pollution. After a few minutes, people adapt and the air is perceived as more acceptable.
- Adaptation improves acceptability most for human bioeffluents, some for ETS, and least for building material sources.
- When defining ventilation requirements for adapted people, human bioeffluents may be

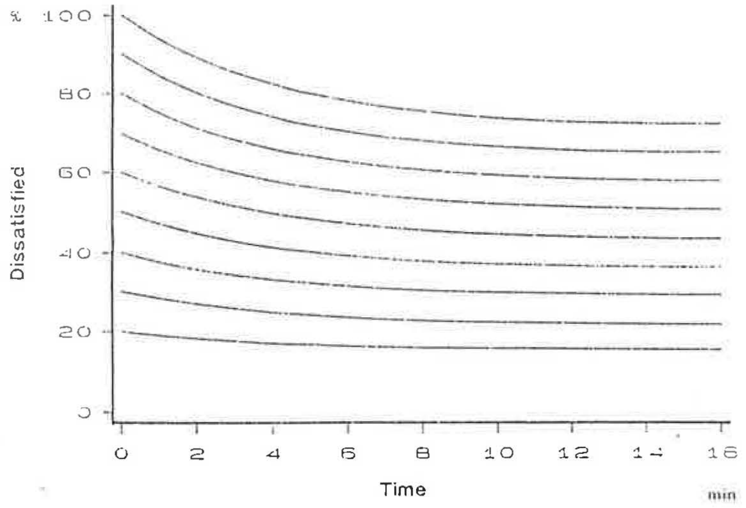

Figure 5 — Adaptation model for building materials.

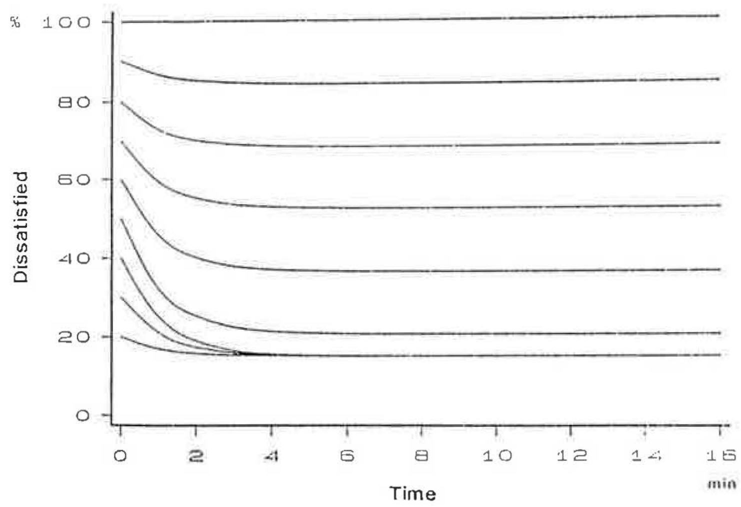

Figure 6 — Adaptation model for tobacco smoke.

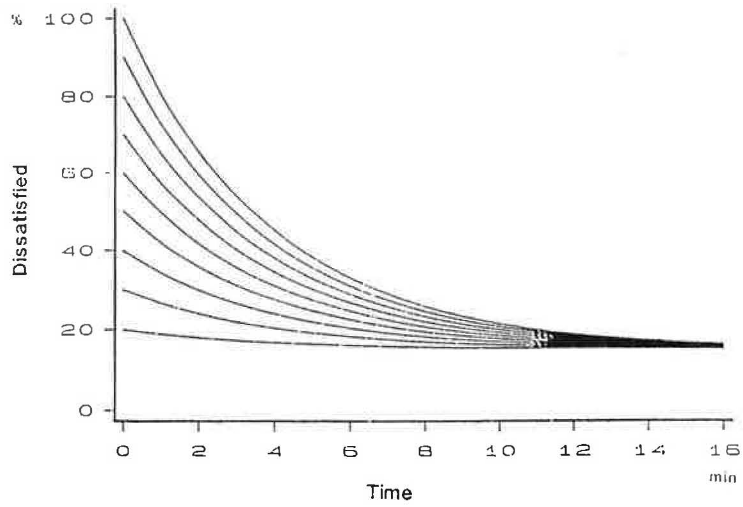

Figure 7 — Adaptation model for human bioeffluents.

neglected, ETS source strength may be reduced 50%, and building materials source strength may be reduced 30%.

Implications

We think Gunnarsen's work is important because it emphasizes the significance of the type of pollutant source, the time dimension that is important to sensory evaluation approaches, and the implications for operating buildings. Especially important to building operators is the fact that the initial impression is likely to be worse than that obtained just a few minutes later. This suggests that thoroughly ventilating a space just before people enter it may significantly improve people's assessment at the most critical time. In many buildings, ventilation is minimal just before people enter a space and then increases at some later time, after the space heats up.

It is important that those who use Fanger's olf-decipol system understand the system is effective only for evaluating perceived air quality for short-term visitors upon entering a space; it is not appropriate for evaluating the effects of air quality on long-term occupants. As Fanger has cautioned, those who use his system must develop alternative means for evaluating the health effects.

Fanger's work has important implications for the IAQ field. However, we feel strongly that the subjective evaluation of IAQ has limited application to the development of standards for and confirmation of the achievement of acceptable IAQ.

For More Information

P. Ole Fanger, "A Solution to the Sick Building Mystery," *Proceedings of the 4th International Conference on Indoor Air Quality and Climate*, Volume 4. Berlin: Institute for Water, Soil, and Air Hygiene. Pages 49-55. (Available from Institüt für Wasser-, Boden- und Lufthygiene, Corrensplatz 1, D-1000 Berlin 33, Germany.)

P. Ole Fanger et al, "A Comfort Equation for Indoor Air Quality and Ventilation," *Proceedings of Healthy Buildings '88*, Volume 1, Stockholm: Swedish Council for Building Research. Pages 39-51. (Available for SEK 90, for the complete four-volume set, from Svensk Byggtjanst, Box 7853, S-103 99 Stockholm, Sweden.)

P. Ole Fanger, "Introduction of the olf- and decipol-unit to Quantify Air Pollution Perceived by Humans Indoors and Outdoors," *Energy and Buildings* 1988, Volume 12: pages 1-6.

P. Ole Fanger, "Air Pollution Sources in Offices and Assembly Halls, Quantified by the olf-unit," *Energy and Buildings* 1988, Volume 12: pages 7-19.

Lars Gunnarsen, "Adaptation and Ventilation Requirements," *Proceedings from Indoor Air '90, The Fifth International Conference on Indoor Air Quality and Climate*, Volume 1, pages 599-604. (See article in this issue on purchasing copies.)

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Practical Research Briefs

Ventilation Type and Symptom Prevalence

Researchers performing a re-analysis of five studies from the United Kingdom and one from Denmark have found a consistent association between symptom prevalence and type of building ventilation. This, the authors say, has potentially important public health and economic implications.

In an article appearing in the October issue of the *American Journal of Public Health*, Mark Mendell and Allan H. Smith of California have re-analyzed data from the well-known studies. Their analysis included investigations of non-complaint office buildings classified as naturally or mechanically ventilated, air conditioned or not, and humidified or not. (Most of the studies have been discussed previously in *IAQU*.)

The authors state that published studies of building-related health problems in the United States "are almost without exception, case studies of complaint buildings." Therefore, they chose to analyze studies from abroad in order to find studies not involving complaint buildings. They acknowledge that their conclusions may be limited to the countries where the studies they re-analyzed took place.

Results of the Re-analysis

Buildings with simple mechanical ventilation and buildings without mechanical ventilation had similar symptom prevalence to buildings with natural ventilation (with one relatively minor exception). For some symptom categories, mechanically ventilated buildings actually had lower prevalence rates.

Air-conditioned buildings had higher symptom prevalence than non-air-conditioned buildings in all six studies. Air-conditioned buildings, according to the authors, included those without humidification as well as those