AIC 1499

FIELD MEASUREMENTS OF CHARACTERISTICS OF TURBULENT AIR FLOW IN THE OCCUPIED ZONE OF VENTILATED SPACES

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Introduction

Draught, defined as unwanted local cooling of the human body caused by air movement, is one of the most common causes of complaint in ventilated or air conditioned spaces.

The air flow in ventilated spaces is usually turbulent, i.e. the air velocity is fluctuating. The fluctuating air flow may be characterized by the mean velocity and the turbulence intensity, i.e. the standard deviation of the velocity devided by the mean velocity. Fanger and Pedersen (1), exposing subjects to well-defined periodic velocity fluctuations in a climate chamber, found that the mean velocity as well as the velocity fluctuations can cause discomfot. In real spaces, however, velocity fluctuations are not periodic, but random. This was demonstrated in a field study by Thorshauge (2) who measured velocity fluctuations in several ventilated spaces with no or low thermal load. He found a linear relationship between the mean velocity and the standard deviation of the velocity. The turbulence intensity was 20-50%. Fanger and Christensen (3) exposed later one hundred subjects to an air flow with similar fluctuations and established a draught chart predicting the percentage of dissatisfied as a function of air velocity and temperature. It is essential to study whether the turbulence intensity and other flow characteristics vary more in practice than assumed in the draught chart.

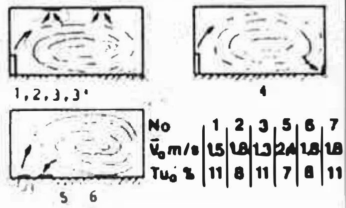
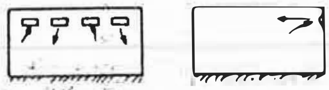
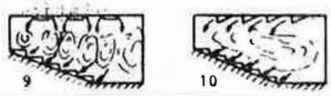
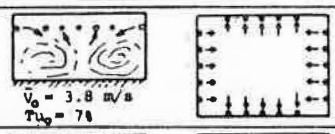
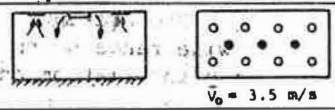
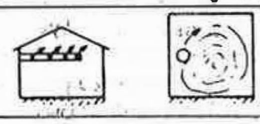
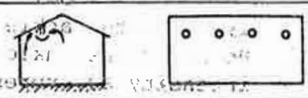
It was therefore decided in this study to investigate the characteristics of turbulent air flow occurring in a wide range of spaces with different size, thermal load and air distribution system, utilizing modern measuring technique.

Experimental conditions

The measurements were performed in different ventilated spaces at different conditions. The spaces were selected to cover typical locations and kinds of outlets and exhaust devices in ventilated spaces in practice. The main characteristics of the ventilated spaces are given in Table 1.

In each space, velocity probes were placed at least in six locations in the occupied zone. At each location, measurements were taken at four heights: 0.1, 0.6, 1.1 and 1.7 m above the floor level as recommended in the ISO standard (4).

Table 1. Main characteristics of the various ventilated spaces.

No. & Symbol	Type of Space	Floor Area (m^2)	Space Volume (m^3)	Air Change (1/h)	Type of Ventilation System Mean Velocity $\bar{V}_0$ and Turbulent Intensity Tu_0 are Given
1 ◪	office	13	34	9.5	
2 ⌖	office	29	76	6.4	
3 ⌀	office with/	56	148	3.0	
3' ◆	without nozzles			7.4	
4 ♁	school room	62	155	3.3	
5 ■	school room	78	210	4.6	
6 ■	school room	78	225	2.3	
7 ◊	swimming hall	1650	15000	1.6	
8 ▲	school room	58	210	4.0	
9 ▷	small auditorium	74	361		
10 ◆	large auditorium	187	850		
11 △	meeting room	108	324	7.4	
12 ⌖	meeting room	39	109		
13 ×	industrial hall	52	182		
14 □	large industrial hall	144	504		
15 ■	large industrial hall	223	771		
16 ▽	lecture room	50	150		
17 ▼	lecture room	50	150	12.5	
18 ⧫	lecture room	50	150		
19 ⊙	lecture room	50	150	15.0	
20 +	with thermal load	50	150		
21 ○	clean room with laminar flow	42	160	25.0	
22 ●	clean room with turbulent flow	146	378		

The measurements were performed utilizing a new DANTEC Multichannel flow analyzer - type 54N10 and a new Brüel & Kjaer Indoor Climate analyzer - type 1213. The two instruments work with omnidimensional temperature compensated probes. Thirteen probes were calibrated by the producer firms. The signals from the B&K probe and some of the DANTEC probes were recorded on a B&K taperecorder - type 7005 and calculated by a B&K signal analyzer - type 2031. With this equipment the mean velocity, the standard deviation of the velocity, a histogram of the velocity, frequency spectra of the velocity fluctuations and the air temperature were measured.

Results

This paper presents preliminary data on mean velocity and standard deviation of the velocity. Measurements in more than 500 points in the investigated spaces were taken. Twenty percent of these measurements had a mean velocity less than 0.05 m/s, and they were ignored since the calibration of the probes does not apply at such low velocities. The standard deviation as a function of the mean velocity in all investigated places at head level (1.1 m) and ankle level (0.1 m) is shown in Figs. 1 and 2. Symbols of each investigated space are shown in Table 1. It is obvious that there is a substantial variability in the turbulence intensity. At head level the turbulence intensity varied around 20-55% which is slightly lower than Thorshauge found and lower than in the draught experiments of Fanger and Christensen (3). At the ankle level the turbulence intensity varies more, up to 70%, but the regression line fits well with the previous studies of Thorshauge (2) and Fanger and Christensen (3). The regression equations on the relationship between standard deviation and mean velocity at each of the four heights are shown in Table 2.

Discussion

The present study comprises around 500 velocity measurements in a wide range of spaces ventilated in different ways. It provides comprehensive information on the mean velocity and the turbulence intensity occurring in practice. The regression line for head height (1.1 m) in Fig. 1 passes nearly through the zero point indicating that the standard deviation of the velocity is proportional with the mean velocity. This is more likely than the regression line of Thorshauge (2) based on fewer points and showing a slightly higher turbulence intensity. The regression line for the ankle level fits well with the experiments of Thorshauge. Both for the ankle and head level the variability of the turbulence intensity as expressed by the correlation coefficient were similar in the two studies. It is obvious that there was a considerable variation in the turbulence intensity from space to space and from point to point. At head level the turbulence intensity varied between 20 and 55%, and this is quite similar to the conditions during the experiments of Fanger and Christensen (3) resulting in the draught chart. At ankle level the turbulence intensity reached values up to 70%.

The draught chart was based on studies where subjects were exposed to velocities fluctuating in a manner which was similar to the practical conditions identified in the present field study. Still the impact of turbulence intensity as such on man's sensation of draught has not yet been determined. Such studies where subjects are exposed to turbulence intensity up to 70% at the same mean velocity are recommended.

The investigated spaces may be separated roughly in two groups. The first group with the air flow directed tangential into the space (cases 1,2,3,3',4,5,6,7,10,13 from Table 1) and the second group (cases 9,11,12 from Table 1) where the air is flowing more directly towards the occupied zone. In the spaces of the first group decreasing of the mean velocity and increasing of the turbulent intensity when the level from the floor increases were observed. In the second group increasing of the mean velocity and decreasing of the turbulent intensity when

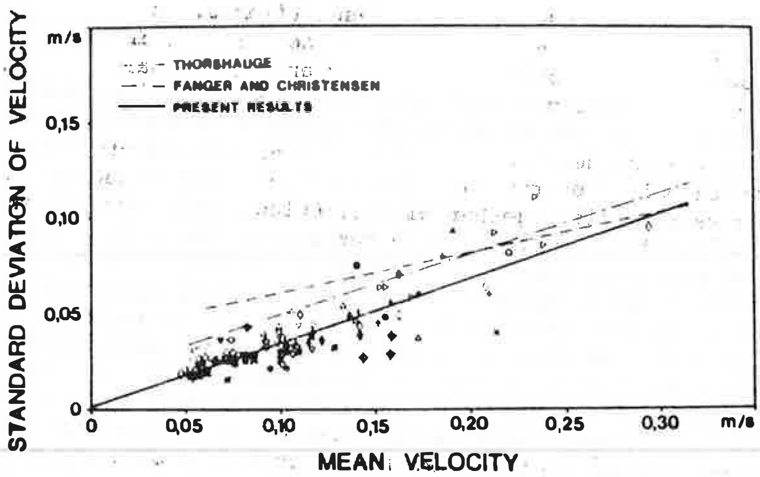


Fig. 1. Standard deviation of the velocity as a function of the mean velocity at head level (1.1 m above floor). For comparison is shown the regression line for the field study of Thorshauge (2) and the line showing the conditions to which Fanger and Christensen's (3) subjects were exposed.

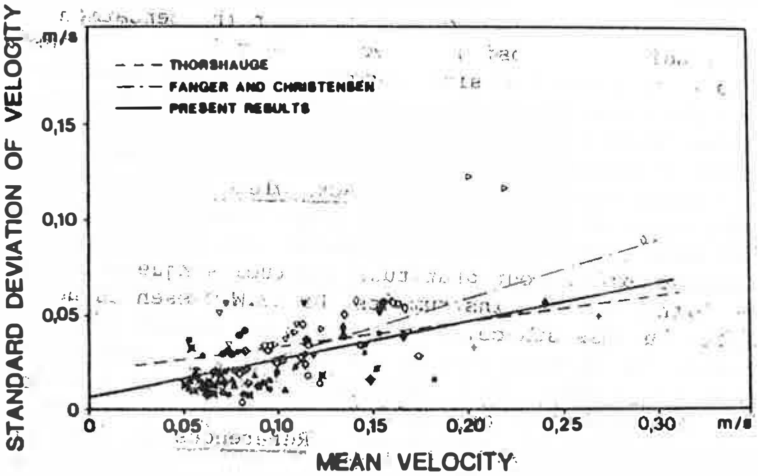


Fig. 2. Standard deviation of the velocity as a function of the mean velocity at ankle level (0.1 m above floor). For comparison is shown the regression line for the field study of Thorshauge (2) and the line showing the conditions to which Fanger and Christensen's (3) subjects were exposed.

Table 2. Regression equations calculated for the standard deviation of the velocity (RMS) as a function of the mean velocity ($\bar{V}$).

Measuring height	Regression equation	Coefficient of correlation
0.1 m	$RMS = 0.191 \cdot \bar{V} + 0.0078$	0.6680
0.6 m	$RMS = 0.330 \cdot \bar{V} + 0.0021$	0.9122
1.1 m	$RMS = 0.328 \cdot \bar{V} + 0.0021$	0.8372
1.7 m	$RMS = 0.266 \cdot \bar{V} + 0.0032$	0.8199

the level from the floor increases (from 0.1 m to 1.7 m). Further studies are recommended on the impact of the air distribution system in the space on the turbulence intensity and other characteristics of the air flow in the occupied zone.

The frequency analysis of the velocity fluctuations revealed that the turbulent energy was spread up to 10 Hz in dependence of the ventilated space. This together with turbulent length scales in all ventilated spaces will be analyzed in a future paper.

Conclusions

Air velocity characteristics were measured at 500 points in the occupied zone of ventilated spaces. The relationship between the mean velocity and the standard deviation was found at four heights.

The turbulence intensity varied from 10% to 70% at ankle level (0.1 m) and from 20% to 55% at head level (1.1 m). This is similar to the experimental conditions during which the draught chart by Fanger and Christensen (3) was established.

The impact of turbulence intensity on the sensation of draught should be studied by exposing subjects to air flow with constant mean velocities and turbulence intensities varying up to 70%.

Acknowledgements

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References

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SUMMARY

H.Hanzawa, A.K.Melikow, P.O.Fanger: Field measurements of characteristics of turbulent air flow in the occupied zone of ventilated spaces. Characteristics of the air velocity were measured at 500 points in the occupied zone of 20 typically ventilated spaces. A relationship between the mean velocity and the standard deviation was found at four heights above the floor. The turbulence intensity varied from 10 to 70% at ankle level (0.1 m) and from 20 to 55% at head level. This is similar to the experimental conditions under which the draught chart by Fanger and Christensen was established. The impact of turbulence intensity on the sensation draught should be studied by exposing subjects to air flows with constant mean velocities and turbulence intensity varying up to 70%.

KURSFASSUNG

H.Hanzawa, A.K.Melikow, P.O.Fanger: Feldmessungen von charakteristika der turbulenten luftströmung in dem besetzten Teil von belüfteten Räumen. Charakteristika der Luftströmungsgeschwindigkeit wurden in 500 Punkten im besetzten Teil von 20 normal belüfteten Räumen gemessen. Eine Beziehung zwischen der Durchschnittsgeschwindigkeit und der Standardabweichung wurde in vier Höhen über dem Fussboden festgestellt. Die Turbulenzintensität lag in Fussknöchelhöhe (0,1 m) zwischen 10 und 70% und in Kopfhöhe zwischen 20 und 55%. Dies entspricht den Versuchsbedingungen, unter denen das Zugdiagramm von Fanger und Christensen erstellt wurde. Die Bedeutung der Turbulenzintensität für die Zugempfindung sollte dadurch untersucht werden, dass man Versuchtpersonen Luftströmungen mit konstanten Durchschnittsgeschwindigkeiten und Turbulenzintensität bis zu 70% aussetzt.

RÉSUMÉ

H.Hanzawa, A.K.Melikow, P.O.Fanger: Mesures de champ des caractéristiques du courant d'air turbulent dans la zone occupée d'espaces ventilées. Les caractéristiques de la vitesse de l'air ont été mesurées à 500 points dans la zone occupée de 20 espaces typiques ventilés. On a trouvé une relation entre la vitesse moyenne et la déviation standard à quatre niveaux au-dessus du plancher. L'intensité de turbulence a varié entre 10 et 70% au niveau des chevilles (0.1 m) et entre 20 et 55% au niveau de la tête. Cela est similaire aux conditions d'essais dans lesquelles a été établi le diagramme de courant d'air, par Messieurs Fanger et Christensen. L'action de l'intensité de turbulence sur la sensation de courant d'air devait être étudiée en exposant des sujets à des courants d'air à des vitesses moyennes constantes et à une intensité de turbulence variant jusqu'à 70%.