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CO-AXIAL and PLANE TURBULENT JETS USING for HEATING and VENTILATING of LOCAL ZONES in LARGE PREMISES

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SUMMARY

A number of the air-jet protectors has been presented. These protectors may be used for heating, cooling and ventilating of local zones in large premises. A new method for calculating air-jet protection thermal parameters has been proposed. For the solution of thermal task the profile of temperature distribution in a cross-section of co-axial or plane nonisothermical turbulent jet has been proposed as well. It was assumed that temperature profile is a result of summing up two independent conventional profiles. These profiles are united by special form-parameter. The system of equations for calculating of air-jet protection thermal parameters has been obtained. Comparison of the calculation results and some experimental data shown their good coincidence. That experimental data have been received by authors and al.

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INTRODUCTION

A considarable part of modern buildings have large volumes. As usial in those volumes there are a lot of zones where technological equipment or single working places are concentrated. Thus, there is no need in using air conditioning systems for serving the whole volume of premises. It is sufficient to ensure the microclimate conditioning in only these local zones. For these premises AIR-JET PROTECTORS (AJP) may be preffered.

GENERAL PERFORMANCES of AIR-JET PROTECTION of LOCAL ZONES

To provide the comfort in the local parts of the building space there are three trends of ventilation technique. The first trend is connected with the usage of solid nontransparent screens. The clean air is supplied to the part of space is singled out by the screens.

The second trend uses the compact turbulent high-speed jets or the laminary air flows. Both the first and the second trends may be used. However they have some defects: the people's body is recooled by high velocity turbulent jet; the laminary flow is no stable relatively environmental flows. Unfortunatly, these methods of air conditioning the local zones are used broadly nonwinthstanding their defects. It is necessary to construct the apparatuses free from these defects and including the following merits (the absence of solid walls and the stability of flows in relation to the ambient air movement). The air-jet protectors proposed by the group of HVAC scientists from Ekaterinburg solve this problem. It is the third trend.

The basis for the air-jet protection is the co-axial or plane turbulent jets. These jets are formed by special air distributors. The jets play the role of the screen that limit part of space in a premise. After issuing from the distributor the jet is subjected to deformation with the formation of inside cavity. It is well known as the Coanda effect. That cavity may be used for placing of single working places or places for rest. The hygienic effect is reached by clean air supply into the cavity. However it requires two independent systems for AJP functioning. The first system forms the peripheral jet-screen. The second system provides the air supply into that zone. This method is known and discribed in special literature. In order to improve AJP we must refus from the central flow and the system connected with that flow.

The schemes of AJP are shown in fig.1. The theoretical schemes are shown in fig.2. The first schemes (fig.1a; 2a) heve jets affected by the flat horizontal surface (it may be the floor if the jet moves from above). The schemes (fig. 1b; 2b; 2c) are expedient to use if there is a possibility to direct the jet from below.

The common schemes give some variants. When line 3 is the central symmetry axis the scheme has a view of AJP with co-axial jet. It is the first variant. When line 3 is the linear symmetry axis we have the second variant-AJP with two plane jets. The third variant is connected with only one plane jet. Here line 3 coincides with solid wall 2. Besides line 3 may be both vertical and horizontal.

After the formation of cavity the jet is divided into two flows. The first moves in direction from the cavity. The second moves into the cavityd suppies the jet inside. This flow is called "downstream". The first flow is called "upstream". These two flows are divided by the conventional surface formed by the streamlines along which the stream function is equal to zero. That streamline is called "reattachment line" as is shown in fig.1a; 2a. The streamline is called "merge line" as is shown in fig.1b; 2b; 2c. The final points of the zero streamlines are called "reattachment point" or "merge point". The conventional surfaces are called "dividing surfaces".

GEOMETRICAL, KINEMATIC and THERMAL PARAMETERS of AIR-JET PROTECTION

The constructioning of AJP includes two stages. First of all it is necessary to calculate geometrical parameters of the jet and the air distributor. The data and explanations for calculation are represented in [1;2]. In order to calculate the kinematic and thermal parameters it is necessary to solute the thermal task for jet of AJP. This solution is discribed below. The paculiarity of this task is a complicated distribution of temperature (T) in a cross-section of the peripheral jet. The temperature on inside boundary of jet is equal to temperature in the cavity (T_{cv}); the temperature on outside boundary is equal to ambient temperature (T_{am}); the initial flow temperature is. In common case $T_o =$ $= T_{cv} = T_{am}$.

It is assumed that real temperature profile ia a result of summing up two independent profiles:

$$\Delta T = \Delta T_l + T_j \qquad (1)$$

where $\Delta T = T - T_{am}$; ΔT_l $T_l - T_{am}$; $\Delta T_j = T_j - T_{am}$

The first profile (ΔT_l) formed as a result of turbulent transmission in a cross-section of jet divided two volumes with different temperatures T_{cv} and T_{am}. This profile has width 2δ (fig.2) and is discribed by G.Shlyhting eqation

$$\Delta T_l = \Delta T_{cv}\,[1-(1-0{,}5\eta)^{1{,}5}]\,.\quad \Delta T_{cv} = T_{cv} - T_{am}\,;\ \eta = z/\delta\,, \qquad (2)$$

where z - coordinate is counted out from outside boundary (fig.2).

The second profile presents a temperature distribution in any cross-section of free nonisothermical two-dimensional jet which has surplus temperature on the jet axis:

$$\left.\begin{aligned} \Delta T_j &= \Delta\tau_m\,[1-(1-\eta)^{1{,}5}] & \eta \in [0;1] \\ \Delta T_j &= \Delta\tau_m\,[1-(1-\eta)^{1{,}5}] & \eta \in [1;2] \end{aligned}\right\} \qquad (3)$$

Thus the temperature T in any point of jet cross-section is

$$\eta \in [0;1] \Rightarrow T = T_{cv} - \Delta T_{cv}(1-0,5\eta)^{1,5} + \Delta\tau_m[1-(1-\eta)^{1,5}];$$
$$\eta \in [1;2] \Rightarrow T = T_{cv} - \Delta T_{cv}(1-0,5\eta)^{1,5} + \Delta\tau_m[1-(\eta-1)^{1,5}]; \quad (4)$$

The parameter $\Delta\tau_m$ is determined from heat maintenance equation

$$Q = \int_W cuT\,dw, \quad (5)$$

where w - area of cross-section; c - specific heat (it is assumed $c = \text{const}$);

u - velocity in the point of cross-section where temperature is equal to: T

$$\left.\begin{array}{ll} u = u_m[1-(1-\eta)^{1,5}]^2 & \eta \in [0;1]; \\ u = u_m[1-(\eta-1)^{1,5}]^2 & \eta \in [1;2]. \end{array}\right\} \quad (6)$$

u_m - velocity on the axis of jet.

After integration (5) with using (4,6) and data of [1;2] we receiv

$$Q/cL = 0,63\,T_{cv} + 0,37\,T_{am} + 0,818\,\Delta\tau_m, \quad (7)$$

where L - volume of air is moved through jet cross-section. Data of [1;2] may be used for difinition of L. On a distance from the distributor nozzle to the reattachment or merge point the heat maintenance of air drawn into the jet is examined as

$$Q = c[L_0T_0 + 0,5(L-L_0)(T_{cv} + T_{am})], \quad (8)$$

where L_0 - initial volume of the jet.

From (8) we have

$$Q/cL = [T_0 + 0,5(\bar{L}-1)(T_{cv} + T_{am})]/\bar{L}, \quad (9)$$

where $\bar{L} = L/L_0$.

It is necessary to note that is an average temperature in cross-section of the peripheral jet. The joint solution of (7,9) gives

$$\Delta\tau_m = 1{,}22\,[T_0 + 0{,}5(\bar{L}-1)(T_{cv}+T_{am}) - (0{,}63_{cv}+0{,}37\,T_{am})\bar{L}]/\bar{L} \quad (10)$$

Parameter $\Delta\tau_m$ may be both more and less zero. Comparison of the calculation results and some experimental data is represented in fig.3. The experimental points have been received by authors and al.

The equations (4,10) give a possibility to determine the average temperature in any part of two-dimensional jet. Average temperature of outside part of jet (nondimensional coordinate has range from zero to any η) is

$$T_{av.out} = \left(\int_0^{\eta} \frac{u}{u_m} T\, d\eta\right) : \left(\int_0^{\eta} \frac{u}{u_m}\, d\eta\right) \quad (11)$$

Average temperature of inside part of jet (the coordinate has range from any η to $\eta = 2$) is

$$T_{av.in} = \left(\int_{\eta}^{2} \frac{u}{u_m} T\, d\eta\right) : \left(\int_{\eta}^{2} \frac{u}{u_m}\, d\eta\right). \quad (12)$$

Integration of equations (11,12) gives

$$T_{av.out} = T_{cv} - \frac{J_2}{J_1}\Delta T_{cv} + \frac{J_3}{J_1}\Delta\tau_m \;; \quad (13)$$

$$T_{av.in} = T_{cv} - \frac{(0{,}333 - J_2)}{(0{,}9 - J_1)}\Delta T_{cv} + \frac{(0{,}736 - J_3)}{(0{,}9 - J_1)}\Delta\tau_m \,. \quad (14)$$

where $J_1 = \int_0^{\eta} [1-(\pm 1 \mp \eta)^{1,5}]^2\, d\eta$;

$$J_2 = \int_0^{\eta} [1-(\pm 1 \mp \eta)^{1,5}]^2 (1-0{,}5\eta)^{1,5} d\eta \;;\; J_3 = \int_0^{\eta} [1-(\pm 1 \mp \eta)^{1,5}]^3 d\eta \,. \quad (15)$$

The upper symbols are used if $\eta \in [0;1]$; the lower symbols are used if $\eta \in [1;2]$. The curves interpreting the functions are given in fig. 4.

For AJP constructioning it is necessary to determine the initial flow temperature. It is assumed that $T_{cv} = T_{am}$. Our investigations showed that this assumption don't lead to big mistakes. Then from (14) it followes

$$T_0 = \left(\frac{0{,}333 - J_2}{0{,}736 - J_3}\right) \cdot \frac{\Delta T_{cv}\bar{L}}{1{,}22} + 0{,}13\bar{L}(T_{cv} + T_{am}) + 0{,}5(T_{cv} + T_{am}) \quad (16)$$

Besides if the temperatures T_0, T_{CV}, T_{am} are known the equation (16) gives a possibility to calculate the initial flow capacity

$$L_0=\left(\frac{0,333-J_2}{122\,(0,736-J_3)}+0,13\right)L\cdot\delta T\,, \qquad (17)$$

where δT - thermal performanance; $\delta T=\frac{\Delta T_{CV}}{\Delta T_0-0{,}5\Delta T_{CV}}$; $\Delta T_0=T_0-T_{am}$.

CONCLUSION

The known methods of heating, cooling and ventilating of local zones in large premises have some defects. It is possible to improve those methods by taking results of the co-axial and plane jets investigations. These investigations make it possibls to construct the air-jet protectors (AJP). The air-jet protectors give a possibility to improve an efficient of local zones heating, cooling and ventilating.

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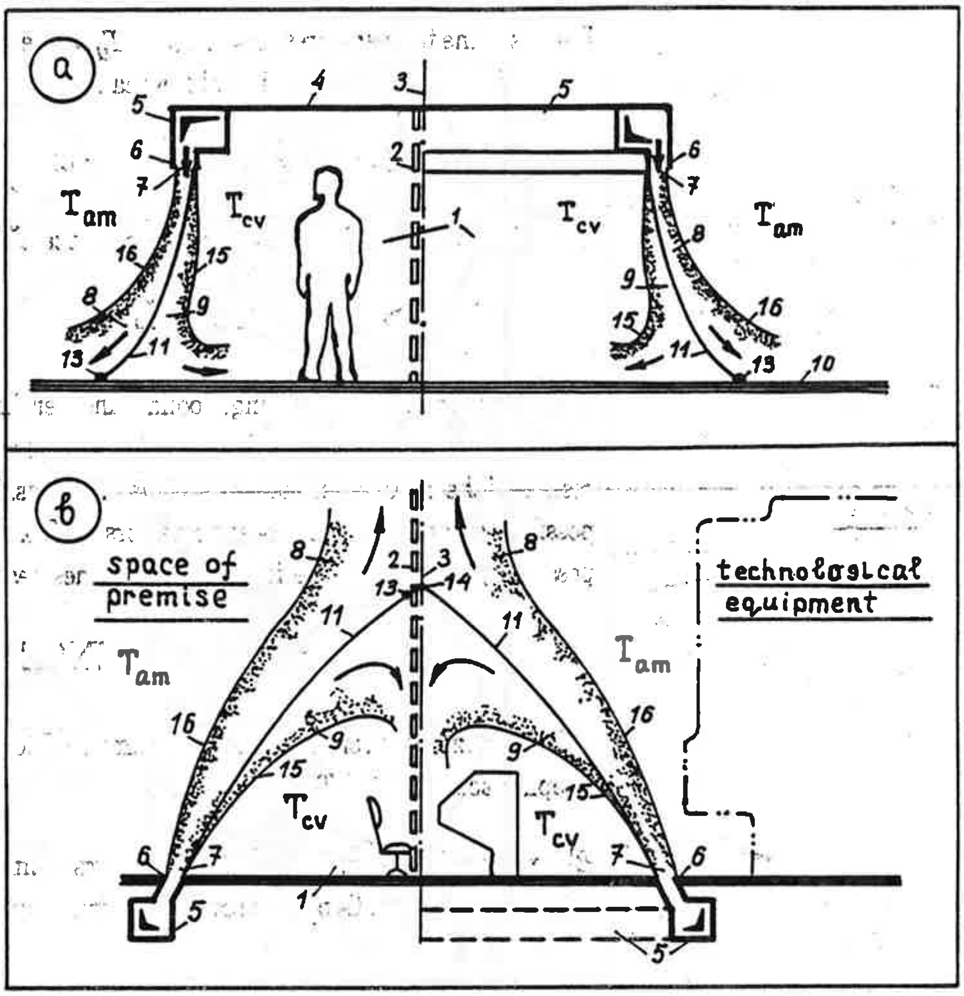

Fig.1 Schemes of air-jet protection (right parts - AJP with co-axial jet ; left parts - AJP with plane jets)

1. cavity ; 2. vertical wall ; 3. axis of AJP ; 4. roof ; 5. air distributor ; 6. nozzle ; 7. initial flow ; 8. upstream ; 9. downstream ; 10. horizontal surface ; 11. dividing surface ; 12. removing flow ; 13. reattachment point ; 14. merge point ; 15. inside boundary ; 16. outside boundary ; 17. axis of jet .

⇨ clean air
➡ removing air

(this nomenclature is common to fig.1 and fig.2)

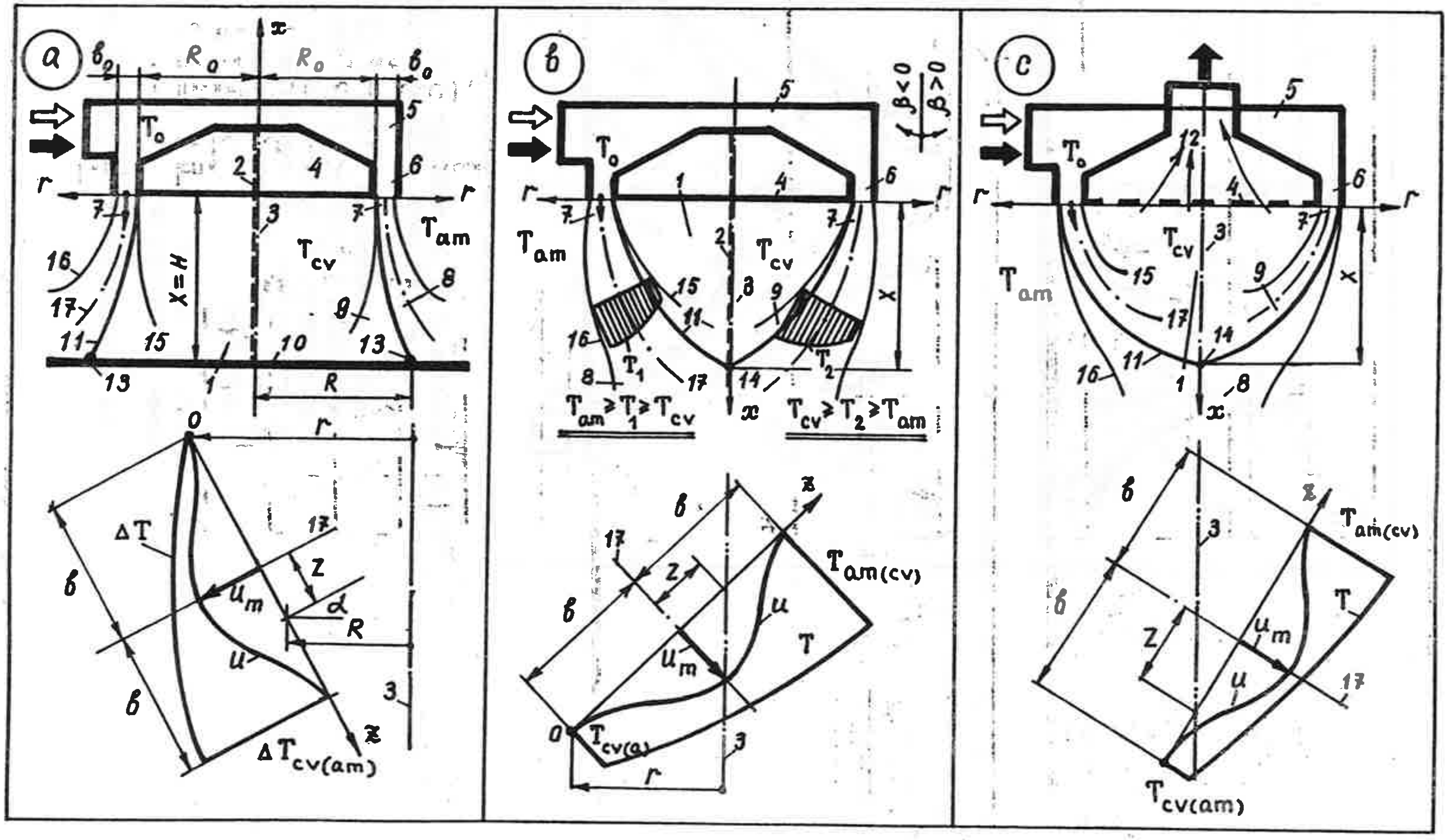

Fig. 2. Schemes for calculation of ΔJP :
a. with jet is reattached to horizontal surface ;
b. with merging jets (co-axial or system of plane jets); with plane jet is reattached to vertical wall ;
c. with flow removing from cavity.

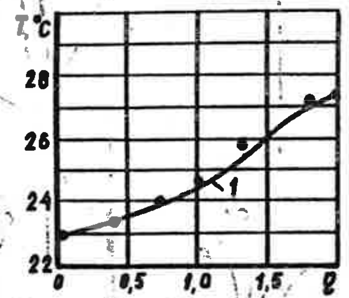

Fig.3. Temperatures profile in cross-section of plane jet

1. theoretical profile ($\Delta\tau<0$);
· experimental data are received by authors.

Conditions of calculation and tests: $T_0 = T_{am} = 23\,^\circ C$; $T_{av} = 27{,}3\,^\circ C$; $x/b_0 = 35$; $\bar{L} = 3{,}14$.

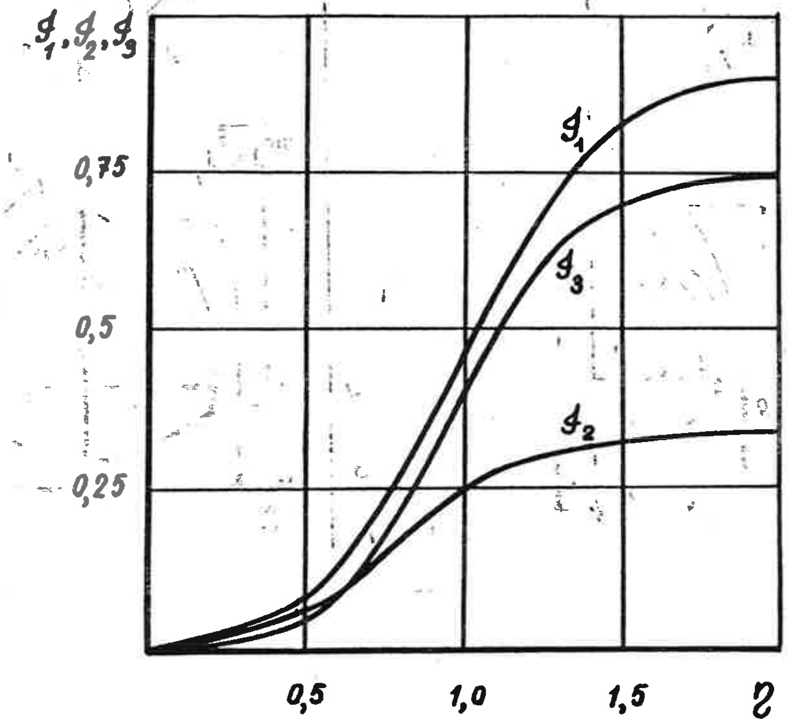

Fig. 4. Values of integrals $\vartheta_1, \vartheta_2, \vartheta_3$.