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Indoor Climate Man's Comfort Response[1]

L'Académie suisse des sciences techniques a consacré sa journée annuelle du 21 octobre dernier à une série d'exposés sur l'impact croissant des nouvelles techniques dans le domaine bâti. Nous publions ici trois des conférences présentées à cette occasion; les exposés en allemand doivent paraître dans la revue *Schweizer Ingenieur und Architekt.*
Rappelons que cette journée s'est déroulée à l'Ecole polytechnique fédérale de Lausanne sous la présidence du professeur Michel Del Pedro, de l'EPFL.

Summary

The composition and thermal properties of the air in the non-industrial environment are of concern because of their impacts on the health and comfort of man. Whereas the interactions between man and the thermal climate have been fairly well established, knowledge about man's response to the air quality dimension of indoor climate is less detailed. After a short presentation of the basic parameters in the thermal climate, new findings concerning the perception of air quality are presented.

Introduction

Designing and constructing a building today involves a variety of technical and economical decisions to be made. The building must be energy efficient; it must look attractive and yet be able to stand up to the forces of nature. But it should never be forgotten that the major aim of the building engineer and

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designer should be to provide an acceptable indoor climate for people, that is, an acceptable thermal and atmospheric environment. The thermal environment covers all parameters influencing man's heat balance, whereas the atmospheric environment comprises all components in the air that affect man's health or well-being. Occasionally the term "Indoor Climate" is used in a much broader context involving such factors as acoustic and lighting environment. Although these parameters are important for the well-being of man they are not included in this paper.
The purpose of this paper is to give an overview of the most important parameters in the thermal and atmospheric indoor environment that influence man's state of comfort.

Thermal Comfort

Thermal comfort is defined as that condition of mind which expresses satisfaction with the thermal environment. Dissatisfaction may be caused by warm or cool discomfort for the body in general or by an unwanted heating or cooling of one particular part of the body (local discomfort). Man's thermal sensation is mainly related to the heat balance of his body as a whole. This balance is influenced by his physical activity and clothing as well as by the environmental parameters: air temperature, mean radiant temperature, air velocity and the humidity of the air. When these factors are known, the thermal sensation for the body under steady-state conditions can be predicted by using the "comfort equation" derived by Fanger [1][2]. The outcome of this equation is the PMV index (Predicted Mean Vote) utilizing a seven point scale with the annotations –3: cold; –2: cool; –1: slightly cool; 0: neutral; +1: slightly warm; +2: warm; and +3: hot.
Due to interpersonal differences it is impossible to specify a thermal environment that will satisfy everybody. A percentage of the occupants can always be expected to be dissatisfied. The PPD index (Predicted Percentage of Dissatisfied) derived by Fanger [1][2] predicts this percentage for a given thermal situation. The relation between PPD and PMV is shown in Fig. 1. The Figure shows that a minimum of 5% dissatisfied are to be expected at PMV=0 (neutral). The thermal standard ISO 7730 [2] recommends the PMV to be in the interval $-0.5 < PMV < +0.5$, corresponding to PPD lower than 10%.
In Fig. 2 is shown the optimal operative temperature (corresponding to PMV = 0) as a function of activity and clothing. The operative temperature is that uniform temperature of an enclosure in which an occupant would exchange the same amount of heat by radiation and convection as in the actual non-uniform environment. The insulation of clothing is measured in the unit "clo" (1 clo = $0.155\ m^3\ K/m^2$, equivalent to the insulation of a business suit) and the activity level in "met" (1 met = $58\ W/m^2$ equivalent to the activity of a sedentary position at rest). The shaded areas in Fig. 2 show the acceptable temperature range corresponding to $-0.5 < PMV < +0.5$ around the optimal temperature. The Figure indicates that the acceptable temperature range is wider the higher the activity and the heavier the clothing. As previously mentioned, thermal dissatisfaction may also be caused by unwanted heating or cooling of one particular part of the body (local discomfort). This can be caused by too high air velocity (draught), by a too high vertical air temperature difference between head and ankles, by a too warm or too cold floor or by a too high radiant temperature asymmetry. Limits are listed in the ISO standard [2] for summer and winter conditions. If these limits are met, it is expected that no more than 5-10% of the occupants will feel uncomfortable due to the above mentioned factors. Draught is a

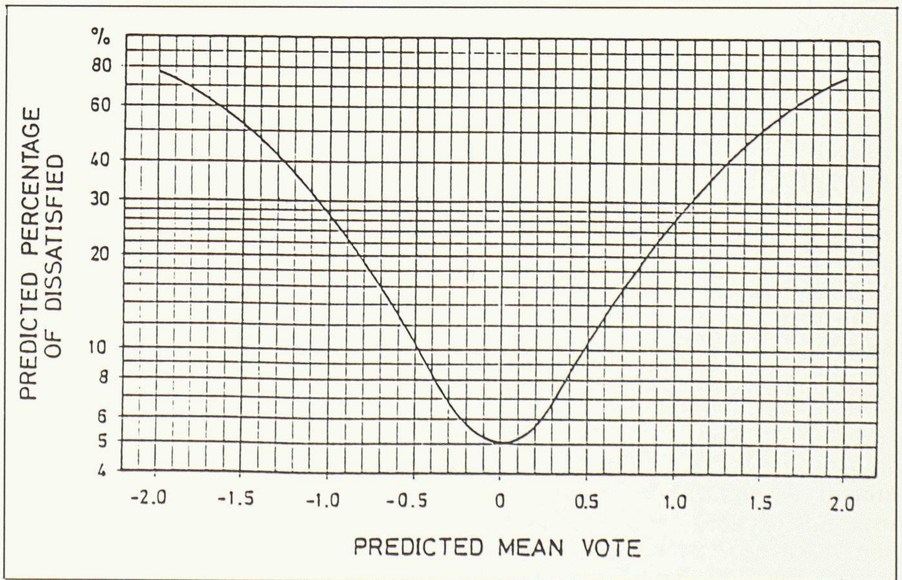

Fig. 1. – Predicted Percentage of Dissatisfied (PPD) depicted against Predicted Mean Vote (PMV).

[1] Paper presented at the annual meeting of the Académie suisse des sciences techniques, October 21, 1987, the theme of which was "L'habitat du futur – Impact des nouvelles techniques".
[2] See References p. 153.

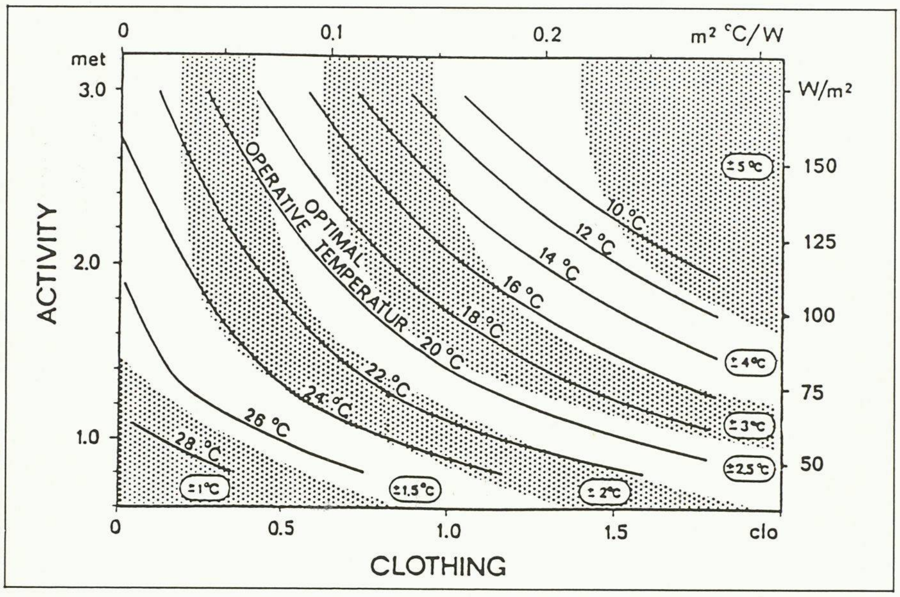

Fig. 2. – The optimal operative temperature as a function of activity and clothing. The shaded areas show the acceptable temperature range corresponding to –0.5 <PMV <+0.5.

serious problem in many ventilated or air-conditioned buildings. Early studies, where human subjects were exposed to laminar airflow, showed that people could tolerate quite high air velocities. But the airflow in the occupied zone of spaces is normally turbulent, and a new study by Fanger, Melikov and Hanzawa [3] found that turbulence emphasizes the nuisance of draught. The strategy to avoid draught is therefore to keep the mean velocity and the turbulence intensity in the occupied zone as low as possible.

Atmospheric Environment

Whereas the interactions between man and the thermal properties of the air are well explored today much less knowledge exists about how the atmospheric environment affects the well-being and comfort of man. The majority of our experience in this field comes from the industrial environment, where certain processes often emit or involve use of large quantities of atmospheric pollutants. Many countries have threshold limit values to protect the workers from several hundreds of gases and vapours in the industrial environment, but little or no legislation or guidelines deal with the indoor air quality in offices, homes, etc.

What is an acceptable indoor air quality in these types of buildings? The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [4] provide a useful definition: "Acceptable indoor air quality is air in which there are no known contaminants at harmful concentrations and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction." What is it that people object to when exposed to indoor air? The presence of e.g. radon or asbestos in the air does not cause any immediate diminution in the state of comfort, even though the health risks associated with this exposure may be substantial. In a growing number of offices and similar buildings the occupants respond to the indoor air with complaints about odours, irritation of the mucous membranes, stale and stuffy air, headache, lethargy, etc. This set of symptoms is often called "the sick building syndrome" [5]. It is well-known that inadequate supply of outside air may lead to a build-up of pollutants produced in the room such as bioeffluents from human beings, tobacco smoke and other combustion products, particulate matter and biological contaminants. These pollutants may, when present in substantial concentrations in the indoor air, lead to the symptoms described above. But the frustrating fact is that most of the observed "sick buildings" have adequate ventilation according to all existing ventilation standards and that all measured chemical compounds are found in concentrations below any conceivable health and comfort limit. Nevertheless, 20, 40 or 60% of the occupants find the indoor air unacceptable.

When recognizing that measurements of physical and chemical substances in the air do not satisfactorily quantify the quality of indoor air, a sensible way to proceed is to use the ultimate measurement equipment: man himself. By use of olfaction and the common chemical sense man is an extremely sensitive instrument for detecting most organic and some inorganic compounds. In order to quantify the impressions experienced by the human sense two new units have been developed [6]: the "olf" and the "decipol". One olf is the emission rate of air pollutants (bioeffluents) from a standard sedentary person in thermal comfort. A considerable amount of data exist on how bioeffluents from human beings are perceived by other people. Fig. 3 shows the percentage of persons finding the air quality unacceptable, when entering a space with a given supply of outdoor air per olf [7].

Any other pollution source can be quantified by the number of standard persons (olfs) required to cause the same dissatisfaction as the actual pollution source. One decipol is the pollution caused by one standard person (1 olf), ventilated by 10 l/s of unpolluted air. These limits were used for the first time in a study by Fanger et al. [8] where the air quality in 15 offices was evaluated by a panel of 54 judges. Each space was evaluated three times: 1) when it was unoccupied and unventilated, to quantify pollution sources from materials in the space, 2) when it

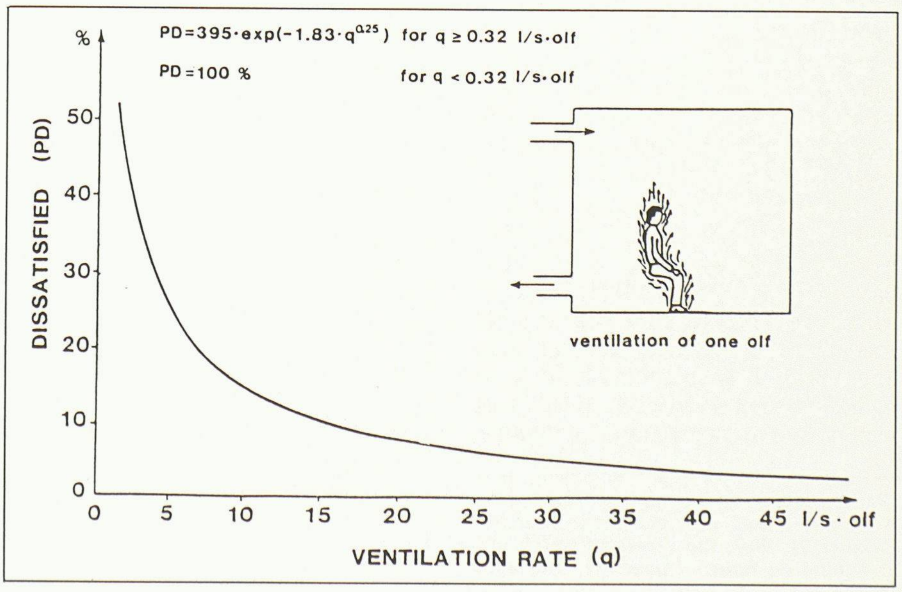

Fig. 3.– Percentage of Dissatisfied (PD) as a function of outdoor air supply per olf.

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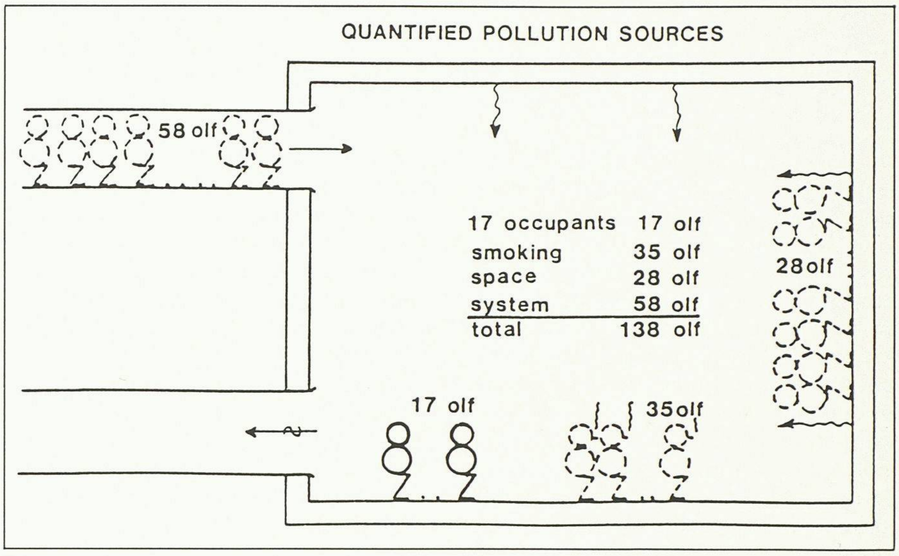

Fig. 4. – Mean values of pollution sources in 15 offices in Copenhagen.

was unoccupied and ventilated, to quantify pollution sources in the ventilation system, and 3) when it was normally occupied and ventilated, to quantify the combined effect of occupants and pollution sources in the space and ventilation system. The results obtained were very unexpected (Fig. 4): the average office had 17 occupants, but materials in the space had a source strength of 28 olfs and the ventilation system polluted 58 olfs! Smoking by the occupants added an extra 35 olfs to the total pollution. So when the average ventilation rate in the offices was measured to be 25 l/s per occupant, which is far above any existing ventilation standard, the actual ventilation rate per olf was only 4 l/s. This explains why on average 34% of the judges were dissatisfied with the air quality.

How do we deal with all these pollution sources in the future? The obvious solution is to remove the olfs hidden in the materials and ventilation systems. An olf-catalogue for different materials should be established so that architects and other building planners in future buildings can select materials with low olf values. Also methods for better cleaning of the building and ventilation system should be studied in order to provide a better indoor climate in the future.

Conclusions

There is no excuse for designing and constructing buildings which do not assure thermal comfort for the majority of occupants. The theoretical and practical framework for understanding the interactions between man and the thermal environment is well developed and should be used in the design phase and, when the building is constructed, instrumentation is available to verify that design criteria are met.

In the future we can expect to see a much greater awareness of the nature of the material used for building constructions and interior decoration. Also new ideas in the way we design and maintain ventilation systems should be promoted in the future.

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Les habitants face à l'habitat du futur[1]

1. Approche sociologique de l'habitat du futur

L'intégration de systèmes techniques avancés dans la conception de l'espace domestique pose, comme partout ailleurs, la question de l'interaction entre l'invention et l'innovation techniques, et le développement social. Le terme «maison du futur», souvent utilisé

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pour désigner un habitat équipé des nouvelles techniques de l'information, exprime un écart sensible entre ces techniques et la vie sociale. La technique de pointe au service de la vie quotidienne soulève de nombreuses interrogations. D'où notre question: le passage de la maison du «tout électrique» à la maison du «tout électronique» répond-il effectivement aux attentes, aux besoins, aux aspirations des habitants?

La sociologie de l'habitation connaît bien les distances qui séparent les représentations des concepteurs des pratiques des habitants.

La planification d'un système domotique ou d'un bâtiment dit «intelligent»

[1] Communication présentée lors de la journée annuelle de l'Académie suisse des sciences techniques, le 21 octobre 1987 à l'EPFL, sur le thème «L'habitat du futur - Impact des nouvelles techniques».