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INFLUENCE OF INITIAL TURBULENCE ON CHARACTERISTICS OF AIR JETS

Introduction

For maintenance of the normalized parameters of air environment in a working zone of rooms it is necessary that distribution of incoming air be effective, as a result the ways and air distribution devices essentially influence technical and economic parameters of a microclimate maintenance system as a whole.

There are a number of air distribution devices, where the effect of interaction between coaxial and non-coaxial flows is used. There is also useful air distribution device with swirl and spread air jets.

One of the most rational ways of air distribution is submission of coming air directly into a room serviced area. For this purpose air distribution devices with high intensity of falling of parameters (velocity V and temperature t) of incoming air are used. As characteristic property of such incoming air jet there is its higher turbulence in comparison with common air jets. Interaction of opposed incoming air jets is a way of increasing its turbulence. It is possible to distinguish interaction coaxial of opposed jets, flows that are directed under a corner one up to one and non-coaxial opposed flows.

Effective way of turbulence increasing is using of interaction of opposite incoming air jets. It is possible to distinguish interaction coaxial of opposite jets, flows that are directed under a corner one up to one and non-coaxial opposite flows. In this work the opportunity of achievement of falling high intensity of parameters is considered at distribution of air supply by non-coaxial incoming air flows, which are in interaction with one another, i.e. they strike one to one.

Another effective way is using of air distribution device with swirl and spread air jets.

The purpose of investigations is obtaining of the charts and analytic equations for determination of the necessary parameters (initial and running velocity, coefficients of extinction of velocity and temperature, coefficient of aerodynamic resistance, noise level) of air jets and air distribution devices at the rated demands.

1. Effect of interaction of opposite non-coaxial flows

There is air distribution device, on which beside above holes in air-pipe there are located opposite half-conic incoming nozzles, axes of which are placed on 0.2÷0.5 part of their diameter. However, in this and other air pipes there are available only not large displacement of axes of opposite flows, and also the interaction flows occurs on small length. Distance between opposite air-departing apertures is less than 5 parts of their diameters. Air distribution devices [1] and similar to them represent devices of opposite air distribution devices in exactly as variant of punching for panel air distribution devices, where air departures and the apertures are located in some lines.

The effect of interaction of opposite non-coaxial flows is considered, at which departure from nozzle at distance between axes of opposite flows is over $0.5 d_0$ and distance between opposite nozzles is in interval from $12 d_0$ to $33 d_0$. As a result of interaction flows there is created the resulting air flow that turns out directly into a working zone.

The experimental investigations have been carried out at such conditions and simplifications:

- air jets are non-isothermal;
- nozzles for air supply are cylindrical with factor of velocity falling $m = 6.8$ and flat holes with width 20 mm and with length 1.5 m and coefficient of velocity extinction $m = 2.5$;
- distance between common nozzles $l = 150 \text{ mm} = 3 d_0$;
- distance between opposite nozzles $l = 75 \text{ mm} = 1.5 d_0$;
- air jet sizeless with lengths $X_p = 0.6$; $X_p = 0.8$; 1.22; 1.64 ($X_p = 12 d_0$; $X_p = 16 d_0$; $X_p = 24 d_0$; $X_p = 33 d_0$);
- initial air velocities in nozzle were: $V = 5 \div 15 \text{ m/s}$;
- air flow rates were: $L = 200 \div 500 \text{ m}^3/\text{h}$.

Air velocity has been measured by thermal electrical anemometer testo-405 at using coordinate device with net of points 5x5 cm.

The basic object of research on the first stage was a resulting air flow, which it turns out at interaction flows. For using with the purpose of air distribution as optimum there is an air flow with high uniformity of velocity on all area of a flow.

Accordingly to the received experimental data by an optimum relation for reception of a uniform resulting flow at $l = 3 d_0$ and $l = 1.5 d_0$ is $X_p = 16 d_0$.

In Figure 1 there are presented results of investigations as three-dimensional.

The received results testify to acceptable uniformity of a resulting flow and opportunity of use of interaction of opposite flows in air distribution devices.

Air distribution devices of such type (height about 2 m) can be used for air distribution in a working zone of rooms, by replacing for example, panel air distribution device of VPP type, or top zone (nozzles for air supply are situated under a ceiling near internal walls of rooms) instead of the punched panels and decorative of ceilings [1]. Thus considerably capacity of materials of air supply system decreases and useful height of a room increases.

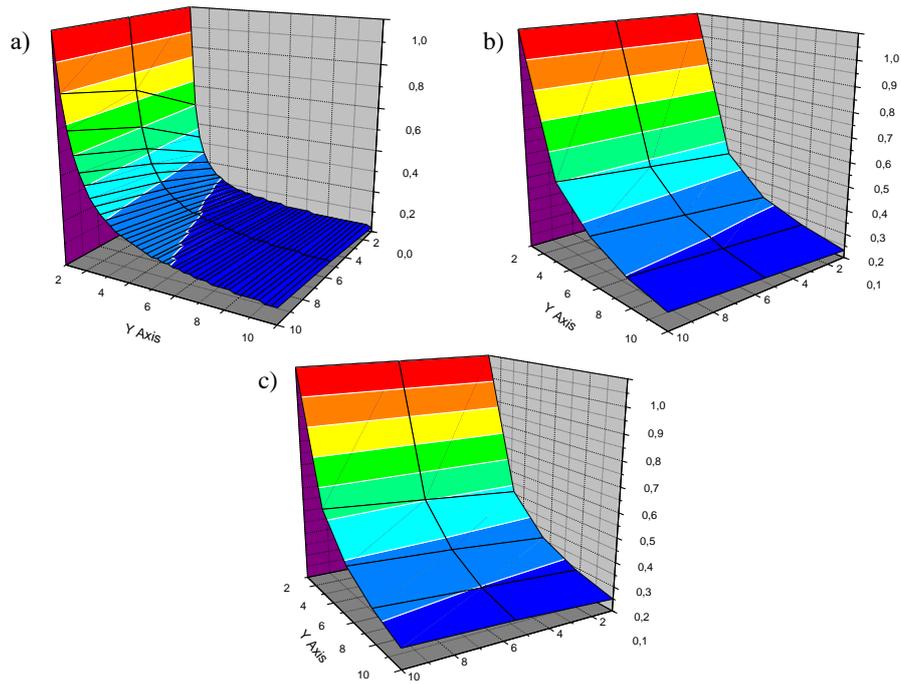


Fig. 1. Results of investigations of air distribution device: a) $x_3 = l_0/b_0 = 2$; $x_4 = L_1/L_2 = 1$; $x_2 = x/X_p = 0; 0.25; 0.5$, b) $x_3 = l_0/b_0 = 2$; $x_4 = L_1/L_2 = 3$; $x_2 = x/X_p = 0; 0.25; 0.5$, c) $x_3 = l_0/b_0 = 4$; $x_4 = L_1/L_2 = 3$; $x_2 = x/X_p = 0; 0.25; 0.5$

In Figure 2 there is presented a universal chart as dependency of relative velocity against 4 variable values h/H ; l_0/b_0 ; L_1/L_2 ; x/X_p .

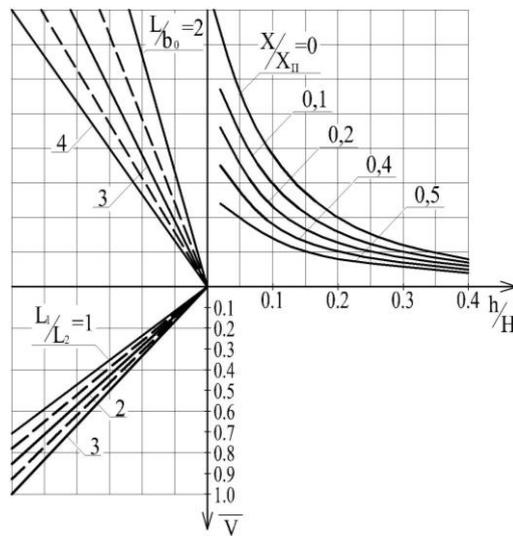


Fig. 2. Chart for determination of air velocity in a room \bar{V}

Presented chart has been approximated by equation (1):

$$\bar{V} = \frac{-0.01 + 0,0025 \frac{l}{b_0} - 0.05 \frac{x}{X_p} + 0.02 \frac{L_L}{L_R}}{1.15 \frac{h}{H} - 0.01 + 0.025 \frac{l}{b_0} - 0.05 \frac{x}{X_p} + 0.02 \frac{L_L}{L_R}} \quad (1)$$

Accordingly to the received experimental data by an optimum relation for reception of a high intensity of velocity extinction of a resulting flow, namely minimal value \bar{V} , there are the following: $h/H = 0.40$; $x/X_n = 0.5$; $l_0/b_0 = 2$; $L_L/L_R = 1$ ($L_L = L_R$).

By this efficiency of opposed non-coaxial air jets using will be maximal.

Coefficient of air distribution devices velocity extinction m is determined by equation (2):

$$m = \frac{V_x}{V_0} \frac{X}{\sqrt{F}} \quad (2)$$

coefficient of temperature extinction n :

$$n = \frac{\Delta t_x}{\Delta t_0} \frac{X}{\sqrt{F}} \quad (3)$$

where: V_x - air velocity on jet axis, m/s; Δt_x - excessive temperature on jet axis, °C; V_0 - initial air velocity of jet leakage, m/s; Δt_0 - initial excessive jet temperature, °C.

The investigations of aerodynamic resistance coefficient ζ and coefficients of velocity m and temperature n extinction have been carried out at the same conditions and simplifications as during air jets research.

TABLE 1

Coefficients of velocity m and temperature n extinction of air distribution devices with opposite non-coaxial air jets

No.	Distance between air pipes/ducts X_p [mm]	Distance between axes of nozzles l_0 [mm]	Square of nozzle F_0 [m ²]	Coefficient of velocity extinction m	Coefficient of temperature extinction n
1	800	100	0.48	0.46	0.33
2	1000	100	0.60	0.48	0.34
3	1200	100	0.72	0.47	0.33
4	800	150	0.72	0.52	0.35
5	1000	150	0.90	0.50	0.34
6	1200	150	1.08	0.48	0.34
7	800	200	0.96	0.51	0.35
8	1000	200	1.20	0.50	0.34
9	1200	200	1.44	0.53	0.36

As we see from Table 1 for base type-sizes of air distribution devices with interaction of opposed non-coaxial air jets coefficients of velocity m and temperature n extinction are much less than 1 ($m < 1$, $n < 1$), namely this device provides high intensity of extinction dynamic and heat jet parameters and turbulence of air flow is good enough.

2. Air distribution by swirl and spread air jets

Air distribution device that supplies air by swirl and spread air jets for providing large air flows in the rooms is presented in Figure 3. Proposed air distribution device may be used in the rooms at such cases: part of air is supplied through the swirl plates, creating turbulent air flow, but another air part - through the circular hole into the top area of a room.

All coefficients of aerodynamic resistance ζ and coefficients of velocity m and temperature n extinction are important characteristics of turbulence. In this article the results of investigations of values ζ , m and n for air distribution device with swirl jet are presented.

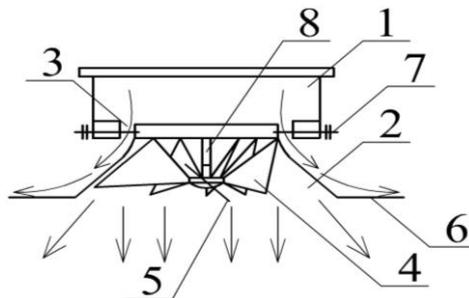


Fig. 3. Air distribution device for air supply into top room area by spread air jet and into serviced room area by swirl air jet: 1 - incoming nozzle, 2 - difusor, 3 - circular regulated hole (for air supply by spread jet), 4 - plates, 5 - handle of steering, 6 - swirl stopper, 7 - screw of the hole adjustment, 8 - core

For air distribution device with swirl jet the angle of plates turn α influences substantially. Investigations of dependency of ζ , m and n values against angle α have been carried out. Angle α was varied from 150 to 900. The results of research are presented on charts (Figs. 4 and 5).

As we see in Figure 4, value ζ is varied from 0.9 to 6.1 depending against α , and in Figure 5 - values m and n are varied accordingly from 0.40 to 1.42 and from 0.29 to 1.26 depending against α . Charts (Figs. 4 and 5) have been approximated by equations (4-6):

$$\zeta = \frac{105.12}{\alpha} - 0.006 \alpha \quad (4)$$

$$m = -0.301 + 0.698 \alpha - 0.041 \alpha^2 \tag{5}$$

$$n = -0.37 + 0.675 \alpha - 0.035 \alpha^2 \tag{6}$$

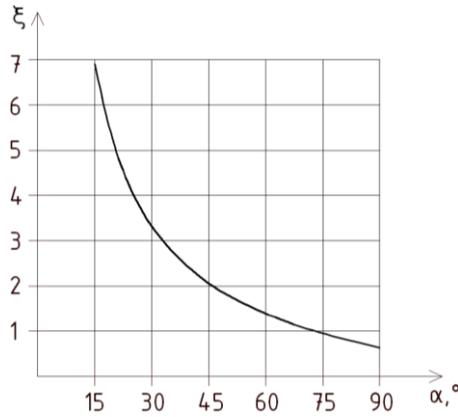


Fig. 4. Coefficient ζ against angle α

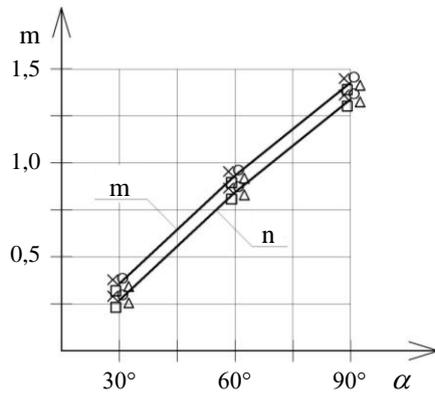


Fig. 5. Coefficients m and n against angle α

Average integral values ζ_{av} , m_{av} and n_{av} are interesting. For instance, average integral coefficient ζ_{av} is determined from equation (7):

$$\zeta_{av} = \frac{1}{90-15} \int_{15}^{90} \left(\frac{105.12}{\alpha} - 0.006 \alpha \right) d\alpha \tag{7}$$

Result $\zeta_{av} = 2.2$ satisfies necessary degree of turbulence, so do results concerning values m_{av} and n_{av} .

There is a relationship between ζ and m and n . These values depend on initial turbulence. High turbulence results in increasing of coefficient of aerodynamic

resistance ζ and decreasing of m and n . Increasing of swirl angle results in decreasing of turbulence. So, it results in decreasing of ζ and increasing of m and n .

The next task is research of jets acoustic properties.

High initial turbulence results in decreasing of initial velocity and as a result - in decrease of noise level.

Comparative chart (Fig. 6) for flat and compact jets, which flow out from a rectangular aperture with a bend, rectangular chink's aperture and cylindrical pipe with a bend, we shall note that noise level is the highest at flowing out of flat jet in cause of a rectangular chink with a bend.

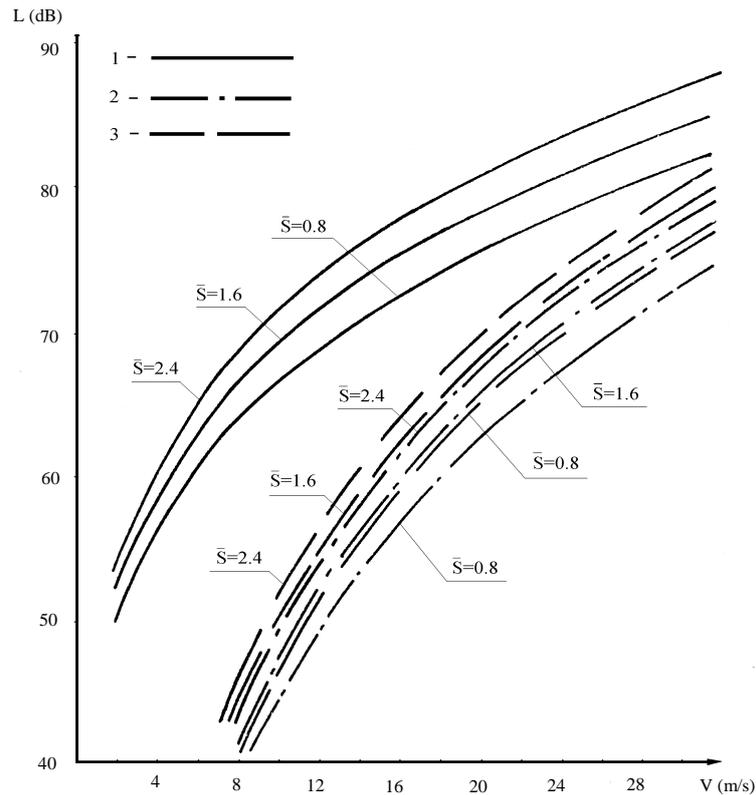


Fig. 6. Chart of noise level L dependence from air jet velocity V and sizeless square \bar{S} of flat and round outlets at jet leakage: 1 - rectangular chink with a bend, 2 - round outlet with a bend, 3 - rectangular chink

On the basis of obtained dependences it is possible to carry out control of air distribution's selection, taking into account limited noise level for particular capacity of incoming outlet.

Experimental research of the acoustic phenomena at the air jets leakage from flat and round outlets was carried out in room $12.0 \times 6.0 \times 3.0$ (h) m. Air was supplied at the various flow rates both through a flat incoming hole of variable width

(200÷600 mm), height (10÷60 mm) and through a round outlet of various diameter (100÷400 mm). Air exhaust was realized through a side hole of diameter 250 mm in a wall under a ceiling.

The noise level was measured by noise-meter ИИМ-1-МІ and vibration of air pipes' metal walls - by vibration meter ДН-3-МІ.

Three noise sources were taken into account, namely: fan, vibration of air pipes' metal walls and aerodynamic noise at the air jet's leakage.

For obtaining universal calculating equations width, height and diameter of the outlets were expressed as sizeless.

Air jet's initial velocity V_0 at leakage from different size and shape incoming holes, noise level and vibration of air pipes' metal walls have been measured; the chart that shows relation between such factors as a noise level, air flow rate and incoming hole's size of both shapes (flat and round), has been created; obtained chart has been approximated by equation for analytic calculation.

Represented data gives a possibility to determine air distribution units' size under maintenance of the rated noise level, when necessary air amount is supplied, and is considered as a base for designing Air Conditioning system.

Conclusions

The analysis of experimental data shows that:

- there is observed air addition of incoming flows at their distribution by air of opposed flows and partially by air of a room, in particular from the nozzles for the air supply;
- in an air distribution device construction $h < 200$ occurs significant turbulence of incoming flows at the expense of parallel and partially of counter movement and compelled unilateral direction of movement of a resulting flow;
- on basis of conducted investigations numeral values of coefficients of velocity m and temperature n extinction of regarded air distribution devices are determined; also coefficient of aerodynamic resistance ζ and noise level.

References

- [1] Vozniak O., Kovalchuk A., Air distribution by opposite non-coaxial air jets, Zbornik prednasok, VII Vedecka Konferencia s medzinarodnou ucastou Kosicko-Lvovsko-Rzeszowska, 2002, 173-178.
- [2] Staroverov I., Directory of Designer Part II, Ventilation and Air Conditioning, Strojizdat, Moscow 1977, 502 p.
- [3] Taliev V., Ventilation Aerodynamics, Strojizdat, Moscow 1979, 296 p.
- [4] Grimitlin M., Air Distribution in the Rooms, Strojizdat, Moscow 1982, 164 p.
- [5] Vozniak O., Dovbush O., Influence of indoor climate on a person heat exchange in a room, Zeszyty Naukowe Politechniki Rzeszowskiej, Aktualne problemy budownictwa i inzynierii srodowiska, część 2, Inzynieria Srodowiska, Rzeszów 2000, 441-447.
- [6] Gubernskiy Y.D., Ismajilova L.I., Ekonomija energiji i topliva pri upravleniji mikroklimatom, Vodosnabzhenije i sanitarnaja tjechnika 1985, 3, 11-12.

- [7] Voznyak O.T., Dynamichnyj mikroklimat ta energooshchadnist, Visnyk Nats. Un-tu «Lvivska politehnika», «Teploenergetyka. Inzhenerija dovkillia, Avtomatyzatsija» 2002, 460, 150-153.
- [8] Voznyak O.T., Myroniuk K., Sukholova I., Zastosuvannya povitrorozpodilu vzayemodiyeyu zustrichnyh nespivvisnyh strumyn, Zbirnyk MOTROL "Motoryzacja i Energetyka rolnictwa", Lublin 2011, 13C, 24-31.
- [9] Yudin Ye., Struggle against Noise in Manufacturing, Moscow 1985.
- [10] Muntea C., Florin D., Kapalo P., Nagy R., Air quality and effect of ventilation in buildings, Visnyk Nats. Un-tu «Lvivska politehnika», «Teoria i praktyka budivnytstva» 2012, 737, 201, 274-279.
- [11] Karelava Z., Vranayova Z., Kaposztasova D., Purcz P., Risk analysis for RWH system and its verification by mathematical methods, Visnyk Nats. Un-tu «Lvivska Politehnika», «Teoriya i praktyka budivnytstva» 2013, 756, 74-77.

Abstract

In this article the results of air distribution device with opposite non-coaxial air jets interaction and also air distribution device with swirl air jets investigations are presented. Research concerns the air flow velocity and temperature decreasing coefficients determination and also both noise level and aerodynamic resistance coefficient were considered.

Wpływ turbulencji początkowej na charakterystyki strumieni powietrznych

Streszczenie

W artykule przedstawiono wyniki badań urządzeń do nawiewu powietrza. Badania dotyczą współczynników zmniejszania prędkości oraz temperatury strumieni powietrza, a także hałasu oraz współczynników oporu aerodynamicznego.