AIR FLOW AND ENERGY MANAGEMENT IN WARM AIR HEATING OF INDUSTRIAL HALLS

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1. Introduction

Effects of warm air heating performance depend on air distribution solution and on thermal properties of the object itself, more than in the case of other ways of heating. Therefore, the shape and the size of the room, supply and outlet openings lay-out, kinetic energy of supply jets and intensity of disturbing convective flows that occur at cool surfaces of the room play essential part here.

The part of supply jets in warm air heating systems consists in generating the turbulent mixing process and secondary flows in a defined space, see Fig. 1 (1, 2).

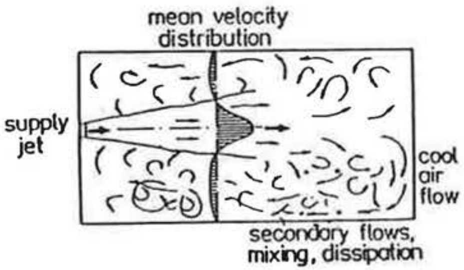

Fig. 1. Pictorial presentation of turbulent mixing and secondary flows generation

When this process is maintained in a proper way it contributes to the equalization of air temperature distribution in the room. In this way, the aim is:

- to obtain required thermal conditions within occuppied zone, estimated by means of horizontal distributions of air temperature and velocity
- to limit excess heat losses in the space above this zone, that can be estimated by means of the vertical gradient of air temperature.

From the point of view of energy management it is also important to maintain the advisable vertical distribution of air temperature, beside the basic task i.e. the proper heating of the occuppied zone.

2. The purpose and the method of approach

The possibilities to improve energy management in the processes of warm air heating of halls were analysed in two aspects, namely:

- the ways of air velocity and temperature distributions forming in the occuppied zone and inthe whole hall by means of parameters selection in supplied jets of heating air were investigated,
- in addition, the effect of the outlet openings location on the vertical distribution of air temperature in the room was investigated.

The processes of air distribution and turbulent mixing were analysed for various geometrical propertions of air heating installation in the hall, the height and the width of which were 15 m and 18 m respectively. The tests were carried out in a physical model, the scale of which was 1 : 7, see Fig. 2. Supply openings were placed at the height 3,5 m, the distance

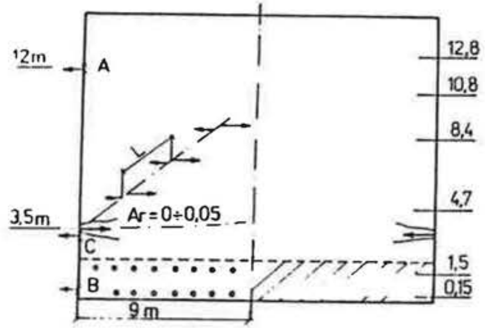

Fig. 2. Scheme of the model of warm air heating of the hall

between them was changed and equaled 2,6 m and 6 m. The openings were equipped with guide vanes, set up parallel, "O", or the angle between the fringe vanes was 90°, "M".

Initial parameters of heating air jets were chosen adequately to the heat losses of the hall, Q = idem, at the air temperature about 16°C in the occupied zone whereas supply air temperature changed within the limits 16 - 45°C and its velocity was varied from 2,5 to 8,5 m/s that correseponded to the frequency of air exchange 1 - 10 per hour.

The measurements of air parameters were carried out in the grid of 54 points at the level 1,5 m for velocity and at the levels 0,15, 1,5, 4,7, 8,4, 10,8, 12,8 m for temperature. Air velocity was measured by means of a thermoanemometer with spherical probe.

Outlet openings were arranged as follows:

- in series C - at the height 3,5 m, near supply openings,
- in series A - at the height 12 m, one large outlet opening,
- in series B - at the height 0,5 m, one large outlet opening.

Diagram of the measurement points as well as of supply and outlet openings is shown in Fig. 2.

In order to estimate the results obtained, in respect to the occuppied zone, for the level 1,5 m, it was calculated:

P_{u1} % - probability of the velocity occurrence within the range $\bar{u} \pm 0,1$ m/s, that characterized the distribution uniformity

P_{u2} % - probability that in the measured velocity distribution velocities from the range 0,15 - 0,35 m/s would occur, that characterized the distribution on account of thermal conditions being felt

P_{t1} % - probability of the temperature occurence within the range $\bar{t} \pm 1$K

where $\bar{u}$ and $\bar{t}$ are mean values of velocity and temperature at the level 1,5 m.

The values P_{u1}, P_{u2} and P_{t1} correspond to the share in percentages of the surface of the occupied zone.

3. Velocity distribution in isothermal conditions

The possibilities to equalize air velocity in the occupied zone were investigated supplying isothermal air jets. Fig. 3 is an example illustrating obtained distributions of frequencies of velocity, $f(\bar{u})$, occurrence in the occuppied zone when the distances between supplied jets axes were 2,6 m and 6 m and the guide vanes were in the position M. The dashed line correspond to the velocities in the supply opening, u_o, optimum on account of the range 0,15 - 0,35 m/s. Table 1 contains data that illus-

trate the probabilities of velocity occurrence P_{u1} and P_{u2} as well as the optimum supply velocities and maximum values P_{u2} corresponding to them at different initial parameters of the jet.

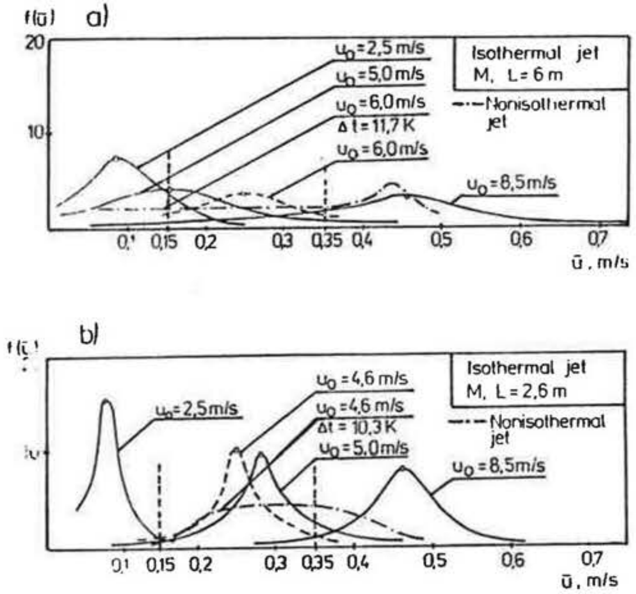

Fig. 3. Frequence of velocity occurrence at the level 1,5 m when the distance between jets L = 6 m or L = 2,6 m and the guide vanes position is M

Table 1. Results of statistical analysis of velocity $\bar{u}$ distribution at the level 1,5 m in isothermal conditions

L m	Vanes position	Initial velocity of the jet u_o m/s						Optimal	
		2,5		5,0		8,5			
		P_{u1}	P_{u2}	P_{u1}	P_{u2}	P_{u1}	P_{u2}	u_o	P_{u2}
2,6	O	38,0	1,0	76,0	55,5	42,0	22,0	5,7	60
	M	39,0	3,0	81,0	78,0	83,0	6,5	4,6	80
6,0	O	33,5	0,5	98,0	3,5	71,0	53,5	3,4	63
	M	34,0	17,0	62,0	47,0	52,0	22,5	6,0	50

It is worth considering that as the initialvelocity of the jet, u_o, increases:

- P_{u1} gradually decreases since the frequency function $f(\bar{u})$ flattens i.e. the dispersion around certain mean value $\bar{u}$ gets wider
- P_{u2} reaches its maximum at certain optimum value u_o; it corresponds to the range 0,15 - 0,35 m/s filled with the function $f(\bar{u})$ to a maximum.

Besides, the optimum velocity u_o and the probability P_{u2} corresponding to it may be influenced by changing the distance and the equipment of supply openings.

4. Parameters distributions in non-isothermal conditions

The ranges of changes of supply jets parameters, when Q = idem, in the course of tests of air velocity and temperature distributions in the hall are given in the Table 2.

Table 2. The ranges of parameters of supply jets with a constant enthalpy flux, Q = idem

u_o m/s	$t_o - t_i$ K	L m	Z 1/h	$\dot{e}$ mW/m^3	Ar
2,5	28 - 12	6 - 2,6	1,2 - 2,8	1,2 - 2,8	0,050
3,5	20 - 8,5	6 - 2,6	1,7 - 4,0	3,4 - 7,8	0,018
5,0	14 - 6,3	6 - 2,6	2,5 - 5,6	10,1 - 23,5	0,006
7,0	10	6	3,4	26,3	0,002
8,5	8	6	4,2	48,2	0,001

u_o, t_o - initial velocity and temperature of the jet
t_i - indoor temperature in the hall
Z - the number of air exchanges
$\dot{e}$ - the kinetic energy of the jet per 1 m^3 of the room
Ar - Archimedes number

The assumed ranges of parameters of supply jets correspond to the values applied in design solutions of warm air heating installations in industrial halls. Calculated Ar-numbers show that supply jets are weakly non-isothermal. However, thermal buoyancy changes the velocity distribution in the occuppied zone in relation to the distribution in analogous geometrical conditions of isothermal jets supplying. It flattens, namely, the runs of

function $f(\bar{u})$, but at the same time it concentrates separate mean velocities and fills in the velocity range 0,15 - 0,35 m/s in a more advantageous way, thus increases the values P_{u2} and makes the values P_{u1} closer to them.

The given tendency of changes of the function $f(\bar{u})$ is illustrated in Fig. 3, where distributions of $f(\bar{u})$ in isothermal and non-isothermal conditions are additionally compared for the same geometrical parameters of the supply jet. The changes of values P_{u1} and P_{u2} may be observed when comparing the data from the Table 3 with the data from the Table 2, line L = 6 m, vanes position M.

Table 5. Results of statistical analysis of distributions of parameters $\bar{t}$ and $\bar{u}$ at the level 1,5 m in non-isothermal conditions, series C, L = 6 m, M

	Initial velocity of the jet u_o m/s				
	2,5	3,5	5,0	7,0	8,5
P_{u1} %	58,5	82,0	73,0	63,0	43,0
P_{u2} %	26,0	70,0	81,0	69,0	51,0
P_{t1} %	81,0	82,0	96,0	83,0	86,0
$\bar{t}_{1,5} - \bar{t}_{0,15}$ K	3,7	1,9	0,4	1,4	0,8
$\bar{u}$ m/s	0,11	0,18	0,20	0,22	0,31

Table 3 gives also some data characterizing air temperature distribution in the occupied zone. Significantly less differentiation of air temperature distribution, P_{t1} = 82 - 96 %, in relation to the velocity dispersion, P_{u1} = 49 - 82 %, may be observed at the level 1,5 m. A little worse temperature distribution occurs at the level 0,15 m. Furthermore, the runs of frequency functions $f(\bar{u})$ and $f(\bar{t})$ of velocity and temperature, respectively, lose the shape typical for Gaussian distributions.

5. Vertical distribution of air temperature in the hall

Some temperature distributions, averaged for individual levels, see Fig.2, are shown in Fig. 5 in the shape of excess temperature profiles in relation to the level 1,5 m at various supply velocities u_o. The data refer to the series C when air was exhausted through the openings placed at the level 3,5 m, close to the supply openings.

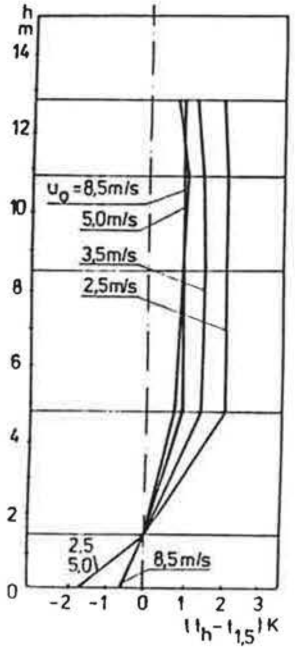

Fig. 4. Vertical profiles of air temperature in the hall

Temperature increments may be observed in the zone up to the height about 5 m. The increments get smaller as the supply velocity u_0 gets higher. Temperature gradients practically approach zero above the level about 5m.

Vertical profiles of air temperature distribution in the hall were similar also in the series A and B with single outlet openings placed under the roof and near the floor, respectively.

The following values of temperature gradients may be assumed as average for the whole height of the hall in warm air heating solutions, analogous as in the series C and in the initial parameters range after Table 2:

u_0 m/s	$\dot{e}$ mW/m^3	grad t K/m
2,5	1,2	0,29
3,5	3,4	0,24
5,0	10,1	0,20
7,0	26,9	0,16
8,5	48,2	0,10

6. Energy distribution in the hall

It has resulted from the observations that in order to obtain the required air temperature distribution in the occuppied zone as well as in the whole hall, an adequate mechanical energy input is necessary to organize momentum transport. This requires kinetic energy of heating air supply jets in the amount of 20 - 50 mW/m^3 of the hall capacity, taking into account the aerodynamical disturbances. It makes about 1 % of the hall nominal heat losses.

It is worth considering that this condition can be satisfied without any additional energy input. For when electric energy consumption is increased at relevantly higher supply velocity, it is compensated, even in terms of fuel consumption, by the reduction of heat losses of the hall at lessened vertical gradient of air temperature.

7. Conclusions

- For the defined dimensions of the hall it is possible to determine the optimum ranges of supply parameters: u_0, L, d, M, on account of required horizontal and vertical air temperature distributions in the hall. In the case of the hall that was tested those ranges were characterized as follows: $\dot{e}_0$ = 10 - 25 mW/m^3, without disturbances, u_0 = 5 - 6 m/s.
- In the tested zones of the hall air temperature distributions were significantly less differentiated in relation to the velocity dispersion.
- From the point of view of energy, mechanical energy input for the proper organization of air momentum transfer in the hall pays out.

8. References

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