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QUALIFICATION OF THE OCCUPIED ZONES OF DIFFERENT TYPES OF AIR SUPPLY SYSTEMS ON THE BASIS OF MEASUREMENTS

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Abstract

After the air engineering installation the presence of the required characteristics of the designed microclimate in the occupied zones of rooms has to be proved. Theoretical researches on air engineering technology and comfort have demonstrated that for the qualification of the occupied zones the measurement of some characteristics is not sufficient. The discovery of this fact has led us to carry out further measuring researches under different conditions.

For the purpose of a correct study of the above phenomena the Laboratory of Air Engineering in the Department of Building Service of the Budapest University of Technology has created a microclimate chamber, illustrated in *Figs 1* and *2*.

Keywords: ventilation, air supply system, occupied zone, measurement.

1. The Interrelation of the Occupied Zone and the Air Supply Systems

The air engineering systems consist of three subsystems. These are the following:

- ventilator / air-conditioning power station;
- ventilation shaft system;
- ventilated / air-conditioned closed space.

The subcomponents of the system bear the same operational importance. But from the point of view of the overall judgement of the system the *closed place (the room)* and within this the *occupied zone* has the priority, as the characteristics influencing the microclimate can be perceived there.

As a consequence an occupied zone dimensioned inaccurately or not dimensioned at all from the point of view of comfort can involve the whole system in a gratuitous risk.

For comfort air engineering systems the aim to be achieved with air conditioning is very simply definable. The most serviceable would be to conduct the ventilating air into the room in a way that it absorbs the heat, humidity and foiling load of the room satisfying at the same time the required characteristics concerning the microclimate of the occupied zone. Practice has shown that keeping the microclimate characteristics on the designed level does not necessarily guarantee the satisfaction of people staying in the room.

In several cases the subjective judgement of the air-condition differs from the results qualified by the microclimate factors calculated on the basis of measurements. In other words, the numerically defined PMV and PPD values [1] [5] of the measured temperature, air speed, degree of humidity, etc. did not justify the value judgement of the microclimate of people staying in the room [3].

Fig. 1. Investigation chamber of air supply system

Those experiences have called and directed the attention of scientists to further researches. Many researchers have seen the cause of differences between theory and practice in the fact that empirical equations defining the indexes of microclimate do not yet express adequately reality [5] [10]. Others have searched for further characteristics in order to make better survey processes occurring in the rooms. Different criteria were created [3] [4], the most important are the criteria draught. So beside PMV and PPD values criteria draught expressing draught effect has become justified. The combined use of both characteristics in most of the cases gives a satisfying result.

For the purpose of better air scavenging of rooms continually new and new air supply systems (ASS) have appeared [6] [9]. In these systems the spinning or inducting air inlet (e.g. the diffuse ASS, or the tangential ASS) is often used. With this air inlet method the medium speed of air reaching the room can be reduced and the starting temperature difference can be increased. These advantages are obtained with the dissipation together with the increasing of the turbulence of the current of air. At the same time research results have shown that air of high turbulence degree (Tu, %) at the same medium speed augments the draught effect [4]. This experience has its physical basis under certain conditions.

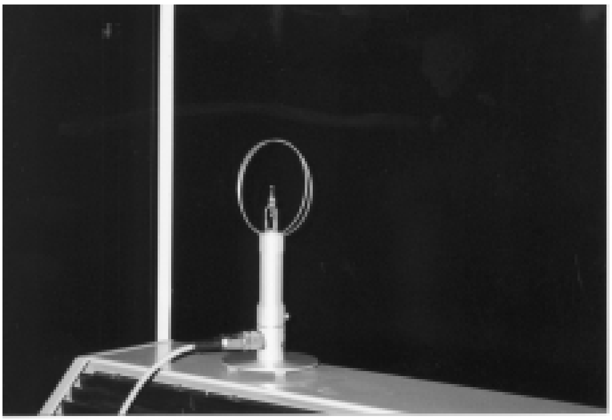

Fig. 2. Sensor of the air speed measuring system

Every body plunged into liquid or gas is surrounded by a boundary layer. This boundary layer behaves as a heat insulation. Heat flow passing through depends largely on the characteristics of the boundary layer, like thickness or nature (laminar or turbulent). It is well known that these features are influenced by the substance circulating around the body (in this case the air). If a current of high turbulence degree reaches the boundary layer surrounding the body, it helps increase heat transmission, partly by reducing the insulating laminar boundary layer. On the other hand, as the turbulent boundary layer becomes prevailing it increases the value of the heat transmission value. The specific heat flow expressed, in the case of laminar boundary layer:

$$q_{\text{lam}} = -\lambda \, \text{grad} \, t \tag{1}$$

for turbulent boundary layer:

$$q_{\text{turb}} = c\rho(u't'), \tag{2}$$

where

$(u't')$ is the medium value of the product of the multiplication of fluctuating speed and temperature.

As the $q_{lam} \ll q_{turb}$ inequality is present, on the concerned parts of the body local overcooling occurs that causes draught effect.

As a logical consequence of the above facts, besides the microclimate index numbers and the draught criteria, the Tu-degree characterising the turbulence of the current has to be indicated as well. There appeared to be two possible ways of doing this, either by asserting it in the draught criteria or by indicating it as an independent characteristic. There have been attempts for both possibilities [2]; [3]; [11]; that we try to compare in the present article.

2. Theoretical Basis of the Qualification of Occupied Zones

The sensor placed in some points of the occupied zone measures speed stochastically changing in the time (*Fig. 3*).

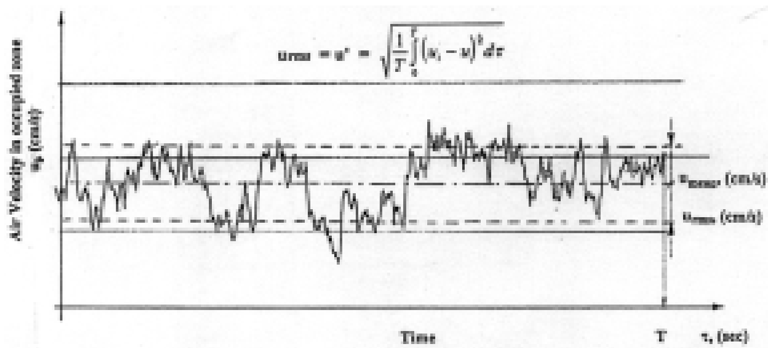

Fig. 3. Air speed measured in the occupied zone of the room

This fact is not surprising, given a turbulent current, which always contains a medium and a fluctuating element:

$$u/\tau/ = u + u', \tag{3}$$

wherein:

$$u = \frac{1}{T}\int_0^T u(\tau)\,\mathrm{d}\tau, \tag{4}$$

or, with data quantized by measurements:

$$u = \frac{1}{n}\sum_{i=1}^{n} u_i. \tag{5}$$

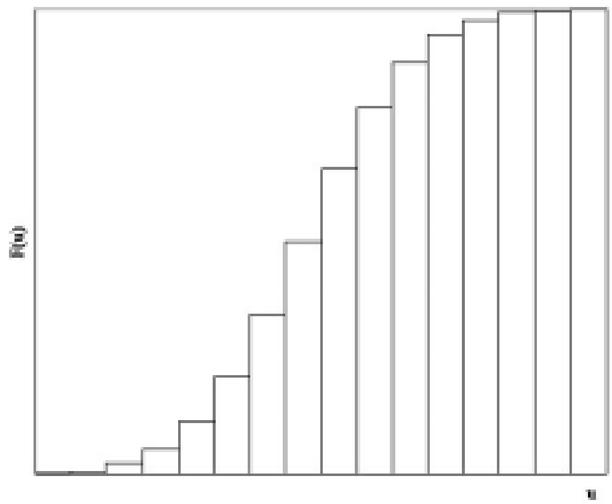

Fig. 4. Cumulated relative frequency of the measured air speed

The changing speed element is taken into consideration with its quadratic integral mean value (RMS):

$$u_{\text{rms}} = u' = \sqrt{\frac{1}{T}\int_0^T (u_i' - u)^2\, \mathrm{d}\tau}\,. \tag{6}$$

The turbulence degree of the flowing air:

$$Tu = \frac{u_{\text{RMS}}}{u} 100\% \tag{7}$$

It seemed useful to establish a relation that contains the characteristic features appearing in the above equations (u; u'; Tu).

The starting point is the cumulated relative frequency of the air speed that can be measured in the occupied zone. The frequency described on the basis of the measured values is illustrated in *Fig.* 4. On the horizontal axle the quantized values of speed, on the vertical axle the cumulated relative frequency of the air speed can be seen. The cumulated relative frequency of each quantized value shows the frequency with which the variable of probability (in our case the speed) takes the value u_i or a lower value.

On the gradually structured histogram the function of the empirical distribution of the air speed can be located with a boundary transition (*Fig.* 5). With the adequate scale distortion of the co-ordinate axles the continuous distribution graph can be converted into a straight line. This line will be the function of the characteristic air flow of the occupied zone. Its placement in the plane represents the mean scavenging speed, while its angle enclosed with the horizontal axle indicates the turbulence of the flowing air.

The description of the straight line on the $[\ln F(u)] - u$ plane is possible if two points are known. In practice we assume that the distribution of different speeds follows the normal distribution. One of the points is the inflexion of the distribution function, as its frequency value is 50%. This is at the same time the maximum of the density function derived from the distribution function. The $f(u)$ density function of the air speed is illustrated in *Fig.* 6.

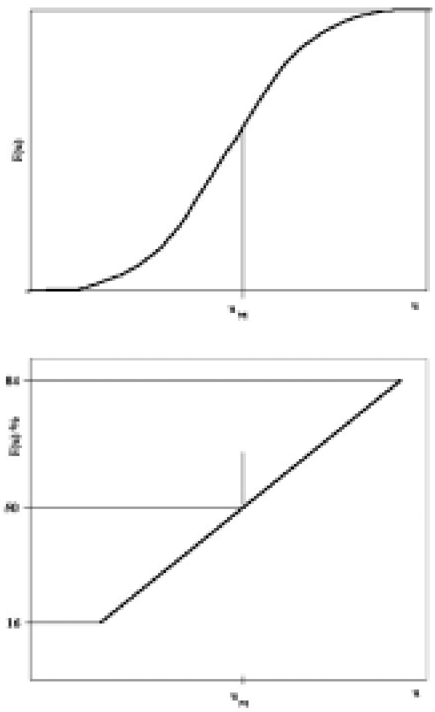

Fig. 5. Distribution Function of the Measured Air Speed

Assuming a normal distribution, relation

$$f(u) = \frac{1}{\sigma\sqrt{2\Pi}} \exp\left[-\frac{(u_i - u)^2}{2\sigma^2}\right] \tag{8}$$

expresses the density function, where the σ as variable is identical to the rms value of the changing element of the air speed, both in form and in value (u_{rms} *Eq.* (6)). This makes it possible for the other defining point of the straight line characterising the air flow to be a value in relation with this, in other words, to be a value defined by the changing element $(u - \sigma)$ or $(u + \sigma)$.

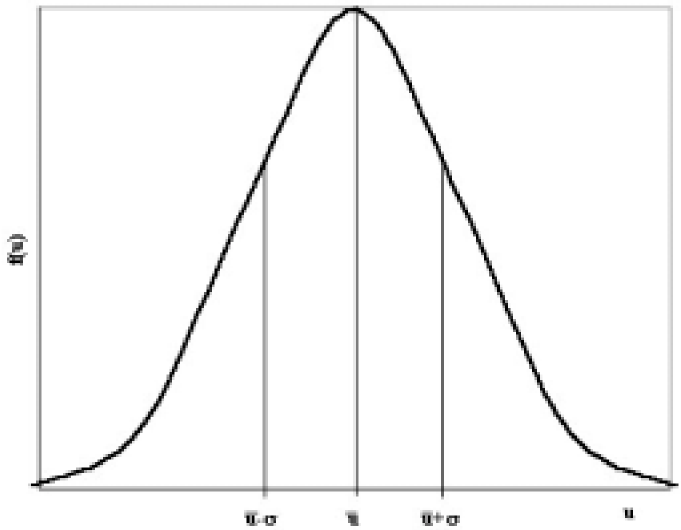

Fig. 6. Density function of the speed

The relation existing between the distribution and the density function is:

$$f(u) = \frac{\partial}{\partial u}(F(u)). \tag{9}$$

From this, the $F(u)$ function is:

$$F(u) = \int [f(u)]\,\mathrm{d}u. \tag{10}$$

Eq. (10) modified to $(u - \sigma)$ value:

$$F(u - \sigma) = \int_{-\infty}^{u-\sigma} (f(u)\,\mathrm{d}u), \tag{11}$$

wherein:

$$\int_{-\infty}^{u-\sigma} (f(u)\,\mathrm{d}u) = \frac{1}{2}\left[\int_{-\infty}^{+\infty} f(u)\,\mathrm{d}u - \int_{u-\sigma}^{u+\sigma} f(u)\,\mathrm{d}u\right]$$

it can be seen that, as $f(u)$ is a symmetrical function,

$$\int_{-\infty}^{+\infty} f(u)\,\mathrm{d}u = 1 \quad \text{and} \quad \int_{u-\sigma}^{u+\sigma} f(u)\,\mathrm{d}u = 0.683. \tag{12}$$

So the value of relation (11) is:

$$F(u - \sigma) = 0.15866 \approx 0.16$$

meaning that the air speed belonging to 16% or 84% gives the other point of the straight line. If we take $(u - 2\sigma)$ as a basis, then the values belonging to the 5% or 95% of the distribution function give the defining point.

3. Measured Data of Diffuse Air Supply System

The table below contains the data measured in the occupied zone of a measurement site. The measured site is an office belonging to category B according to EN 1752, that was designed for a diffuse air supply system. The inlet of the ventilating air is above the occupied zone, through a swirl ceiling diffuser. The exhausts of the leaving air are also ceiling plate diffusers under the ceiling.

Table 1. Activity: 1.1 met, Iclo = 0.9, $\varphi = 40\%$

Measur-ing point	u	Tu	t	u_{84}	u_{rms}	PMV	PPD	PD	Note
	cm/s	%	°C	cm/s	cm/s	–	%	%	–
1	12	38	23.9	16.6	4.6	0.35	7.6	9.4	acceptable
2	14.8	21	23.9	17.9	3.1	0.3	6.9	10.4	acceptable
3	13.8	31	24.3	18.1	4.3	0.42	9.1	10.3	acceptable
4	**34.8**	**36**	**23.8**	**47.3**	**12.5**	**0**	**5.0**	**38.0**	not acceptable
5	15.5	52	24.9	23.6	8.1	**0.54**	**11.1**	13.8	not acceptable
6	8.9	29	25	11.5	2.6	**0.66**	**14.1**	5.0	not acceptable
7	8.4	33	24.7	11.2	2.8	**0.6**	**12.6**	5.4	not acceptable
8	11.3	33	24.9	15.0	3.7	**0.6**	**12.7**	7.1	not acceptable
9	25	34	24.1	33.5	8.5	0.23	6.1	**22.9**	not acceptable
10	20.4	10	23.9	22.4	2.0	0.22	6.0	12.1	acceptable
11	24.1	39	23.9	33.5	9.4	0.18	5.6	**23.8**	not acceptable

The table illustrates the output data of an automatic measuring system. The sensor of the measuring system was a sound of high sensibility and low inertness, that was placed in the occupied zone of the room (*Fig.* 2). The measuring system gave the results according to the fixed programming indicated in the heading of the table.

The graphical processing of the measured results is illustrated in *Fig.*7. On the basis of the figure and the data of the table we can draw the following conclusions:

1. The measuring point number '4' illustrates well the necessity of combined application of the index numbers of the microclimate and the draught criteria. The 5% for PPD value forecasts ideal microclimate, but the high PD draught risk shows the unacceptableness of the air-condition.

2. In one of the measuring points the medium scavenging speed of the occupied zone did not exceed the limit value defined in draught criteria. Still the subjective judgement of the occupied zone expressed some dissatisfaction.
3. The medium scavenging speed of the zone showed dissipation in a wide interval, that is:

$$8.4\ \text{cm/s} < u < 34.8\ \text{cm/s}.$$

   What brings us to the conclusion that the scavenging of the occupied zone is not homogeneous, is that active and dead zones alternate on that part of the room. That means that the designed diffuse air supply system has not been produced.
4. The directional factor of the lines characterising the occupied zone shows a well defined tendency on $f(u) - u$ plane. In the direction of bigger medium speeds the angle enclosed with the horizontal axis diminishes. This fact indicates the increasing of the fluctuating speed element. But it does not necessarily lead to the increasing of the turbulence degree.

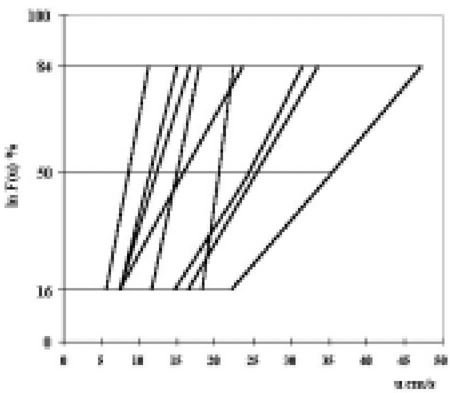

Fig. 7. Measuring results

Summarising, we can conclude that from the point of view of the draught effect the average air speeds are acceptable. But the transformed distribution function shows the inhomogeneous character of the occupied zone that appears both in the scavenging and the turbulence effect. Both effects influence the comfort level of the room, so the overall judgement of the air-conditioning system. The distribution function referring to the speeds illustrates the qualifications of the occupied zones.

Researches both in laboratories and on site have drawn the attention to the fact that the human reaction to effects influencing him are not yet sufficiently clarified. Further questions arise concerning related branches of science. For example, it seems necessary to continue studying from a physiological point of view whether a current of air of high turbulence degree or of a relatively high fluctuating speed element causes unpleasant sensation in people.

List of Designations

c specific heat;
$F(u)$ distribution function;
$f(u)$ density function;
Iclo insulating capacity of clothing;
PMV predicted mean vote;
PPD predicted percentage of dissatisfied;
PD percentage of dissatisfied;
q heat flow;
u medium speed;
u_{rms} fluctuating element of speed;
t air temperature;
t' fluctuating value of air temperature;
T judging time;
Tu turbulence degree;
λ heat transmission factor;
σ dissipation;
t time;
ρ substance density;
φ relative degree of humidity;

Inferior Letters:

i momentary value;
lam laminar;
turb turbulent;

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