NIS #3461

Indoor Air Quality

Hidden olfs in sick buildings

Investigators examine hidden pollution sources in 15 Copenhagen office buildings

By P. Ole Fanger
ASHRAE Fellow

THE AIM of ventilation is to provide fresh air for human beings. Unfortunately, in many buildings, this aim is not achieved. Dissatisfaction has been documented in hundreds of detailed field studies in offices, schools, dwellings and other non-industrial buildings in Europe, North America and Japan (1-11). High percentages of occupants complaining of unacceptable air quality have been identified. The complaints comprise the perception of stale and stuffy air, irritation of mucous membranes, headache, lethargy, etc. These symptoms are usually called the "sick building syndrome" (12).

The symptoms are not just occurring in a few special buildings. They occur in nearly all buildings, but with wide variations in the percentage of occupants who are bothered. A recent opinion poll among American office workers showed that 24 percent found the air quality at their workplace unacceptable and 20 percent found that the quality of air impaired their work (13).

In some buildings there are obvious reasons for bad air quality. The air supply may, for instance, be lower than designed. But the frustrating fact is that most of the buildings studied in different parts of the world complied with existing ventilation standards, i.e., air supply and air distribution were as designed and often better. Furthermore, all measured chemical compounds were in concentrations well below any conceivable health or comfort limits. Nevertheless, 20, 40 or 60 percent of the occupants found the indoor air unacceptable. It looks like an effect without a cause and it has been called "the sick building mystery."

Chemistry and perception

When an occupant says the indoor air is stale, stuffy and unacceptable, less fresh than outdoor air, we should acknowledge that he is right. Indoor air is provided to meet an individual's needs and only the individual can judge whether they are met. The human being is the ultimate judge of perceived air quality. If we as chemists, physicists, hygienists or engineers cannot find the chemical or physical reason why the air is felt to be unacceptable, it is our problem. If we cannot measure the difference between stuffy and fresh air, it is because our measurement technique is not good enough, not refined enough, compared to the human senses.

Thousands of chemical compounds may be present in indoor air. But they often occur in small concentrations that are hard to detect with present chemical techniques of analysis. Still, some may be above their thresholds for odor or irritation and contribute to the stuffiness of the air. Inadequate methods for measuring low concentrations is not the only problem. Even if we were able to identify every single molecule in a space, the next problem is knowing the impact on humans of the individual chemicals at such low concentrations. And, even if that information also were available, we do not know how each chemical is perceived when it occurs together with thousands of other chemicals.

How do we quantify the quality of indoor air when chemistry fails to help us? The answer is to use man as a meter; to acknowledge that man's nose is the most sensitive instrument available; and that this "instrument" in real buildings defines whether the air is fresh or stuffy, acceptable or unacceptable.

In a recent field study in office buildings (14) a panel of judges was used to quantify the perceived air pollution by the new decipol unit and to quantify the pollution sources by the new olf unit (15). One olf is the emission rate of pollutants from a standard person, defined as an average sedentary adult in thermal comfort with a hygienic standard of 0.7 bath/day. Any other pollution source may then be quantified by the number of standard persons (olfs) required to make the air equally unacceptable as the actual pollution source. One decipol is the pollution caused by one standard person (one olf) ventilated by 10 l/s (20 cfm) of unpolluted air (15).

Field study conducted

Pollution sources were quantified by the new olf unit in 15 randomly selected offices in Copenhagen. The spaces were

This article is a follow-up to "The olf and decipol," which appeared in the October *ASHRAE Journal*

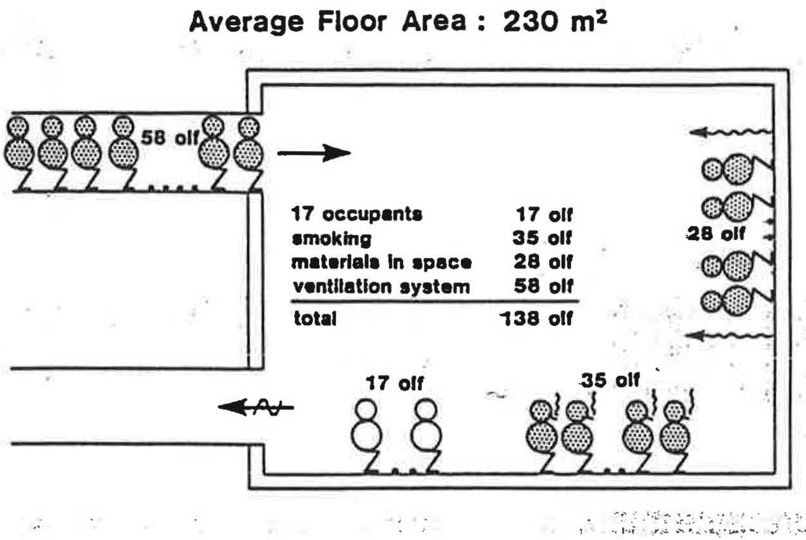

Figure 1—Average pollution sources in 15 offices in Copenhagen. An average of 17 occupants worked in each office.

visited three times by 54 judges, who assessed the acceptability of the air: (1) while unoccupied and unventilated to quantify pollution sources in the space, (2) while unoccupied and ventilated to quantify pollution sources in the ventilation system and (3) while occupied and ventilated to determine pollution caused by occupants and smoking. (Detailed information about the field study is given in reference 14.)

The perceived air pollution in the occupied offices varied between 0.2 and 5.9 decipol (3-49 percent dissatisfied) with an average of 3.3 decipol or 34 percent dissatisfied. Carbon dioxide, carbon monoxide, particulates and total volatile organic compounds were measured, but as in many field studies, these measurements did not explain the large variations in perceived air quality. The pollution sources were quantified for each space, and the mean values for all 15 offices are given in *Figure 1*.

In the average office with 230 m^2 (2500 ft^2) floor area, 17 occupants were working. The surprising result is that materials in the space had an average source strength of 28 olfs, and the ventilation systems polluted 58 olfs. Tobacco smoking polluted 35 olfs in the offices. Although there were only 17 occupants in the space, there were, in total, 138 olfs present. Only 13 percent of the pollution was caused by the bioeffluents from the occupants.

For each occupant there were 6 to 7 hidden olfs present, polluting the air in the space (*Figure 2*); 1 to 2 olfs were hidden in the materials in the space, 3 olfs were hidden in the ventilation system and 2 olfs were caused by tobacco smoking.

These results are in contrast to ventilation standards over more than a century, which have assumed that human beings are the principal or exclusive polluters in offices and similar spaces. Standards have implicitly assumed that spaces and ventilation systems are clean and do not contribute to the indoor air pollution. Influenced by the basic studies by Pettenkofer (16) and Yaglou (17) on human bioeffluents, the required ventilation has therefore normally been specified as outdoor air supply per occupant. The present study shows that human bioeffluents contribute only slightly to the pollution in modern office buildings.

The outdoor air quality was excellent (0.2 decipol) and the supply to the 15 offices was on average 25 l/s (50 cfm) per occupant. This is far above existing ventilation standards. From an engineering or hygienic point of view one would consider these spaces to be overventilated, yet 34 percent judged air to be unacceptable due to the heavy pollution sources that made the ventilation rate only 4 l/s (8 cfm) per olf.

The many hidden olfs in the spaces and in the ventilation systems are the reason why such high percentages of people found the air unacceptable. None of the 15 offices investigated were identified beforehand as a "problem building." They were selected randomly. Since the complaints were so high, even in these generously ventilated offices, it is no wonder that complaints of air quality are frequent in many buildings in practice, ventilated simply according to existing ventilation standards.

Hidden olfs in the spaces and the ventilation systems make the air stuffy, stale and unacceptable. The extensive and hitherto unknown pollution sources are the likely explanation to the sick building mystery. Why were these hidden pollution sources not identified earlier? Probably because no way of quantification existed previously, except the chemical method, which was usually insufficient. Also, many pollution sources are rather unconcentrated, usually spread over large areas. This makes them unnoticed except for extreme cases, e.g., formaldehyde from special wood products or insulation foams.

The judges assessed the air just after entering each space. Is this immediate impression of the air sufficient to give a fair assessment of the air quality? The irritants and odorants in the air stimulate immediately the chemical and olfactory sense (18). This means that the stale and stuffy air and the irritated mucous membranes, characteristic of the sick building syndrome, are perceived at once. With time, odor intensity will decrease, while irritation may remain constant (18, 19). The total impression of air quality will normally be strongest in the beginning and a judgment then will tend to be conservative. In ventilation theory (17) the aim has traditionally been to provide air quality which is felt acceptable from the first moment a person enters a space. Although some adaptation may take place later, a negative first impression of the air quality in a space must be avoided.

Are the hidden pollution sources also causing other symptoms like headache, lethargy, etc., claimed to be part of the sick building syndrome? We do not know. But we do know that it is characteristic for the symptoms of the sick building syndrome to disappear when people leave the building and are exposed to fresh air. If the hidden olfs in the building were removed so that the air is fresh and pleasant indoors, it seems likely that the other symptoms of the sick building syndrome would disappear simultaneously.

Although the pollution sources on average were alarmingly high for the 15 offices, there were large differences from building to building (14). Some ventilation systems were virtually clean and some spaces had very low olf-values. This stimulates optimism for the future. It is obviously possible to construct low-olf buildings.

Prevention and cure

An obvious way to prevent and cure sick buildings is to avoid or reduce the hidden olfs.

Catalogs with olf-values per m^2 of common building materials should be established so that architects can select

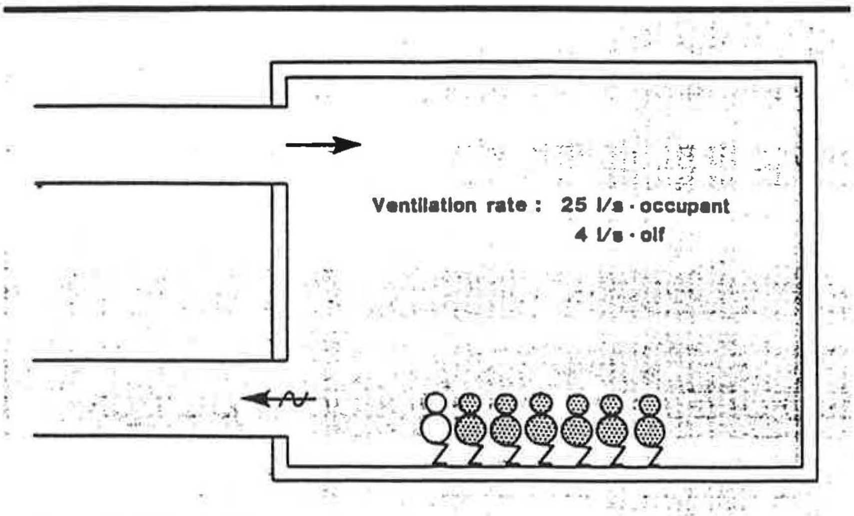

Figure 2—For every occupant (1 olf) in the 15 office buildings there were six to seven hidden olfs present (gray).

building materials with low olf values. Similarly we should establish olf-values for carpets, furniture, office machines, books, paper, etc., in order to avoid accumulating high pollution sources in our buildings. This may cause a revolution in the way we construct and furnish buildings. What can be done until we have an olf catalog? The simple advice in practice is to use the human nose. Samples of alternative building materials, carpets, etc., should be compared to avoid high-polluting materials ruining the indoor air quality and creating sick buildings.

Methods for cleaning of buildings should be modified to maintain low olf-values. Reduction of pollution sources rather than just aesthetics should be the primary aim of cleaning in buildings.

It is even more important to avoid pollution sources in ventilation and air-conditioning systems. Potential pollution sources should be identified. Attention should be given to filters, humidifiers, heating and cooling coils and sound attenuators. A primary aim for future HVAC researchers must be to develop new ventilating and air-conditioning systems that have virtually no pollution sources when they are new and can be kept clean easily during the lifetime of the system.

Ventilation should be designed to handle not only human pollutants but also pollution from materials and system. This important extra and previously ignored pollution load could in future ventilation standards be expressed in olfs per unit floor area.

Conclusions

Extensive hidden pollution sources in building materials and ventilation systems are a likely explanation to the sick building syndrome. For each occupant in 15 randomly selected office buildings there were on average 6 to 7 hidden olfs from other pollution sources: 1 to 2 olfs were hidden in the materials in the space, 3 olfs were hidden in the ventilation system, and 2 olfs were caused by tobacco smoking. The ventilation rate was on average 25 l/s (50 cfm) per occupant but, due to the extensive hidden pollution sources, only 4 l/s (8 cfm) per olf. This explains why 34 percent judged the indoor air to be unacceptable. The results are in contrast to ventilation standards which have assumed human beings to be the principal or exclusive polluters in offices and similar spaces.

Prevention and cure of sick buildings require systematic removal or reduction of unnecessary hidden olfs. This will improve air quality, decrease required ventilation and energy consumption, and diminish the risk of draft. ■

References

(1) I. Andersen and G.R. Lundquist: Indoor climate in schools. Danish Building Research Institute, Copenhagen, 1966. 100 p.

(2) B. Berglund, L. Johansson and T. Lindvall: A longitudinal study of air contaminants in a newly built preschool. Environment International, 8, 1982, pp. 111-115.

(3) T.D. Sterling, E. Sterling and H.D. Dimich-Ward: Air quality in public buildings with health related complaints. ASHRAE Trans., 89, 2A, 1983, pp. 198.

(4) J. Melius, K. Wallingford, R. Keenlyside and J. Carpenter: Indoor air quality – the NIOSH experience. Ann. Am. Governm. Ind. Hyg., Vol. 10, 1984, pp. 3-7.

(5) M.J. Finnegan, C.A.C. Pickering and P.S. Burge: The sick building syndrome: prevalence studies. Brit. Med. J., 289, 1984, pp. 1573-1575.

(6) J.A.J. Stolwijk: The sick building syndrome. In B. Berglund, T. Lindvall and J. Sundell (Eds.): Indoor Air. Vol. 1. Swedish Council for Building Research, Stockholm, 1984, pp.23-29.

(7) P. Kroling: Gesundheits- und Befindensstorungen in klimatisierten Gebauden. W. Zuckschwerdt Verlag, Munchen, 1985.

(8) A.S. Robertson, P.S. Burge, A. Hedge, J. Simms, F.S. Gill, M. Finnegan, C.A.C. Pickering and G. Dalton: Comparisons of health problems related to work and environmental measurements in two office buildings with different ventilation systems. Brit. Med. J., 291, 1985, pp. 373-376.

(9) O. Valbjorn and P. Skov: Influence of indoor climate on the sick building syndrome prevalence. In B. Seifert et al. (Eds.): Indoor Air '87, Berlin, Vol. 2, 1987, pp. 593-597.

(10) H. Komine, S. Yoshizawa and Y. Tochihara: The investigation on IAQ and subjective evaluations of occupants for indoor environments in Japanese office buildings. In B. Seifert et al. (Eds.): Indoor Air '87, Berlin, Vol. 3, 1987, pp.123-128.

(11) S. Wilson and A. Hedge: The office environment survey. A study of building sickness. Building Use Studies Ltd., London, 1987.

(12) WHO, Indoor air pollutants: exposure and health effects. EURO Reports and Studies 78, 1983, pp. 23-26.

(13) J.E. Woods, G.M. Drewry and P.R. Morey: Office worker perceptions of indoor air quality effects on discomfort and performance. In B. Seifert et al. (Eds.): Indoor Air '87, Berlin, Vol. 2, 1987, pp. 264-268.

(14) P.O. Fanger, J. Lauridsen, P. Bluyssen and G. Clausen: Air pollution sources in offices and assembly halls, quantified by the olf unit. Energy and Buildings, Vol. 12, No. 1, 1988, pp. 7-19.

(15) P.O. Fanger: Introduction of the olf and the decipol units to quantify air pollution perceived by humans indoors and outdoors. Energy and Buildings, Vol. 12, No. 1, 1988, pp. 1-6.

(16) M.V. Pettenkofer: Uber den Luftwechsel in Wohngebauden. Munchen, 1858.

(17) C.P. Yaglou, E.C. Riley and D.I. Coggins: Ventilation requirements. ASHVE Trans., 42, 1936, pp. 133-162.

(18) T. Engen: Perception of odor and irritation. Environment International, Vol. 12, 1986, pp. 177-187.

(19) L. Molhave, B. Bach and O.F. Pedersen: Human reactions to low concentrations of volatile organic compounds. Environment International, Vol. 12, 1986, pp. 167-175.

About the author

P. Ole Fanger is a professor at The Technical University of Denmark. Together with his international research team at the Laboratory of Heating and Air Conditioning, he has performed extensive studies on the indoor environment and its impact on humans. He is president of the Federation of Nordic HVAC Societies (SCANVAC) and was a president of the first international conference on indoor air in 1978. In 1985 he was president of CLIMA 2000, the first world congress on HVAC.