Indoor Air Vol 5

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AIR MOVEMENT AND DRAUGHT

N.K.Christensen, O.Albrechtsen and P.O.Fanger
Laboratory of Heating & Air Conditioning
Technical University of Denmark

Z.Trzeciakiewicz
Technical University of Gliwice, Poland

Abstract

One hundred subjects were exposed to air velocities fluctuating in the same manner as in typically ventilated spaces in practice. Each subject participated in three experiments at 20, 23 and 26°C, dressed to obtain a neutral thermal sensation. In each experiment the subject was exposed to six mean velocities from 0.05 to 0.40 m/s. He was asked whether and where he could feel air movement and whether it was felt uncomfortable. A relation was established between the percentage of people feeling draught and the mean velocity. The subjects were most sensitive to draught on the head region. Lower velocities than those prescribed in present standards are required to reduce complaints of draught in ventilated spaces in practice.

Introduction

Draught is defined as an unwanted local cooling of the human body caused by air movement. In many ventilated spaces it is a serious problem, often causing complaints, even though measured velocities may be lower than prescribed in existing standards (1,5,7). To improve conditions it is essential to know the human response to air velocity and to develop better methods for designing air distribution in spaces. This paper deals with the human response.

Numerous studies have measured the convective heat transfer coefficient for the entire body. This is useful for setting up a heat balance for the human body and for predicting the thermal sensation for the body as a whole ( ). But such information is of limited value for predicting a local cooling felt as a draught. A person may feel thermally neutral for the body as a whole yet may not be comfortable if air movement causes a cooling of a particular part of the body.

There are few specific draught studies available. Houghton (4) studied ten male subjects exposed to constant, local velocities at the back of the neck and at the ankles. McIntyre (6) used a similar method where he exposed the head region of subjects to constant local velocities. But in ventilated spaces the air velocity fluctuates and is never constant. Fanger and Pedersen (3) exposed subjects to a periodically fluctuating air flow directed towards the back of the neck or the ankles. It was shown that a fluctuating air flow is more uncomfortable than a constant flow. The changes in air velocity from second to second were felt to be unpleasant. The maximum velocity and the frequency of the fluctuating air flow had an influence on the sensation of discomfort. The percentage of persons feeling uncomfortable when exposed to a periodically fluctuating air flow was established.

In real spaces the occupants are not exposed to a well-defined, periodically fluctuating air flow. Fluctuations in practice will be of a stochastical nature. In a field study in Copenhagen (8) the velocity fluctuation was determined in twelve typically ventilated spaces. The fluctuations in the occupied zone could be described by the standard deviation of the velocity. For all twelve spaces one linear relation between standard deviation and mean velocity was found to apply with good approximation. In many ventilated spaces the mean velocity is thus sufficient to characterize the air flow at a point. The purpose of the present study is to establish the scientific basis required to predict the human response to fluctuating air velocities as they occur in practice. An important aim is to establish the percentage of the population feeling draught when exposed to a given mean velocity.

Experimental plan

It was decided to expose 100 subjects to velocity fluctuations. The subjects were exposed to increasing mean velocities up to 0.40 m/s. Each subject was studied during three experiments at an air temperature of 20, 23 and 26°C. The aim was at all three temperatures to keep him thermally neutral for the body as a whole by modifying the clothing. Such an adaptation of the clothing will probably also take place in most cases in practice. During the first hour of each experiment the subject was therefore encouraged to modify his clothing until he felt thermally neutral. During the last 1 1/2 hours the clothing was constant and the subject was exposed to six different levels of the mean velocity as shown in Fig. 1.

Facilities

For the experiments an existing laboratory space was modified to function as a draught chamber. The size of the chamber was 6x6x3 m. The roof and an outside wall were well insulated and there were no windows. The subject was seated at the location shown in Fig. 2. In an adjacent control room the observer could see the subject through a small window. All instruments as well as the air conditioning system were situated in the control room.

It was essential that the subject in the draught chamber was exposed to velocities fluctuating in the same manner as in typically ventilated spaces in practice, as identified by Thorshauge (8). Since an earlier study (3) had indicated that man is most sensitive to velocities coming from behind, this main flow direction was aimed at where the subject was seated. Several types, numbers and locations of air diffusers were tested to fulfil these requirements. It was finally decided to use four plane, quadratic diffusers (FLAEKT CTLS) situated as shown in Fig.2.

Three sides of each diffuser were covered by tape so that the air was supplied horizontally to the space as shown in Fig. 2. The air rotated in the space around a vertical axis. In this way the subject was exposed to a mainly horizontal air flow from behind.

The mean velocity around the subject was controlled by changing the supply air up to a flow rate of 1500 m^3/h. The air temperature around the subject was controlled by heating or cooling the supply air in an air conditioning system.

The air temperature and velocity were measured at a point 1.1 m above the floor and 0.15 m behind the back of the neck of the subject. At this distance the temperatur and velocity field were undisturbed by free convection currents from the human body. In some experiments corresponding measurements behind ankles and elbows were taken. The air temperature was measured by resistance thermometer, while the air velocity was measured by an omnidirectional and temperature-compensated probe (DISA 55R48 and 56C15) with a time constant <0.1 s.

To mask changes in the noise level when the air supply was changed a tape of fan noise was played over loudspeakers in the draught chamber. The subject was thus exposed to a constant noise level independent of the air flow and velocity.

Subjects

One hundred persons (50 males and 50 females) served as subjects in the experiments, most of them being university students. All subjects were volunteers who were paid for taking part in the experiments. Each subject participated in three 3-hour experiments on three different days. The three experiments took place at the same time of the day, either at 8.45-11.45 am, 11.45-2.45 pm, 2.45-5.45 pm or 5.45-8.45 pm. The 900 experimental hours took place during autumn 1981, winter 1981-82 and autumn 1982.

The subjects were asked to wear normal clothing, but it was not permitted to wear boots, gloves, a scarf, sweater or blouse with a high neck that would protect the neck from draught. For the experiment at 26°C the subjects were asked to bring some light summer clothing.

Experimental Procedure

Each subject reported 15 minutes prior to the commencement of the experiment and it was ascertained that he did not feel sick. He was informed about the experimental procedure, and the questionnaires he was asked to fill in during the experiment were explained to him. He then entered the chamber and was seated in the chair. During the experiment the subject was allowed to read, write or do some handwork. He was not permitted to eat, but moderate smoking was allowed.

During the experiment, mean velocities as shown in Fig. 1 were maintained. During the first hour the mean velocity was kept at 0.20 m/s which is approximately the average of the velocities maitained during the last 1 1/2 hour of the experiment. During the first hour the subject was encouraged every ten minutes to modify his clothing if he felt warm or cool. Extra clothing was available in the draught chamber. During the last 1 1/2 hours of the experiment no modification of clothing was allowed. The subject was then exposed to six 15-minute periods with increasing mean velocities as shown in Fig. 1. At each velocity level the subject was asked 5, 10 and 15 minutes after the beginning of the period whether he had felt an air movement during the previous five minutes, whether it was uncomfortable, and where it was felt. At the end of each velocity period and every 10 minutes during the first hour the subject was questioned about his general thermal sensation, and at the end of the experiment he was asked to list the articles of clothing he was wearing.

Results

For each of the 300 experiments the mean velocity during each of the six 15 minute velocity periods was determined. The mean values were close to the planned values shown in Fig. 1.

The key question to each subject was whether he felt any air movement and if yes, whether this air movement was uncomfortable. He answered this question three times during the 15-minute period, at each velocity level. It was decided to demand two answers out of three as "uncomfortable" before classifying the velocity as draught, i.e. to classify the subject at that velocity as "dissatisfied".

Fig. 3 shows the percentage of subjects who felt draught on the head region (the dissatisfied) as a function of the mean velocity at the neck. The head region comprises head, neck, shoulders and back. The three lines in Fig. 3 are based on a probit analysis of the percentage feeling draught versus the square root of the mean velocity. The square root was selected since heat transfer by forced convection is approximately proportional to the square root of the velocity (1). There was a significant influence of the air temperature on the percentage of dissatisfied. There was no significant difference between the draught responses of men and women.

In Fig. 4 the responses at all three temperatures are pooled for the head region and compared to the responses at the feet, arms and legs. The percentage of dissatisfied is related to the air velocity behind the corresponding part of the body. Fig. 4 shows that the subjects were more sensitive to draught on the head region than on other parts of the body.

Discussion

The present study shows that many people are surprisingly sensitive to a fluctuating air flow. Houghton (4) and McIntyre (6) studied constant air flow and found considerably fewer dissatisfied than in this study. However, in real spaces the air flow does fluctuate. The discomfort found in the present study (Fig. 3) agrees quite well with the previous study where subjects were exposed to a periodically fluctuating air flow (3). But the present study is more realistic than all earlier studies since the subjects were exposed to velocities fluctuating in the same way as in real ventilated spaces.

At low air velocity <0.04 m/s where natural convection control heat transfer, a small percentage of the subjects felt a draught (Fig.3). This is not a velocity-related dissatisfaction and is therefore in Fig.5 subtracted from the percentage of dissatisfied. Fig. 5 represents thus the percentage of dissatisfied caused by air flow in the space.

The present study was performed with subjects clothed to maintain thermal neutrality at all three air temperatures. The subjects wore normal indoor summer and winter clothing. This means that only the head region, the hands, and in some cases the ankles and lower arms were uncovered. Among these uncovered areas the head region was found to be the most sensitive (see Fig. 4). Other areas of the human body covered by clothing may be more sensitive to draught. The present data apply therefore only for persons wearing normal indoor clothing.

The influence of air temperature on the percentage of dissatisfied is significant and only to be expected from a heat transfer point of view. Especially at 20°C there are many dissatisfied, e.g. 20% at a mean velocity of 0.15 m/s which is the limit in several recent standards (1,5,7). The present study explains the many complaints of draught occurring in practice and underlines the importance of maintaining lower air velocities than prescribed in present standards, in particular at low air temperatures.

Conclusions

- A relation has been established between the percentage of people feeling draught and the mean velocity of an air flow fluctuating as in typically ventilated spaces in practice (Fig. 5).
- People wearing normal indoor summer or winter clothing are most sensitive to draught on the head region.
- Lower air velocities than those prescribed in present standards are required in order to reduce complaints of draught in ventilated spaces in practice.

Acknowledgement

The present study was funded by the Danish Government Fund for Scientific and Industrial Research (STVF).

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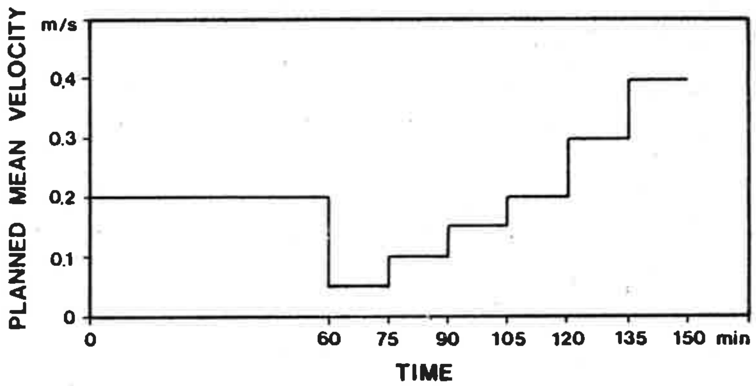

Fig. 1. Planned mean velocity during each experiment.

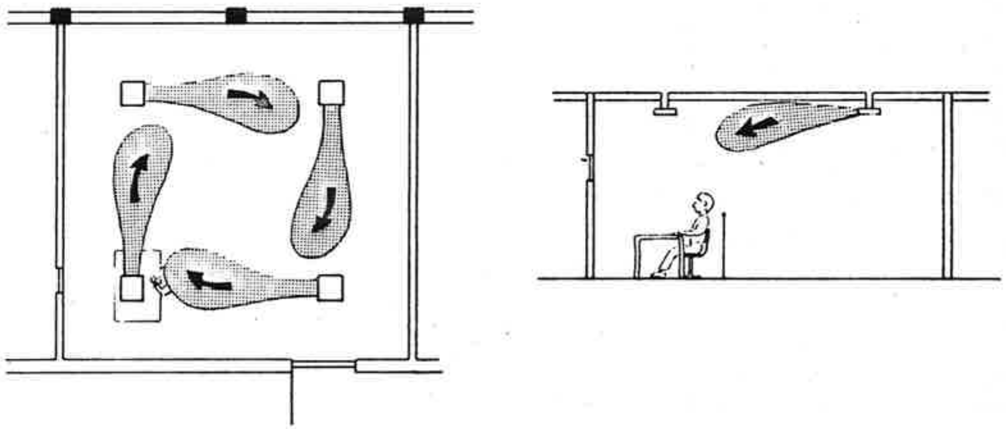

Fig. 2. The position of the subject, the air velocity sensor and the air diffusers in the draught chamber.

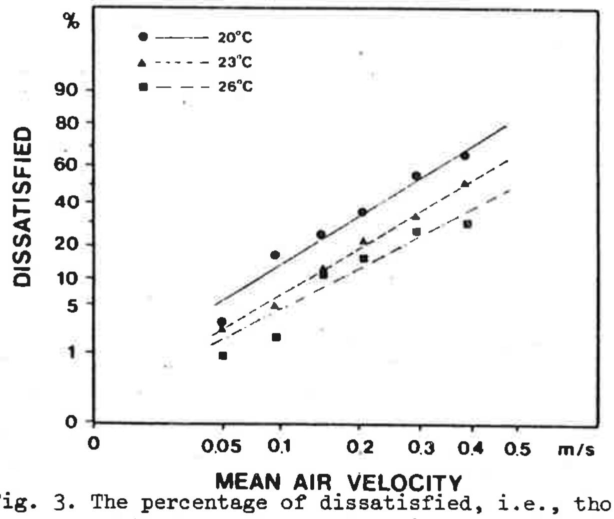

Fig. 3. The percentage of dissatisfied, i.e., those feeling a draught at the head region as a function of the mean air velocity at 20, 23 and 26°C.

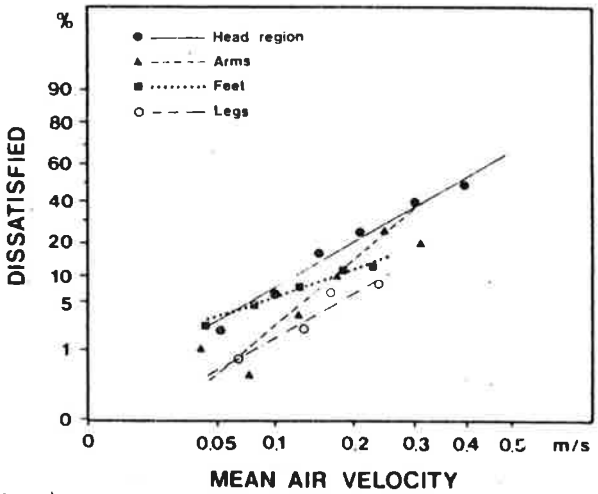

Fig. 4. The percentage of dissatisfied, i.e., those feeling a draught at different parts of the body as a function of the local mean air velocity. Data at 20, 23 and 26°C pooled.

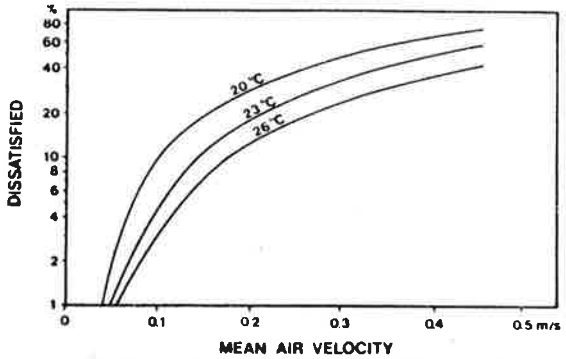

Fig. 5. The percentage of dissatisfied caused by air movement at the head region as a function of the mean air velocity at 20, 23 and 26°C.

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