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Indoor climate – CIB W77

Assessment of draught by an artificial skin

SPECIFIC INDOOR CLIMATE ANALYZER SIMULATES HUMAN SKIN ON HEAT TRANSFER AND SURFACE TEMPERATURE

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Dr.-Ing. Erhard Mayer of the Fraunhofer-Institut für Bauphysik, FhG (Director Prof. Dr.-Ing. habil. Karl A. Gertis) has established that the indoor climate analyzer or artificial skin has proved useful for the objective evaluation of air movement for degrees of turbulence above 20%, and that the convective heat transfer coefficient, instead of mean air velocity, can be used as a basis for thermal comfort.

Des expériences physiologiques indiquent que la température de la peau de l'homme reflète l'inconfort dû au froid (courants d'air). Le Dr.-Ing. Erhard Mayer du Fraunhofer-Institut für Bauphysik, FhG, directeur Prof. Dr.-Ing, Kari A. Gertis, a établique l'analyseur du climat intérieur ou peau artificielle s'est avéré un outil utile pour l'évaluation objective des mouvements de l'air pour des turbulences supérieures à 20% et que l'on peut utiliser le coefficient de transfer de chaleur par convection pour calculer le confort thermique à la place de la vitesse moyenne de l'air.

Posing the problem

Complaints about draught rank first among complaints about general thermal discomfort in air-conditioned rooms. Draughts can be caused by too high a mean velocity and/or too high a turbulence in the air flow (ref. 1 and 2), and possibly also by the frequency of air fluctuations (ref. 3). The physical quantity of air movement in relation to mean velocity, turbulence and frequency gives the convective heat transfer coefficient. Measurements of this heat transfer coefficient were compared with psychophysical assessments of draughts to establish if there is a direct relationship.

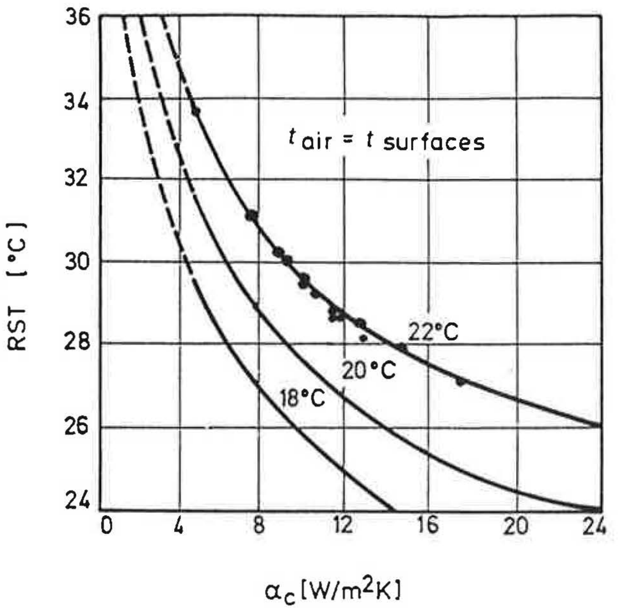
Measuring methods

Heat balance

Heat loss from man essentially consists of convection and radiation. Neglecting other heat losses, such as by evaporation, a simplified heat balance can be formulated, for example for the forehead:

$$\underbrace{120\ \mathrm{W/m^2} = \alpha_c\,(\mathrm{RST}\text{-}t_a)}_{q_c} + \text{const.}\ \underbrace{\left[\left(\frac{\mathrm{RST}+273.2}{100}\right)^4 - \left(\frac{t_{sf}+273.2}{100}\right)^4\right]}_{q_r}\ \mathrm{W/m^2}$$

where 120 $\mathrm{W/m^2}$ = forehead heat flow produced by metabolism (body resting); q_c = convective heat loss; q_r = radiant heat loss; α_c = convective surface-heat-transfer coefficient; RST = resultant surface temperature, the surface temperature of the skin resulting from the thermal conditions of the body and the surrounding rooms, which according to Benzinger (ref. 4) is decisive for cold



$$120\ \mathrm{W/m^2} = \alpha_c\,(\mathrm{RST} - t_a) + 4.9$$

$$\left[\left(\frac{\mathrm{RST} + 273.2}{100}\right)^u - \left(\frac{t_{sf} + 273.2}{100}\right)^u\right]\ \mathrm{W/m^2}$$

Fig. 1. Resultant surface temperature (RST) as a function of the convective heat transfer coefficient α_c for ambient temperatures 18, 20 and 22°C, according to the formula (curves) and measured by the indoor climate analyzer (dots)

discomfort; t_a = air temperature; and t_{sf} = temperature of the surrounding surfaces.

The decisive influence exerted by the convective surface-heat transfer coefficient on thermal comfort becomes obvious when the formula is represented in a graph (see Fig. 1).

Principle of the indoor climate analyzer (artificial skin)

Heat balance can be simulated by an artificial skin, as shown in Fig. 2. It consists of a surface resistor of defined area (middle), electrically heated at a constant rate of 120 W/m^2. To avoid unintended heat-flows, eight counter heaters, and nine back-counter heaters were installed. The value measured is the resultant surface temperature (RST) which can be calculated from the measured electrical resistance and a calibration curve. The RST meter is coated black to simulate the emission coefficient of the human skin of 0.96. Results of the RST measurements at different air movements are plotted in Fig. 1.

The pure convective heat flow q_c is measured by a similar sensor, the q_c meter. This differs from the RST meter in not being coated, so the high reflection coefficient of the platinum provides a nearly pure convective heat loss. The q_c meter adjusts its surface temperature to that of the RST, and the power necessary for this is measured. The indoor climate analyzer calculates the convective surface heat

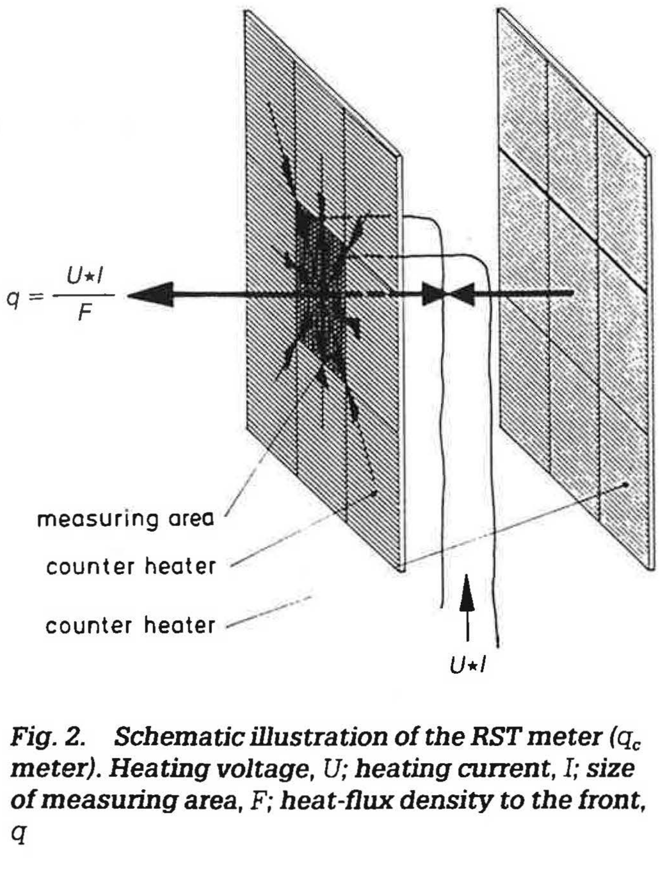


Fig. 2. Schematic illustration of the RST meter (q_c meter). Heating voltage, U; heating current, I; size of measuring area, F; heat-flux density to the front, q

Fig. 3. Indoor climate analyzer consisting of the sensor mounted on a tripod with stepping motor, and electronics

transfer coefficient α_c from the measured RST, q_c and air temperature by

$$\alpha_c = q_c \sqrt{(RST - t_a)}$$

The whole indoor climate analyzer is demonstrated in Fig. 3.

Psychophysical measurements

The psychophysical draught measurements which are correlated with the artificial skin measurements were carried out by Fanger *et al.* in the laboratory of Heating and Air Conditioning, Technical University of Denmark and are described in detail in ref. 2.

Measuring results and discussion

Air movements of different mean air velocities (0 to 0.8 m/s) and degrees of turbulence (14 to 55%) have been produced in the climate test chamber of the Fraunhofer-Institut für Bauphysik. The indoor climate analyzer was tested under these conditions, with constant ambient temperature and with airflow from the front. The measurements confirm the earlier results – a parabolic correlation between the product of mean air velocity and degree of turbulence and the convective heat transfer coefficient (ref. 1; Fig. 4). The different slopes of the curves in Fig. 4 and in ref. 1 are caused by different methods of statistical evaluation of air velocity. For the present study, a modern fast-Fourier-transformation analyzer was used. Recent Danish psychophysical draught measurements (ref. 2) confirm these results. Fifty subjects exposed to air velocity from the back ranging from 0.05 to 0.4 m/s with different degrees of turbulence have reported on their sensations of air movement or draught. Air temperature was kept constant at 23°C. The original results from these inquiries are presented in Figs 5 and 6. Fig. 7 summarizes the results for different ranges of turbulence, with the product of mean air velocity and turbulence degree representing the independent variable.

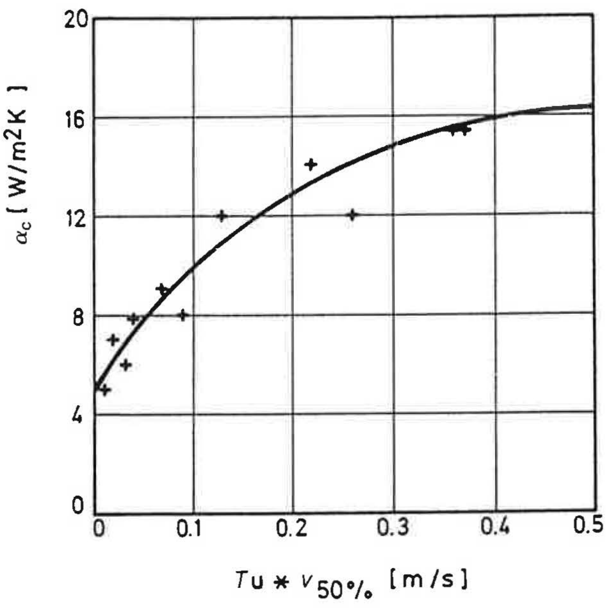


Fig. 4. Convective heat transfer coefficient a_c as a function of the product of turbulence degree T_u and mean air velocity $V_{50\%}$, measured by the indoor climate analyzer. Turbulences between 14 and 55%

It can be recognized that this product, i.e. the time dependent fluctuation of air (standard deviation) affects the sensation of air movement as well as sensing dissatisfaction due to draught. The indoor climate analyzer measurements also depend on this mathematical product, therefore the results from both physical and psychophysical tests should be compared (Fig. 8). The percentages of subjects sensing air movement and dissatisfaction due to draught are drawn as a function of the convective heat

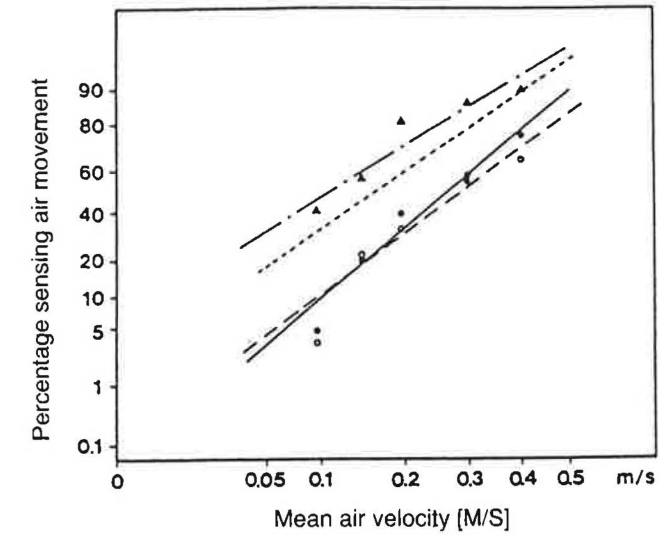


Fig. 5. Percentage of subjects who could sense an air movement in the region of the head as a funciton of the mean air velocity, at low, medium and high turbulence (ref. 2). ●—— Low turbulence (T_u <12%); ○ – – – Medium turbulence (20% < T_u <35%); ▲– · – high turbulence (T_u >55%); ------ Fanger and Christensen (35% < T_u <55%) .....

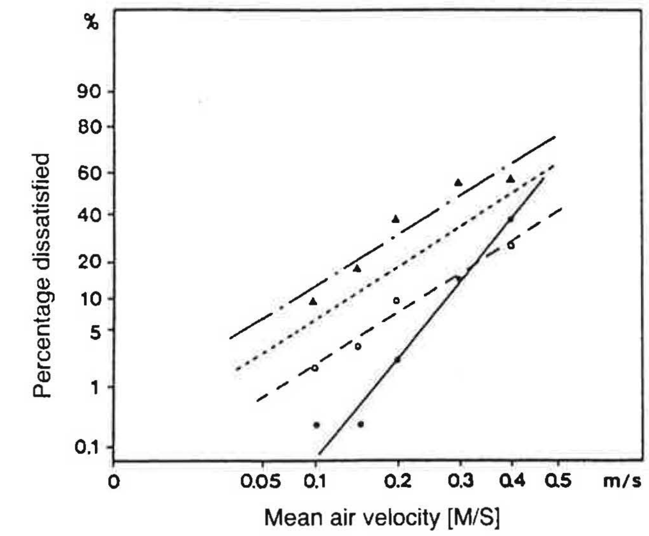


Fig. 6. Percentage of dissatisfied subjects (those feeling a draught in the region of the head) as a function of mean air velocity at the three levels of turbulence intensity. The points with 0% dissatisfied have been plotted at 0.2% (ref. 2). Symbols as Fig. 5

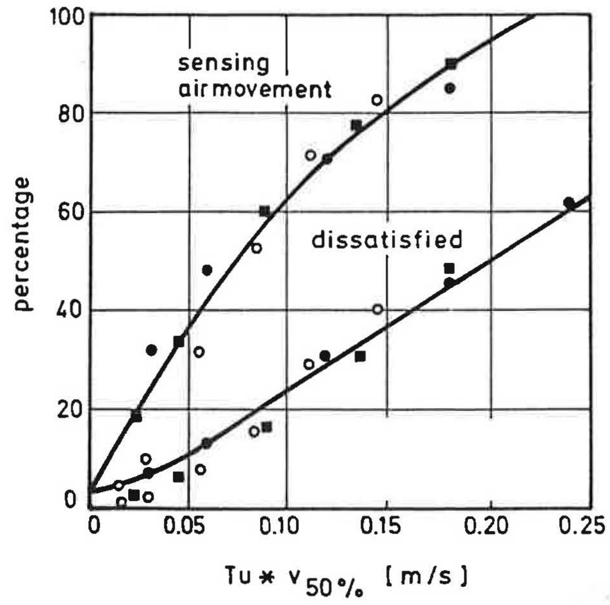


Fig. 7. ***Percentages of subjects sensing air movement and dissatisfaction as a function of the product of turbulence degree T_u and mean air velocity $V_{50\%}$, at turbulences higher than 20% (from Figs 5 and 6).*** ○, ***20%*** $<T_u<$ ***35%;*** ■, ***35%*** $<T_u<$ ***55%;*** ●, $T_u>$***55%***

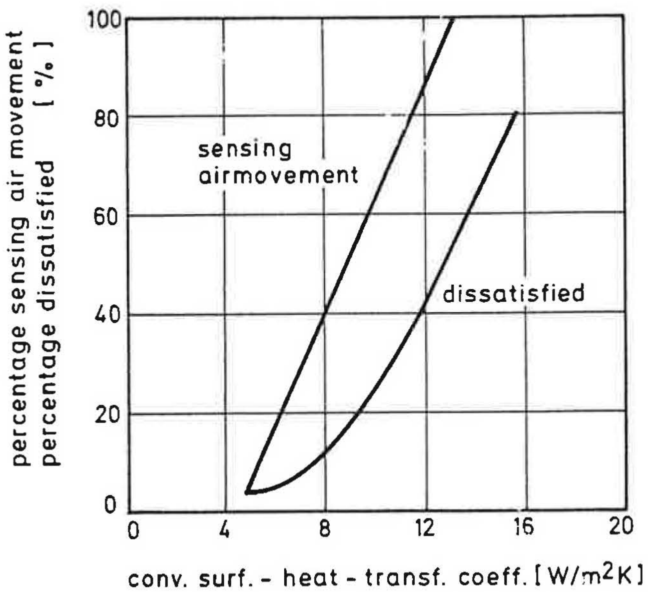


Fig. 8. ***Percentages of subjects sensing air movement and dissatisfaction as a function of the convective heat transfer coefficient α_c at turbulences higher than 20% (from Figs 4 and 7)***

transfer coefficient, at turbulence degrees above 20%. The curves begin at a natural convection value of 5 W/m^{2}K and a minimum percentage of 5% dissatisfied, which according to Fanger always occurs. The correlation between the convective heat transfer and the air movement sensation is even clearer than for dissatisfaction due to draught: it is a straight line. A limit of 10% dissatisfied limits the maximum heat transfer coefficient to 7.5 W/m^{2}K and a limit of 20% : 9.5 W/m^{2}K. The corresponding percentages for sensing air movement are 35 and 55%.

Conclusions

The indoor climate analyzer (artificial skin) has proved useful for the objective evaluation of air movements which create draught. This was established for degrees of turbulence above 20% with airstreams from behind and in the head region. It still has to be proved for other conditions. The convective heat-transfer coefficient integrates the physical quantity of the different characteristics of air movement, such as mean air velocity, turbulence intensity and probably frequency of fluctuations.

Therefore this coefficient should be used as the basis for thermal comfort, rather than the mean air velocity. Airflow measurements by different anemometers and analysis equipment can hardly be compared. These influences have to be investigated in future, possibly with the help of the artificial skin.

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