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INFLUENCE OF AIR TURBULENCE ON THE CONVECTIVE SURFACE-HEAT-TRANSFER-COEFFICIENT

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Abstract

The physical reason for draft of air phenomena is in the first place the convective surface-heat-transfer-coefficient. To find out about the influence of turbulence of air motion on the draft sensation, it is necessary to carry out measurements of the surface-heat-transfer-coefficient in dependence of the air turbulence. The results of first measurements of this kind are subject of the present paper.

1. Methods of measurements

Air velocities differing in amount and turbulence were created in a climate test room with constant ambient temperature. These air velocities were analysed by means of a lately developed anemometer which is non-directional and temperature-compensating (1,2) see fig. 1. This is called a Thermistor-constant-temperature-anemometer with a very low time constant (10 ms).

The convective surface-heat-transfer of air motions analysed by means of the anemometer was measured at an artificial head, heated up to 34° C at an air temperature of 22° C (see fig.2). Especially the influence of the very quickly varying (turbulent) air velocities on this unit was to be examined, and for their measurement an instrument was needed which registered with almost no delay and possibly without influencing the measuring value. Such an instrument is the Laser-differential-interferometer (LDI) (3).

Essential characteristic of an LDI is the partition of a (laser) beam of light into two partial beams, capable of interference, taking a parallel course next to each other through the medium to be examined (here the air in front of the heated head) and are reunited subsequently, see fig. 3. In case there is a difference of density in the medium (here due to differing air temperature) and, thus, a difference in refraction number, the two partial beams have optical ways of different lengths. The consequence is a corresponding phase displacement and depending hereon intensification or attenuation of the intensity of light by interference.

In the present case - after evaluation of the results of interference - the LDI furnished measuring data on the difference of density and thus difference of air temperature between the two partial beams. To determine the total profile of temperature in front of the heated head, the two partial beams must be guided step by step through the field in question and the separate values of temperature difference must be added up.

With the aid of the LDI, the temperature curve near a heated body can be registered optically, thus meeting the requirements mentioned above. Taking into consideration the fact, that the development of temperature in front of a heated body originates in dependence of the loss of heat of this body by the moved air, the convective surface-heat-transfer-coefficient can be found by means of calculation.

2. Results of measurements and discussion

2.1 Thickness of temperature boundary layer and convective surface-heat-transfer-coefficient

Concerning the connection between air temperature $\vartheta(x)$ and the distance x from the heated body (head), surface temperature ϑ_O (here 34 °C) it was found:

$$\vartheta(x) = (\vartheta_O - \vartheta_\infty) \cdot e^{-\frac{x}{d}} + \vartheta_\infty \qquad (1)$$

where ϑ_∞ represents the air temperature in great distance from the heated body (here 22 °C) and d the thickness of temperature boundary layer. This means the distance from the heated body where the temperature difference between head and room air has come down to the e-part (Euler constant).

Considering the fact that there is no air motion in the place x = o mm, and the loss of heat that is not due to radiation (heat flow density q) but solely to heat conductivity of the air (heat conductivity λ_{air}).

$$q = \lambda_{air} \left(\frac{d\vartheta}{dx}\right)_{x=o} \qquad (2)$$

as well as with the equation already known for the convective surface-heat-transfer-coefficient:

$$q = \alpha_K (\vartheta_O - \vartheta_K) \qquad (3)$$

by equating (2) with (3) and also using (1)

$$\alpha_K = \frac{\lambda_{air}}{d} \qquad (4)$$

is obtained.

2.2 Air motion and convective surface-heat-transfer-coefficient

Different combinations of degree of turbulence and average air velocity in undisturbed condition were tested in the climate test room and then the resulting α_K-values in front of the heated artificial head measured by means of the LDI (see fig. 3). The results are presented in fig.4. It was found, that α_K rises parabolically together with the product out of degree of turbulence Tu and the average air velocity $V_{50\%}$. Where

$$Tu = \frac{S}{V_{50\%}} \qquad (5)$$

with the standard deviation S of air motion, that is

$$\alpha_K = \alpha_{EK} + 2.7 \sqrt{S \cdot 100 \frac{s}{m}} \quad [W/m^2K] \qquad (6)$$

and α_{EK} represents the selfconvection.

Following equation (6) the minimum convective heat loss, f.i. when there is no air motion, is about the same as selfconvection. However, even in flowing air without turbulence (S = 0 m/s) the selfconvection would not be exceeded. This can be explained by the effect of the heated air layer at the body surface, which, in this case, was not disturbed by the air motion free of turbulence (hardly possible in practice). This would mean, the thickness of boundary layer of this air flow was beyond the thickness of temperature boundary layer of the air heated by the body. In the curve segment up to the point marked by broken lines, at 22° C air temperature, there are no draft phenomena yet, according to earlier measurements (3).

3. Summary of results and outlook

So far, measurements as mentioned above led to the following statements:

1. The convective surface heat transfer increases same as the result of degree of turbulence and average air velocity, equal to the standard deviation of air velocity variations, that is
2. beginning with the selfconvection, the convective surface-heat-transfer-coefficient rises parabolically with increasing standard deviation.
3. The disturbance - more or less strong - of the heated air close to the body, rising due to selfconvection, consequence of pulsation (variation) of air motions, of exterior influences (i.e. inlet of air through air conditionning) is of major importance for the convective loss of heat.
4. The amount of the convective surface-heat-transfer-coefficient α_k is inversely proportional to the thickness of boundary temperature layer of air heated by the body.

The presented results have been obtained by means of first measurements of the kind described above. More measurements will be required to make a more detailed and more comprising statement on the effect of air motions on the convective loss of heat and thus, on the thermic comfort of man. Turbulence and average value of air velocity should then be variated, more than it has been done now; furthermore, flowing direction and geometry of the heated body and - last but not least - the influence of frequencies of air motions on the convective surface-heat-transfer-coefficient which have not been considered yet, must still be examined.

4. References

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Acknowledgement

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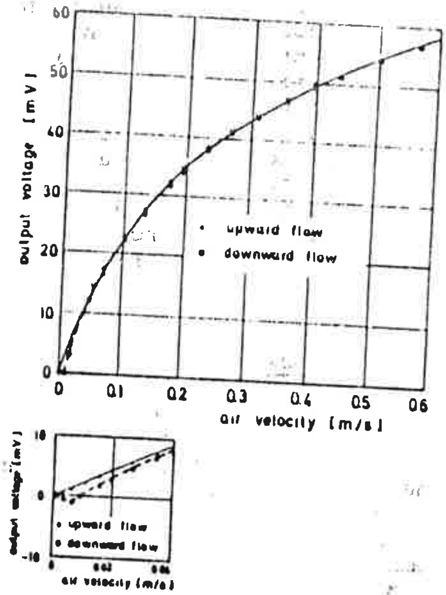

Fig. 1: Calibration curve for the developed anemometer in the range of 0m/s up to 0,6 m/s (top) and detailed figure in the range of low air velocities between 0 m/s and 0,04 m/s, at increased scale (bottom), (●) for upward flow and (o) for downward flow.

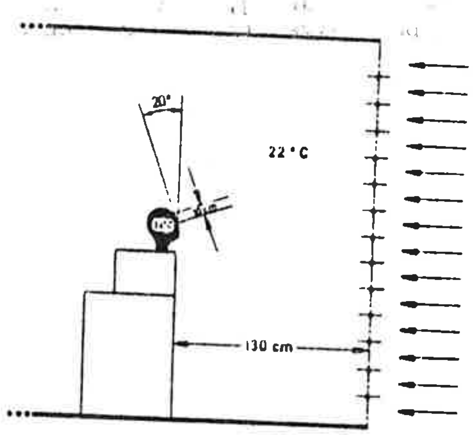

Fig. 2: Position of the artificial heated head in the climate test room, longitudinal section.

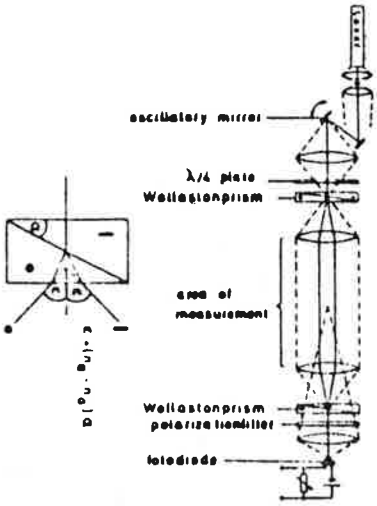

Fig. 3: top: Construction of the Laser differential-interferometer (top plan view).

bottom: Section through a Wollaston prism with wedge-angle α and the divergency angle ε. The broken lines and dots show the direction of polarization of the partial rays, n_a and n_o are the refraction figures herefore.

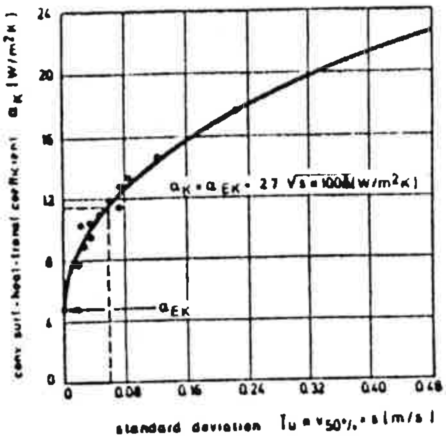

Fig. 4: Measured connection between the convective surface heat-transfer-coefficient α_K and the product from degree of turbulence Tu and average air velocity $v_{50\%}$, i.e. standard deviation s of air motion (dots), as well as calculated connection between α_K and S.