VENTILATION TECHNOLOGY - RESEARCH AND APPLICATION

8th AIVC Conference, Überlingen, Federal Republic of Germany
21 - 24 September 1987

PAPER 6

DRAUGHT MEASUREMENTS IN VENTILATED AND NON-VENTILATED BUILDINGS

DR. E. MAYER

Fraunhofer Institut für Bauphysik
Institutsbereich Wärme/Klima
(Leitung: Prof.Dr.-Ing.habil. K.A. Gertis)
Postfach 1180
D-8150 Holzkirchen 1
B.R.D.

SYNOPSIS

Measurements of the air temperature and air velocity were carried out in four buildings without air-conditioning using a newly developed anemometer whose sensitivity allows the examination of the dynamic behaviour of air movements. Recent results describing the physical reasons of draft problems were employed in order to re-examine the correlation between air movements and draft problems in a building. From the resulting evaluation criteria follows that besides, the environmental temperature and the mean air velocity, the magnitude of the turbulent fluctuations is important. Measured with these criteria the air movements of all buildings without air-conditioning lie within the range of thermal comfort. The air movements in most of the buildings with air-conditioning lie also in the range of thermal comfort, however, almost half of the values lie within the range of thermal discomfort or in the transitional range. This result coincides almost entirely with the results from questionaires about the thermal comfort in the tested buildings. The number of complaints about draft problems is significantly higher in air-conditioned rooms than in rooms without air-conditioning.

1. BACKGROUND OF INVESTIGATIONS

The following has been stated in the frame of a German represetative survey [1] : In air-conditioned buildings there are significantly more complaints about discomfort and health problems than in not air-conditioned buildings - and this clearly in relation with draft phenomena. To verify this statement in field research, inquiries have been made in comparable collectives in several buildings with and without air-condition and simultaneously a physical analysis of the respective indoor climate.

2. REALIZATION OF INVESTIGATIONS

2.1 Objects investigated and time of measurements

Researches were made in ten different buildings, partly with repeated measurements at different times. Table 1 contains a list of objects, mentioning the equipment with air-condition, the exact times of measurements

Object measured	with air-cond.	without air-cond.	Time of measurement	Outdoor air temp. daily mean value in °C
Bezirksamt Wedding old and new buildg. Berlin		x	December 1983	0,5
Bezirksamt Steglitz, Berlin	x		December 1983 July 1984	0,0 12,0
1. Oberschule Wilmersdorf, Berlin	x		December 1983 July 1984	-1,0 12,0
Kopernikus Oberschule Steglitz, Berlin	x		July 1984	14,0
Siemens-Gymnasium, München	x		March 1984	-1,0
Sophie-Scholl-Oberschule, Schöneberg, Berlin		x	July 1984	12,0
Grasser-Gymnasium, München		x	March 1984	-2,5
Arbeitsamt, Heidelberg	x	x	April 1984	6,0
Konzertsaal, München	x		July 1984	17,0

Table 1: Survey of objects investigated, mentioning measuring time and daily mean value of outdoor air temperature.

The outdoor air temperatures were given by the German Weather Service (Deutscher Wetterdienst).

and the respective daily average values of outdoor temperature. The indoor climate systems are in all cases induction systems with ceiling air outlets. Most of the measurements were made in offices and class rooms, in one case in a big, air-conditioned concert-hall with 630m^2 of basal surface and about 11m height.

The measurements were made during several periods "typical" for climatization of rooms: winter (December 1983), transition time (March and April 1984) and summer (July 1984). Basically the room s were tested without occupation, in case of the concert-hall with and without orchestra.

2.2 Measuring instruments used

2.2.1 Anemometer

To make an exact analysis of air movements in living quarters, it is necessary to measure air velocities with high resolution, non-directional and fast, since air movements are subject to permanent variations. Until recently, non-directional measuring of air velocities (not applying here) of 0 m/s to 0,5 m/s was practically impossible [2] . The reason herefor was a usually high temperature of the anemometer sensor of more than 100^{o}C. The self-convection produced with downward current at a velocity of up to 0,1 m/s an ambiguous (that is to say not useable) measuring signal and compared to the ascending current not tolerable differences of measuring signals (fig. 1, top). Only with the developed anemometer working with comparatively low sensor temperature of about 40^o C [3] it is possible to make non-directional measurements of low air velocities (fig.1 bottom). In paragraph 3 it is shown that especially fast changing of directions and amount of air velocity are the physical cause of draft phenomena. Therefore, a further essential requirement to an anemometer is a short time constant. The newly developed anemometer corresponds to this requirement with a time constant of 10 m/s (fig. 2).

2.2.2 Air temperature measuring device

To measure the air temperature, a customary resistor thermometer was used.

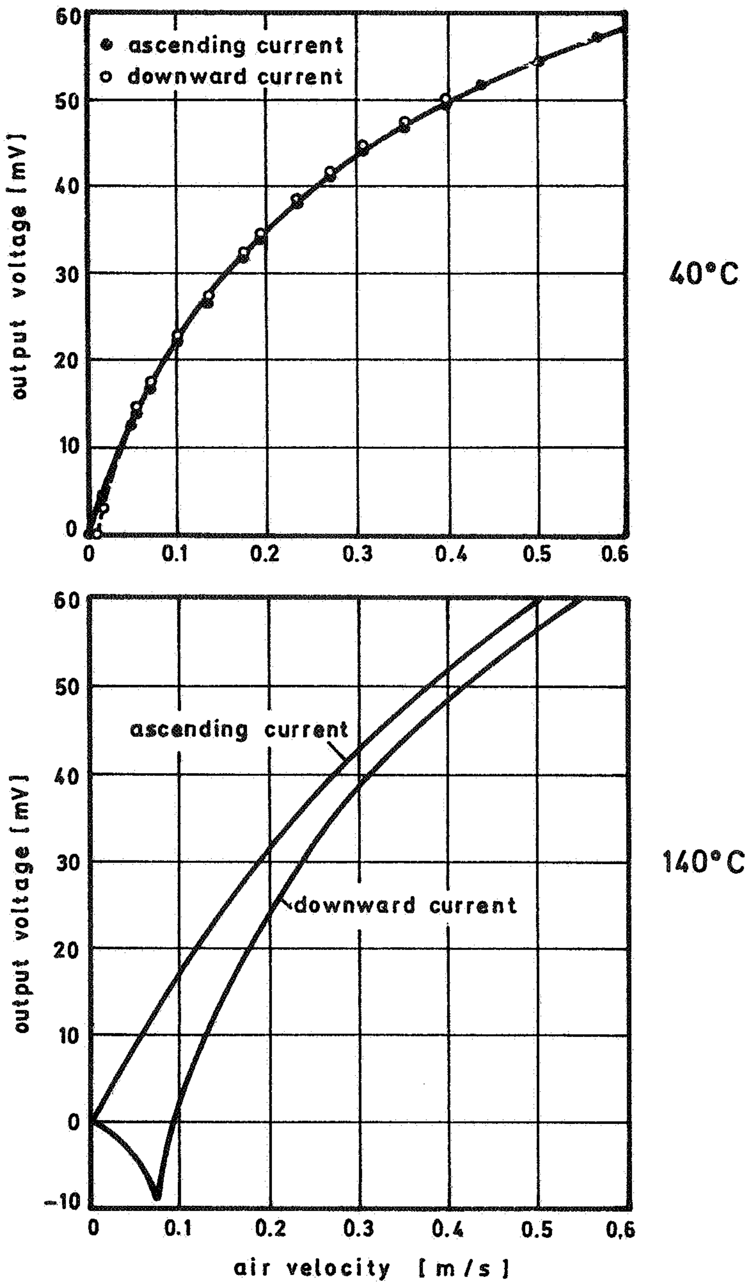
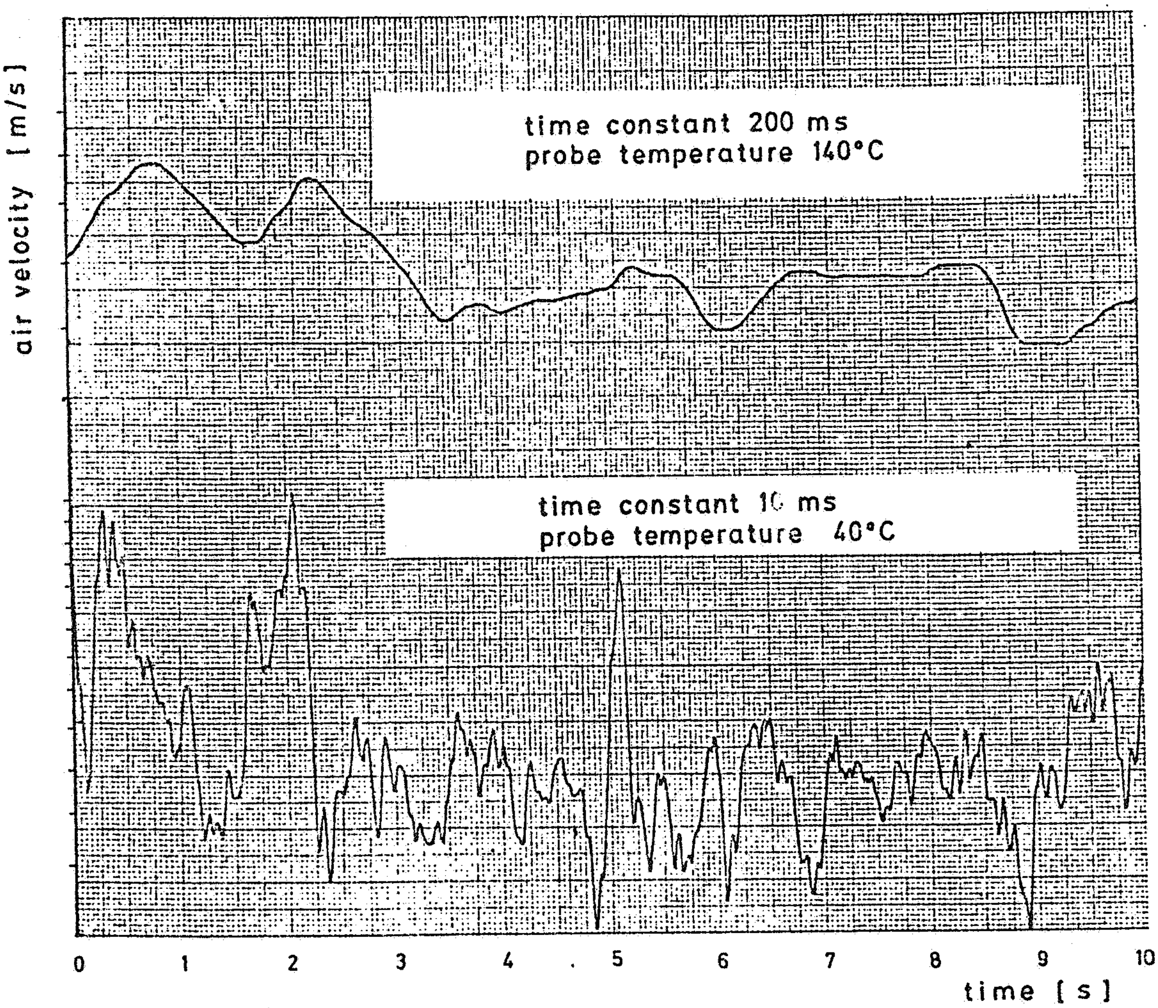


Figure 1: top: Calibration curves of a constant temperature anemometer heated up to c. 140°C.

bottom: Calibration curves of a newly developed anemometer heated up to c. 40°C, for ascending and downward air streams.



<u>Figure 2:</u> Anemometer measuring signals registered at the same time and at the same place with differing time constant.

top: older anemometer same as in fig.1 top

bottom: newly developed anemometer same as in fig. 1 bottom.

2.3 Registration of measuring values and evaluation

In the tested rooms those spots were chosen for measurement were persons stayed. In these areas measurements of air velocity and air temperature were generally taken in three levels above floor level:
O,2 m, about height of ankles
1,3 m, about height of head when seated
1,8 m, about height of head when standing.

For statistic evaluation of air velocity measurements, the measuring signals are lead to a classifier and are scanned - always during c. 5 min. - in intervals of about o,3 seconds. The relative cumulative frequency per velocity class can then be read off.These are registered in a Gauß probability paper (fig. 3, top). In a Gauß normal distribution of air velocity, the entered measuring points must be in a straight line, which was the case here. From the probability paper the corresponding air velocity mean values (5O % values) and the standard deviation (difference between 84 % and 5O % value) can be read off. The quotient of these two values is called turbulence intensity and in combination with the average value is used to judge draft phenomena (see par. 3). Both values are shown in the diagram in fig. 3, bottom.

3. EVALUATION OF RESULTS

Aim of the present researches is an evaluation of the stated air velocities with regard to draft phenomena. As mentioned above, the mean value of air velocities as well as the turbulence thereof are essential. This is explicitly explained in [4] and presented briefly in the following.

3.1 Evaluation of results considering mean value and turbulence of air velocities

When evaluating the air velocity, we presume that "draft" exists from the moment when the convective loss of heat of man becomes as great as to be disagreable and/or the surface temperature drops too low. From the physical point of view, the convective surface-heat-transfer coefficient and the surrounding temperature are responsible herefor.

In the cited report [4], first measurements at a heated artificial head with air stream to the front show a parabolic relation between product of mean air velocity

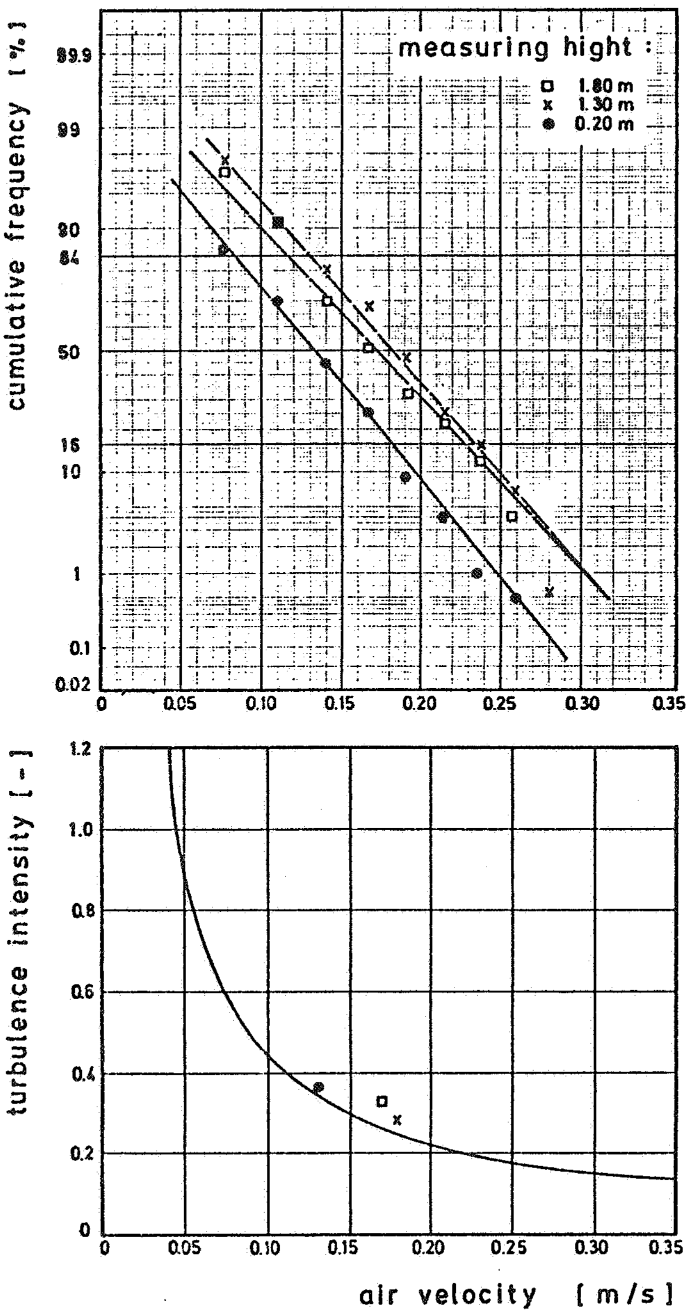


Figure 3: Cumulative frequency and turbulence intensity of air velocities measured in a room. The hyperbola from the bottom figure can be taken from figure 5, in this case a surrounding temperature of 21,5 °C.

and turbulence intensity on the one hand and the convective loss of heat (surface-heat-transfer coefficient) on the other hand (fig. 4). Taking further into consideration

- former exemplary indoor climate measurements in air-conditioned offices and clean rooms, where, for 22°C surrounding temperature a maximum admissible surface-heat-transfer coefficient of about 12 W/m²K was found [4] (dotted line in fig. 4), as well as

- the heat balance equation for dry heat loss presented in [4] ,

figure 5 can be derived. In this diagram there are - similar to fig. 4, bottom - the maximum admissible values of the convective surface-heat-transfer coefficient for the different surrounding temperatures (top margin of fig.). The curves are hyperbola, since the coefficients according to figure 4 are determined by the product of turbulence intensity and mean air velocity (right margin in fig. 5).

A comprehensive presentation of all measuring results and evaluation is shown on figure 6, top. By means of the relation shown in figure 4, the respective convective surface-heat-transfer coefficients can be computed from the values of mean air velocity and turbulence intensity. In figure 6, top, the convective surface-heat-transfer-coefficients are registered with the measured surrounding air temperatures. Distinction is made between values measured in air-conditioned and unair-conditioned buildings. Furthermore, an evaluation curve is drawn, limiting the top of still comfortable (free of draft) combinations of values. This curve is easy to be derived from figure 5.

It is obvious that the values measured in unair-conditioned rooms are lower than those in air-conditioned rooms. In the "comfortable" range (below the limiting curve) lie almost all values of unair-conditioned rooms. Not quite half of the values of air-conditioned rooms are in the "uncomfortable" range, many in height of the limiting curve, some even higher. For unair-conditioned rooms the convective surface-heat-transfer coefficients ranged between 7 W/m²K and 10 W/m²K, average about 8,5 W/m²K; for the air-conditioned rooms c. between 7 W/m²K and 15 W/m²K, average about 11 W/m²K. This result coincides with the results of investigations in the tested nine objects, saying that in rooms with air-condition there are considerably more complaints about draft than in rooms without air-condition.

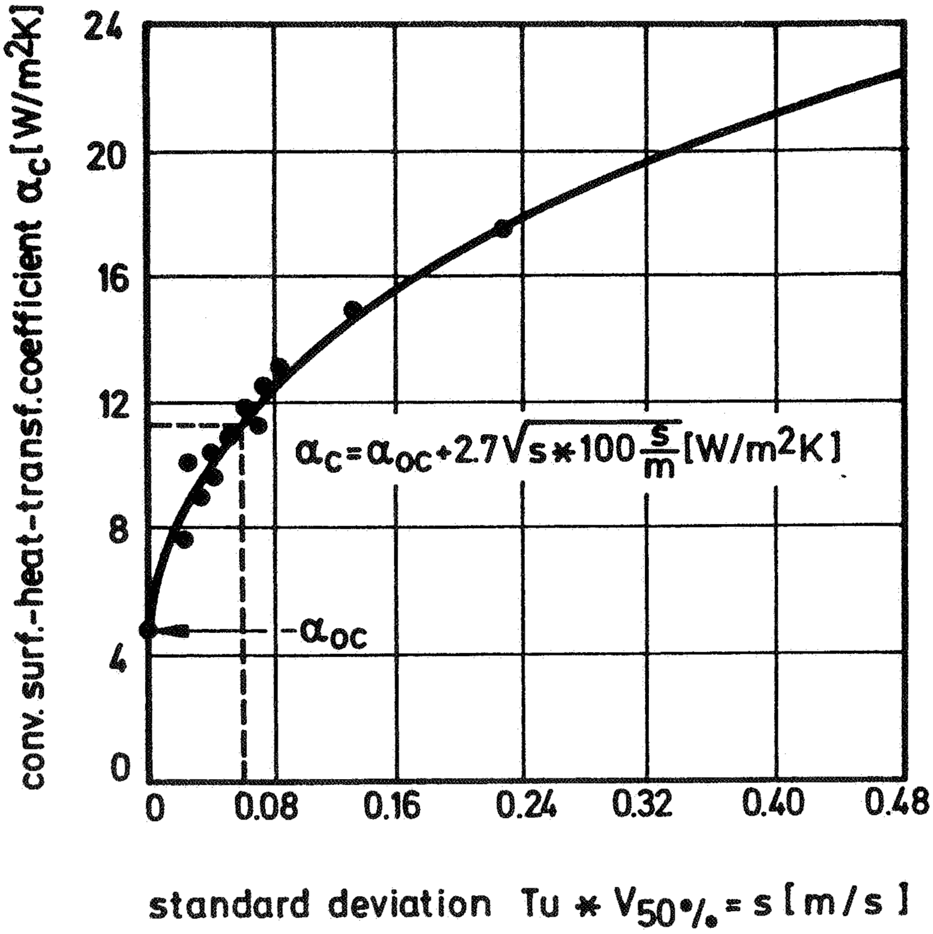


Figure 4: Measured correlation between convective surface-heat-transfer coefficient and the product of turbulence intensity and mean air velocity, i.e. the standard deviation of air motion (dots), as well as computed correlation.

α_K: convective surface-heat-transfer coeff.

s : standard deviation

α_{EK}: convective surface-heat-transfer coefficient with self-convection.

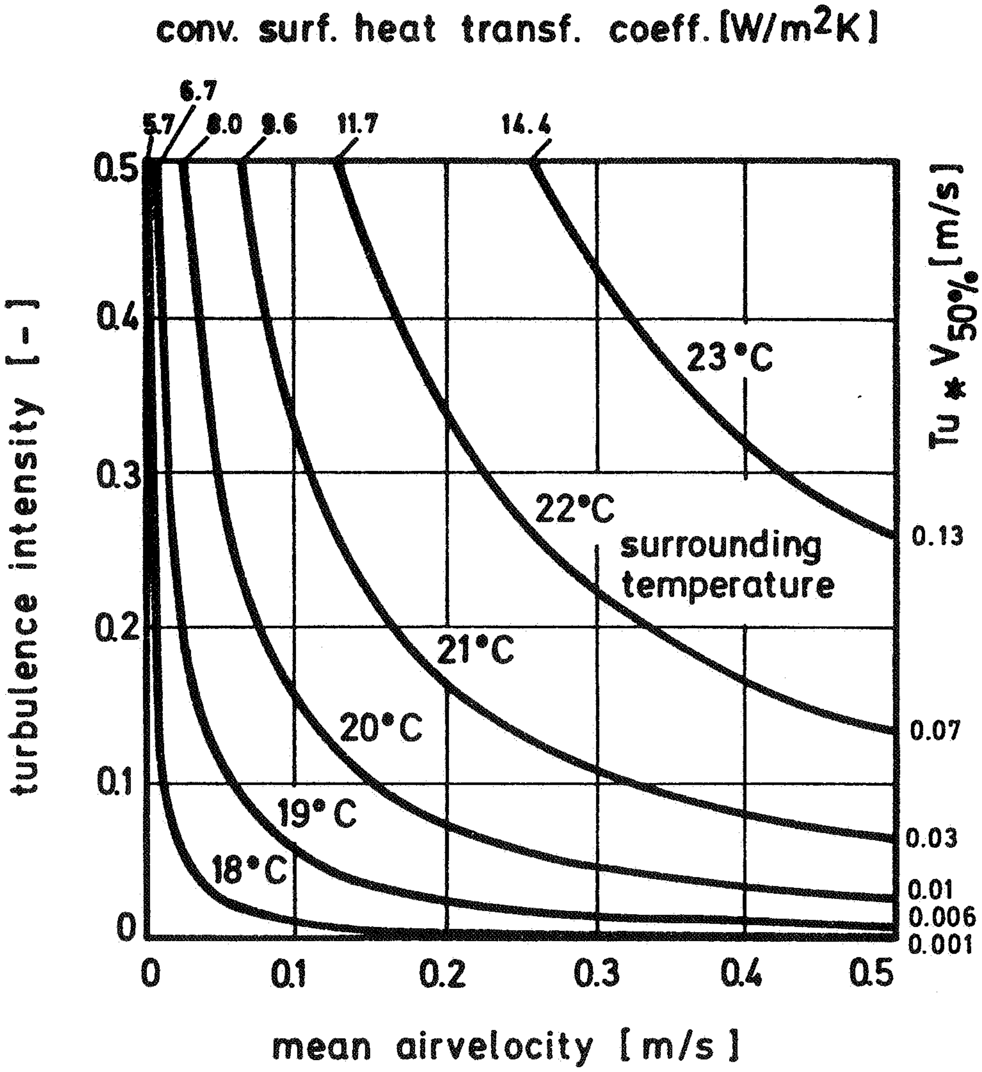


Figure 5: Correlation between turbulence intensity and mean air velocity in different surrounding temperatures. At the top margin of the figure there is the maximum admissible convective surface-heat-transfer coefficient presented in different surrounding temperatures, found on the basis of provisional measuring results in 1 .

$v_{50\ \%}$: mean air velocity or 50 %-value

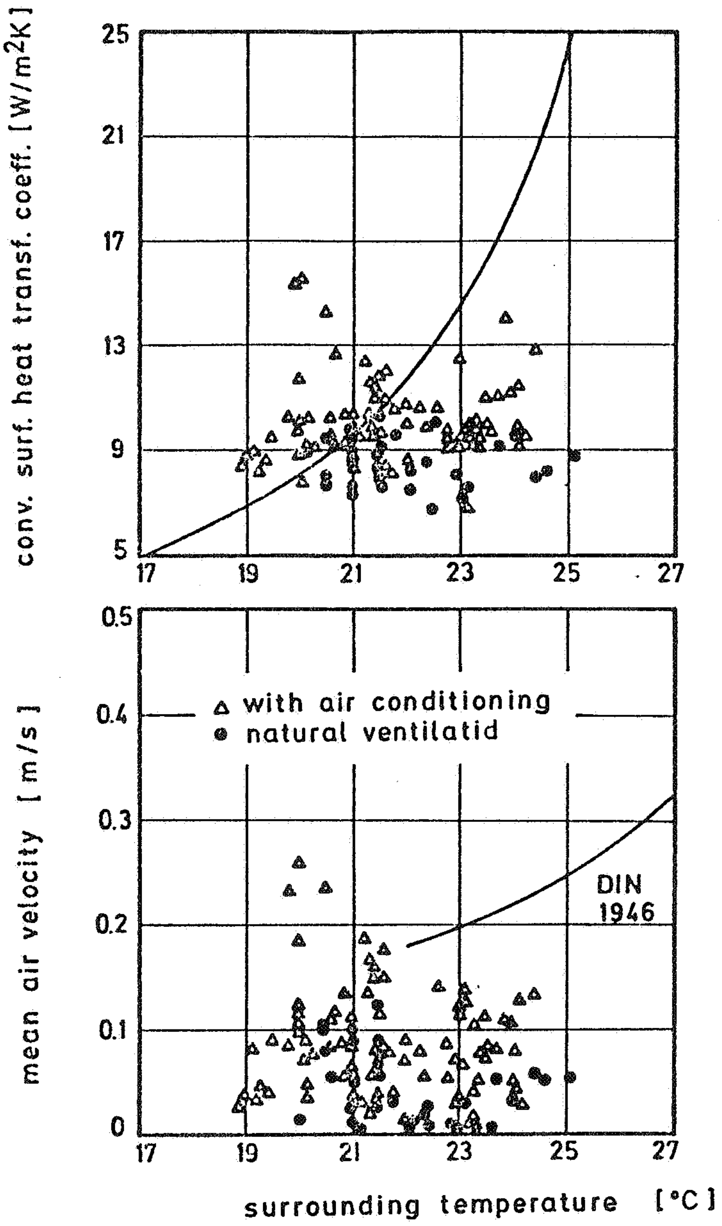


Figure 6: top: Convective surface-heat-transfer coefficients depending on surrounding temperatures, as well as evaluation curve acc. to figure 5.

bottom: Mean air velocities and surrounding temperatures, as well as evaluation curve according to DIN 1946, part 2 [4].

Complaints about draft, more frequent in summer, can be explained by the aid of figure 6. Presuming that the convective surface-heat-transfer coefficients remain basically independant of the season - the present results are confirming this - the air temperature e.g. 18°C, the maximum admissible value of 6 W/m^2K (fig.5) is surpassed in any case. However, air temperatures of 18 °C in the area of air outlets must be expected in summer.

3.2 Evaluation of results according to DIN 1946

The usual evaluation of air motions according to DIN 1946, part 2 [5] depends solely on the average air velocity and air temperature. In figure 6, the measured values and the evaluation curve according to DIN are entered in a corresponding diagram.

It can be stated that the measured values in the range of the DIN-curve, i.e. above 22°C air temperature, are admissible - in accordance with figure 6, top. All measured values with air temperatures below 22°C would be "forbidden" according to the curve. Since almost half of all measuring values are within this range of temperature, the present DIN-evaluation curve does not seem appropriate for practice. If the DIN-curve was continued to the bottom with constant incline, almost all measuring points would lie below the extended curve. This would show a more optimistic evaluation than following the curve in figure 6 top.

4. SUMMARY AND CONCLUSIONS

Measurements of air velocity and air temperature were carried out in four objects with air-condition and in six objects without air condition. The measurements were made in 60 measuring spots, in the height of 0,2 m (ankle), 1,3m (head when seated), 1,8 m (head when standing). A newly developed anemometer was used here which especially permits to analyse air motions regarding their dynamic behaviour. New test results (some still to be completed) describing the physical causes for draft phenomena were employed to examine the causal correlation between air motion and draft phenomena. Resulting evaluation criteria showed that besides the air temperature (surrounding temperature) and the temporal mean value of air motion, the turbulence intensity as well is decisive for draft phenomena.

Measured with these criteria practically all air motions in buildings without air-condition are within the comfortable range. The majority of air motions measured in buildings with air-condition is in the comfortable range. Less than half of the measuring values are in the uncomfortable range, many close to the comfort limiting curve, some clearly above. This result coincides with results of other investigations in the tested buildings, saying that in rooms with air-condition there are more complaints about draft phenomena than in unair-conditioned rooms. Other than these new criteria of comfort, the valid DIN 1946 does not consider temporal dynamic behaviour of air velocities. It must be added, that according hereto, air temperatures below 22°C would not be admissible.

Further steps have to be taken to eliminate complaints in air-conditioned buildings and from the present investigations the following conclusions can be drawn:

4.1 The criteria used up to the present for evaluation of air velocities are incomplete.

4.2 The dynamic behaviour of air motions (turbulence) must be taken into consideration.

4.3 Due to the physical test results, it seems more reasonable to apply the convective surface-heat-transfer coefficient than the air velocity as measuring unit for evaluation of draft phenomena.

4.4 The physical investigations, including the dynamic behaviour of air motions in rooms, must be completed and subtilized to confirm the provisional marginal comfort values. To this aim also psycho-physical investigations are required. Above all, there must be systematic researches to find out whether draft phenomena are the <u>sole</u> cause for complaints or whether other causes as <u>well</u> (f.i. minor air quality) have any influence.

4.5 From the technical point of view we have to find out precisely whether the complaints are due to basic deficiencies of indoor climate installations or, whether the installations do not reach the desired values i.e., whether they are badly serviced and adjusted.

REFERENCES

1 KRÖLING, P.
"Gesundheits- und Befindensstörungen in klimatisierten Gebäuden."
W. Zuckerschwerdt Verlag, München, Bern, Wien (1985).

2 MOOG, W.
"Ähnlichkeitstheoretische Überlegungen bei Raumstörungen."
Klima-Ingenieur 6 (1978), H. 11, S. 267 - 270.

3 MAYER, E.
"Entwicklung eines richtungsunabhängigen Anemometers für geringe Luftgeschwindigkeiten. Bericht B Ho3/81 des Fraunhofer-Instituts für Bauphysik."

4 MAYER, E.
"Entwicklung eines Meßgeräts zur getrennten und integrativen Erfassung der physikalischen Raumklimakomponenten."
Dissertation. Technische Universität, München (1983).

5 DIN 1946
"Raumlufttechnik. Part 2: Gesundheitstechnische Anforderungen."
Beuth-Verlag, Berlin Januar 1983.

ACKNOWLEDGEMENTS

This work was funded by the Bundesministerium für Forschung und Technologie, branch Humanisierung des Arbeitslebens.