#4137

ROOM
-VENT
'90

Method for air velocity calculation in the occupied zone of a ventilated industrial hall

A2

S. Mierzwinski
W. Nawrocki
Z. Trzeciakiewicz
Institute of Heating, Ventilation and Air Protection
Silesian Technical University
Gliwice, Poland

METHOD FOR AIR VELOCITY CALCULATION IN THE OCCUPIED ZONE OF A VENTILATED INDUSTRIAL HALL

S.Mierzwiński, W.Nawrocki, Z.Trzeciakiewicz
Institute of Heating, Ventilation and Air Protection
Silesian Technical University
Gliwice, Poland

Distribution of ventilating air, particularly in industrial objects, is substantially affected by the shape and the size of the room, location of the air inlets and their equipment, the kinetic energy of the supply air streams and the energy of disturbing convective streams at the surfaces of the room partitions. When the distribution of the ventilating air is to be improved it is necessary to combine the effects of possibly all the factors influencing air parameters in the occupied zone. The solution of the problem has been searched for many years while the research has been carried out :

- by means of mathematical models of the occurring phenomena, where numerical methods are employed
- by means of natural scale experiments or tests in physical scale models of ventilated objects.

In the case of complex analysis of factors influencing the occupied zone conditions, physical scale modelling is considered as toilsome. However, model tests, understood as a series of adequate experiments, make it possible to determine a model of the tested process. When considering the aplication of the experiment design method, the number of experiments and the time consumption may be substiantially limited.

The paper presents the tests and analyses carried out by means of this method. The acquired functions describing the tested phenomenon may be applied also to calculation of various cases within the assumed range of changes of the input parameters without any further experiments.

2. Assumptions for tests.

In order to analyze the air flow in the physical model it was assumed that the mean velocity in the occupied zone and its spatial distribution are mainly affected by:

- Supply stream velocity, u_n
- Distance between the inlets, s
- Direction of the supply streams, flowing out of the inlets , α_n
- Excess of the supply air temperature, Δt_n

The scale of the physical model was 1:7.5 (Fig.1). The model corresponded to a section of an industrial hall, 15 m high; the bay width was 18 m. The inlets were placed at the height of 3.5 m. The inlets of square cross-section 0.4 * 0.4 m were equipped with vertical directing blades, parallel to the flow direction and generated orderly streams. Output openings were placed at the same level as the inlets. There were not any heat sources inside the hall.

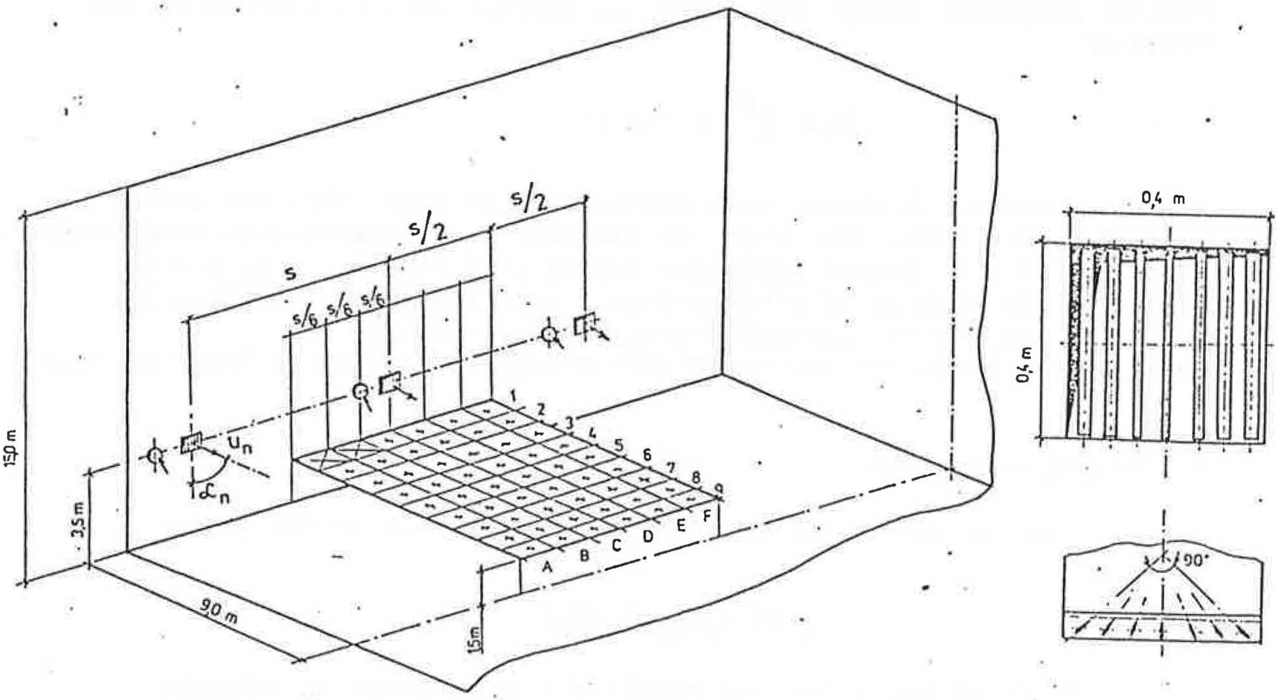

Fig.1. The values of u_n, s, α_n, Δt_n changing within the ranges given in Chapter 4.

3. Experiment design

Tests of ventilation processes carried out by means of the experiment design method are most often based on 2^n factorial experiment, complete or fractional, or on central composite design. 2^n factorial experiment yields a linear description of the tested phenomenon. For coded values of 3 variables the function describing the phenomenon will be the first order polynomial:

$$y' = k_0 + k_1x_1 + k_2x_2 + k_3x_3$$

The central composite design yields for 3 coded variables the second order polynomial as follows:

$$y' = k_0x_0 + k_1x_1 + k_2x_2 + k_3x_3 + k_{11}x_1^2 + k_{22}x_2^2 + k_{33}x_3^2 +$$
$$+ k_{12}x_1x_2 + k_{13}x_1x_3 + k_{23}x_2x_3$$

The number of necessary observations is different for the two of the designs. For 2^n factorial it is equal $N = 2^m$ where m is the number of variables. Thus, for 3 variables, 8 or 4 measurement series are necessary for complete and fractional 2^n factorial experiment, respectively. For central composite design the number of observations is defined by the relation:

$$N = 2^m + 2m + 1$$

For 3 variables, 15 measurement series must be made. When the number of variables increases, the ratio of the number of observations necessary for 2^n factorial and central composite desing gets smaller. E.g. for 4 variables the numbers of observations are 16 and 25 for complete 2^n factorial and central composite design, respectively.
Mathematical basis for the experiment design method can be found in (1,2).

4. The scope of tests.

The following relation was to be determined in the tests:

$$\bar{u}_i = f(s, u_n, \alpha_n, \Delta t_n)$$

Tests of the effect of supply air temperature on velocity distribution in the occupied zone require observations in thermally steady-state conditions and therefore models where heat loss streams may be changed.
Such the tests were carried out previously and their results prove that in the considered parameter range such the relation is of relatively little significance (3,4).
The values considered as x-variables were changed within the following ranges:
For central composite design:
- Distance between the inlets: $s \in \langle 2.5; 6.37 \rangle$
- Supply velocity: $u_n \in \langle 2.5; 12.5 \rangle$
- Supply direction: $\alpha_n \in \langle 0; 40 \rangle$

For 2^n factorial:
$s \in \langle 2.84; 6.03 \rangle$
$u_n \in \langle 3.39; 11.61 \rangle$
$\alpha_n \in \langle 3.55; 36.45 \rangle$
Velocity in the occupied zone was measured at the level of 1.5m above the floor.

5. Results of the tests.

In order to estimate the results of the tests of air velocity distribution in the occupied zone the following values were determined:
- Probability P_{u1} of the air velocity occurrence within the range from 0.15 to 0.35 m/s, which is considered as conclusive from the point of view of thermal comfort, at the level of 1.5 m above the floor.
- Probability P_{t1} of the temperature occurrence within the range from t_i-1K to t_i+1K at the level of 1.5 m.
- Difference Δt of mean temperatures at 2 levels: 1.5 m and 0.15 m.

The results are presented in Fig.2 and in Table 1 .
For $s = 6m$, $\alpha_n = 0°$ and for various air supply velocities, Fig.2 presents frequencies of the air velocity occurrence in the occupied zone in

isothermal and non-isothermal conditions. The mean velocity interval in the occupied zone of industrial halls 0.15-0.35 m/s, which is of importance for the feeling of thermal comfort conditions, is also denoted.

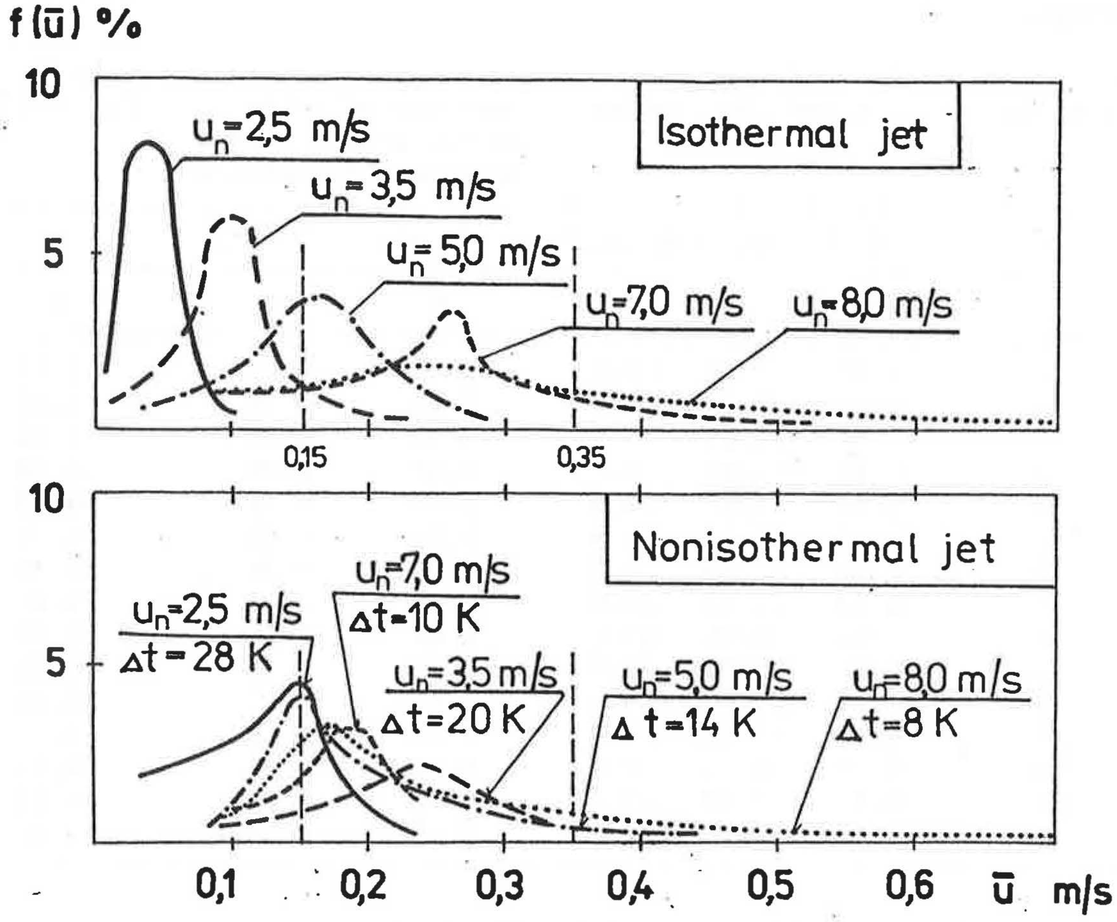

Fig.2 Frequency functions of velocity at the level 1.5m at isothermal and non-isothermal supply of air.

Table 1. Results of statistical analysis of distributions of parameters $\bar{t}$ and $\bar{u}$ at the level 1.5m in non-isothermal conditions.

Air supply velocities	2.5	3.5	5.0	7.0	8.5
P_{u1} %	26.0	70.0	61.0	64.0	51.0
P_{t1} %	91.0	82.0	96.0	83.0	86.0
Δt K	3.7	1.9	0.4	1.4	0.8
$\bar{t}_1$ C	17.5	17.3	15.4	15.7	15.6

Table 1 presents the values of probabilities of the velocity and temperature occurrence in the occupied zone while air is supplied with different velocities and the temperature excess is up to 8.5 K.

The values of mean velocities in the occupied zone, calculated on the basis of measurement results of each observation appear in Tables 2 and 3 in their 5th columns.

Table 2. Measurement and calculation results of the central composite design.

observation	x-variable values			average velocity in the occupied zone measured	calculated	$(\bar{u}_i - \bar{u})$
m	s, m	u_n, m/s	α_n,°	$\bar{u}_i$, m/s	$\bar{u}$, m/s	
1	2	3	4	5	6	7
1	2.84	3.40	3.5	0.06	0.07	-0.01
2	6.03	3.40	3.5	0.10	0.15	-0.05
3	2.84	11.60	3.5	0.26	0.29	-0.03
4	6.03	11.60	3.5	0.47	0.39	0.08
5	2.84	3.40	36.5	0.05	0.14	-0.09
6	6.03	3.40	36.5	0.08	0.05	0.03
7	2.84	11.60	36.5	0.36	0.31	0.05
8	6.03	11.60	36.5	0.24	0.24	0.0
9	2.50	7.50	20.0	0.24	0.18	0.06
10	6.37	7.50	20.0	0.13	0.18	-0.05
11	4.44	2.50	20.0	0.03	0.00	0.03
12	4.44	12.50	20.0	0.22	0.24	-0.02
13	4.44	7.50	0.0	0.19	0.18	0.01
14	4.44	7.50	40.0	0.14	0.13	0.01
15	4.44	7.50	20.0	0.08	0.10	-0.02

Table 3. Measurement and calculation results of the complete and fractional 2^n factorial experiment.

observation	x-variable values			average velocity in the occupied zone measured	calculated	$(\bar{u}_i - \bar{u})$
m	s, m	u_n, m/s	α_n,°	$\bar{u}_i$, m/s	$\bar{u}$, m/s	
1	2	3	4	5	6	7
Complete experiment:						
1	2.84	3.39	3.55	0.06	0.07	-0.01
2	6.03	3.39	3.55	0.10	0.11	-0.01
3	2.84	11.61	3.55	0.26	0.33	-0.07
4	6.03	11.61	3.55	0.47	0.37	0.10
5	2.84	3.39	36.45	0.05	0.03	0.02
6	6.03	3.39	36.45	0.08	0.07	0.01
7	2.84	11.61	36.45	0.36	0.29	0.07
8	6.03	11.61	36.45	0.24	0.33	-0.09
Fractional experiment:						
1	2.84	3.39	36.45	0.05	0.08	-0.03
2	6.03	3.39	3.55	0.1	0.1	0.0
3	2.84	11.61	3.55	0.26	0.26	0.0
4	6.03	11.61	36.45	0.24	0.27	-0.03

Table 4
Comparison of measurement and calculation results for the central composite design, complete and fractional 2^n factorial.

Type of experiment	Mean velocity in the occupied zone		$(\bar{u}_i - \bar{u})$	$\sqrt{D^2}$
	$\bar{u}_i$, m/s	$\bar{u}$, m/s		
1	2	3	4	5
Central composite design	0.08	0.1	-0.02	0.0768
Complete 2^n factorial	0.08	0.25	-0.15	0.0837
Fractional 2^n factorial	0.08	0.18	-0.08	0.0787

6. Analysis of the results

The results prove that the probabilities of the occurrence of the required velocities, P_{ui}, are different and vary from 26% to 70% while the probability of the temperature occurrence within the assumed range of changes ±1K is more than 80% for all the variants (Fig.2, Table 1). According to Fig.2 velocity distributions were flattened for all the tested cases of non-isothermal air stream supply when compared with isothermal conditions. At the same time, for supply velocities up to 5 m/s, the probability of the velocity occurrence within the range 0.15-0.35 m/s increased, while it decreased for the values higher than 5 m/s.

From the point of view of uniformity of temperature distribution at the level 1.5 m, all the tested variants are characterized by the probability of the temperature occurrence within the assumed range 16±1K greater than 80% .Therefore, air temperature fields in the occupied zone are equalized in an easier way than air velocity fields in this zone.

The values of velocity in the occupied zone, $\bar{u}_i$, calculated according to the acquired regression functions for every observation of the designed experiment are presented in Table 2 and Table 3 in 6th column.

The differences between the measured (column 5th) and calculated velocity values in the occupied zone are given in 7th column.

In order to answer the question which of the types of the designed experiment describes the tested phenomenon in the best way, the results obtained from measurements by means of central composite design and complete and fractional 2^n factorial experiment were calculated

Table 4 presents the results for the follwing parameters:
- distance between inlets s = 4.4 m
- supply velocity u_n = 7.5 m/s
- supply direction $\alpha_n = 20°$

The values of the measured mean velocity in the occupied zone appear in 2nd column in Table 2.
The values of this velocity calculated for $s = 4.4$ m, $u_n = 7.5$ m/s, $\alpha_n = 20°$ appear in 3rd column, whereas 4th column presents the differences between velocities calculated by means of different experiment design types in reference to central composite design.
Standard deviation $\sqrt{D^2}$ of the mean velocity in the occupied zone appears in 4th column.
The value of $\bar{u}_i$ variance was calculated according to the following formula:

$$D^2_{y-y'} = \frac{1}{N-K-1} \sum_{m=1}^{N} (y-y')^2$$

where

$$K = \frac{m(m+3)}{2}$$

7. Response surfaces describing mean velocity in the occupied zone.

On the basis of the mean velocity values calculated when employing the measurement results, the regression coefficients were determined for each of the experiment types.
In result, the response surfaces for the particular experiments are as follows:
For central composite design:

$$\bar{u}_i = 0{,}2859 - 0{,}1544\,s + 0{,}0155\,u_n + 0{,}0015\alpha_n + 0{,}0209\,s^2 + 0{,}0007\,u_n^2 + 0{,}0001\alpha_n^2 + 0{,}0004\,s\,u_n - 0{,}0016\,s\,\alpha_n - 0{,}0002\,u_n\alpha_n$$

For complete 2^n factorial experiment

$$\bar{u}_i = -0{,}0660 + 0{,}0126\,s + 0{,}031\,u_n + 0{,}0012\alpha_n$$

For fractional 2^n factorial experiment

$$\bar{u}_i = 0{,}0025 + 0{,}0047\,s + 0{,}0213\,u_n + 0{,}0001\alpha_n$$

The response surfaces describing the relation $\bar{u}_i = f(u_n, s, \alpha_n)$ may be practically used to calculate ventilation processes in all cases when values u_n, s, α_n fall within the input parameter ranges taken into account in the tests.

8. Conclusions.

1. The tests of air velocity distribution in the occupied zone, by means of the experiment design method, have proved that the phenomenon is

described in the best way when central composite design is applied.

2. The relation $\bar{u}_i = (u_n, s, \alpha_n)$ obtained in result of the tests, makes it possible to calculate ventilation parameters in different conditions if only the input parameters are within the analysed ranges without any further experiments.

References.

1. Mańczak K : Experiment design technique. PWN Warszawa 1976 (in Polish)

2. Cohran W.G., Cox G.: Experimental designs.

3. Kateusz P., Mierzwiński ., Nawrocki W., Trzeciakiewicz Z. : Model tests of air velocity and temperature distribution at warm air heating. Proceedings of the conference on "Tests of systems in heating, ventilation, air conditioning and district heating" Wrocław - Szklarska Poręba 22nd-26 th April, 1986 (in Polish)

4. Medyńska E.,Nawrocki W.,Trzeciakiewicz Z. : Experiment design in air distribution tests. Zeszyt naukowy Pol.Śl. Inżynieria Środowiska No 33. (in print)

SUMMARY

It is often necessary to determine the value of the air velocity in the occupied zone in order to define thermal-sanitary conditions, to evaluate ventilation rate, etc. The air velocity distribution in this zone is influenced by many factors such as the parameters of the supplied streams, the shape of the room etc. The tests of the air velocity distribution in the occupied zone were carried out and then followed by an attempt to present the measurement results in a multi-parameter relation obtained with the use of the experiment design method. The mean velocity values and its effective fluctuations were measured by means of a hot sphere thermoanemometer. The mathematical analysis of the results of the experiment, carried out in a physical scale model of the tested industrial hall, yielded a linear-square relation of the mean velocity in the occupied zone versus the distance between the air supply ventilators, the air supply velocity and direction. The results of the model tests were compared with the values calculated with the use of the mathematical relation.