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CRITERIONAL RELATIONSHIPS USED TO DESCRIBE THE CIRCULATION OF AIRFLOWS IN A SPACE

Mikhail I.Grimitlin and Viktor I.Buyanov
Research Institute of Occupational Safety
St.Petersburg, Russia

SUMMARY

It is proposed to characterize the law-governed patterns of air circulation in ventilated spaces with heat emissions by using a system of dimensionless complexes and simplexes. Such a system is described, the appropriate criterional relationships are specified and recommendations on practical application of the established laws are given.

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INTRODUCTION

It is necessary to know the laws of airflows circulation in ventilated spaces in order to be able to provide a rational air-exchange set-up throughout the year by controlling these airflows/I/. The formation of air circulation patterns in ventilated spaces with excessive or insufficient heat emissions is affected by a great number of factors, such as in-space layout design; the capacity of the heat sources; their geometrical dimensions and location in relation to each other and to the room; the method of air supply and sometimes that of air extraction; aerodynamic and thermal characteristics of air distribution equipment; the quality of enclosing structures from the point of view of their thermal engineering properties; the parameters of the outside environment.

BRIEF BACKGROUND INFORMATION

Attempts have been made to apply the criterional relationships used in meteorology /2/ and ventilation engineering to the description of the process of airflows circulation. For example, the process of air stratification in a room under the impact of heat dissipation is described in /3/ with the aid of Richardson number Ri, and here number K is introduced as a modification of Richardson number, which expresses the relationship between the energies of inflow and convective jets in a room. The relationships between the characteristics of temperature distribution, air velocities in a ventilated space and the values of K and Ri numbers for some particular cases of air supply and extraction have been found experimentally /3/.

Extension of the obtained results to other methods of designing air-exchange set-up in a room has proved wrong. It has been shown by us that, for example, with the same value of K there can be considerable differences in the distribution of velocities and temperatures in the room volume. In fact, if the air is supplied by inflow jets which possess the same energy, the supply being concentrated in one case with the air discharged through a single inlet, and dispersed in another case, for example, through a perforated ceiling, the differences in the distribution of air velocities and temperatures through the occupation zone will be significant.

The research which has been done and literature analysis testify to the fact that the laws of airflows motion in a ventilated space can only be described by a system of criteria.

PROPOSED CRITERIONAL RELATIONSHIPS

It is suggested that such a system should be composed of three groups. Each of these groups characterizes one of the main features of the process of airflows motion in an enclosed space.

The first group includes criteria which describe the motion of inflow jets, taking into account the effect of the confined space and the impact of gravitational forces. In this case it is proposed to assess the conditions under which the designed circulation pattern can be disturbed due to gravitational forces by using the running value of Archimedes criterion.

For compact, fanned-out and conical jets this criterion is found from the formula:

$$Ar_x = \frac{n}{m^2} Ar_o \frac{x}{\sqrt{F_o}} \tag{I}$$

where $Ar_o = g\sqrt{F_o}\,\Delta t_o / v_o^2 T_{env.}$
is the Archimedes number at the jet outflow.

For plane jets

$$Ar_x = \frac{n}{m^2} Ar_o \left(\frac{x}{b_o}\right)^{3/2} \tag{2}$$

where $Ar_o = g\, b_o \Delta t_o / v_o^2 T_{env.}$

In order to ensure the pre-determined pattern of inflow jets motion Ar_x number must be calculated taking into account the specific dimensions of a room. The values of Ar_x obtained from formulae (I) and (2) must not exceed the critical values /I/.

The conditions for replenishing the inflow jets with environmental air when the jets are being discharged into the occupation or service zone from above downwards are characterized by the relationship between a jet area (F_j) and the room area per one air diffuser (F_r).

The relative jet areas ($\bar{F}_j = F_j / F_r$) are calculated from the following relationships:

for compact jets -

$$\bar{F}_j = \frac{F_o}{F_r}\left[C_1 + C_2 \left(\frac{H - h_{oz}}{1.13\sqrt{F_o}} - C_3 \right)\right]^2, \tag{3}$$

for fanned-out jets -

$$\bar{F}_j = 1 - 0.15\left(2 - \frac{H - h_{oz}}{\sqrt{F_z}}\right)^2 , \qquad (4)$$

for conical jets -

$$\bar{F}_j = 9.27\,\frac{(H - h_{oz})^2}{F_z} \qquad (5)$$

The values of constants C_1, C_2, C_3 are found experimentally.

In most cases the value of $\bar{F}_j$ must be within

$$0.2 \leq \bar{F}_j \leq 0.5 \qquad (6)$$

When air is supplied through diffusers by conical jets, $\bar{F}_{j\,max} = 0.6$; in the case of fanned-out or double jets supply $\bar{F}_{j\,max} = 0.7$

In the event of concentrated air supply the conditions for the development of a jet are determined by the location of the critical section x_{cr} beyond which air begins to withdraw from the jet. The relationship

$$x_{cr} = 0.31\, m\sqrt{F_z} \qquad (7)$$

is used for compact jets, and

$$x_{cr} = 0.15\, m^2 H \qquad (8)$$

for plane jets.

<u>The second group</u> includes dimensionless simplexes which describe the development of convective flows coming off heat sources in a room: the relative area of the heat sources $\bar{f} = f/F_z$, the relative perimeter of the heat sources $\bar{p} = p/p_z$, and the relative height of the room

$\bar{h} = h / \sqrt{F_t}$.

The conditions for a stable vertical motion of convective flows should be as follows:

$$\bar{f} < 0.4 \; ; \; \bar{p} < 0.8 \quad \text{and} \quad \bar{h} < 1.4 \qquad (9)$$

When the first and the second conditions are violated, convective flows deviate from the vertical, as proved by G.M.Pozin /4/, whereas in the case of violation of the third condition we have discovered a phenomenon of thermal jets disintegrating into vortices beginning at a height of I.4 $\sqrt{F_t}$

It is proposed to include number K_x which expresses the relationship between the "running" kinetic energies introduced by inflow and convective jets into the zone of their collision per unit of time into the third group of indices describing the interaction between inflow and convective jets. The zone of their collision is assumed to be the space within the boundaries of the colliding flows with the centre in the point of intersection of geometrical axes of those jets. Corresponding realtionships for design calculations have been obtained which are given in Table I.

The values of number K_x for specific cases when one kind of jets prevails over the other one have been found experimentally.

Based on these data, the conditions for designing the suppression of convective jets by inflow jets have been found, which are given in Table 2.

The circulation patterns of air flows are determined using the above system of criteria in the following way. The character of convective flows motion is found from the indices of the second group. If the flows can possibly deviate from the vertical in their motion, the relationships given in

Table 2 are to be used to find out a solution for suppressing convective jets, having previously ensured the designed pattern for the inflow jets with the help of the indices of the first group.

If the vertical motion of the convective flows is stable, the air supply set-up either includes or doesn't include the suppression of convective flows, depending on the required value of the air-exchange coefficient.

Table I

Relationships Used to Determine K_x Number

Type of colliding jets	Formula for design calculations
A compact inflow jet and a compact convective jet	$4.49 \cdot 10^{-4} \frac{m}{x y Q_c} \left(\frac{T_{env.} G_o}{\sqrt{F_o}} \right)^3$
A fanned-out inflow jet and plane convective jets	$7.46 \cdot 10^{-4} \frac{m}{x y Q_c} \left(\frac{T_{env.} G_o}{\sqrt{F_o}} \right)^3$
A plane inflow jet and a plane convective jet	$5.30 \cdot 10^{-4} \frac{m \sqrt{B_o}}{\sqrt{x} y Q_c} \frac{(T_{env.} G_o)^3}{F_o^2}$

CONCLUSIONS

Relationships which describe the laws of development and interaction between air flows in ventilated spaces with heat emissions have been proposed. In particular applications these relationships offer a solution for the problem of designing ventilation and air conditioning systems with a variable value of the air-exchange coefficient throughout the year, which makes it possible, as shown in /5/, to reduce heat and cold consumption.

Table 2

Design Calculations for the Interaction between Colliding Inflow and Convective Jets

Type of Colliding Jets	Conditions for Suppression of Convective Jets by Inflow Jets
Coaxial compact jets	$\frac{m}{H^2 Q_c}\left(\frac{T_{env.} G_o}{\sqrt{F_o}}\right)^3 \geq 3 \cdot 10^4$
A fanned-out inflow jet and convective jets	$\frac{m}{H(1.4H + \sqrt{F_z})\, Q_c}\left(\frac{T_{env.} G_o}{\sqrt{F_o}}\right)^3 \geq 10^4$
Compact jets at an angle to each other (inclination ϑ of geometric axis of the inlet to the horizon within $0^\circ < \vartheta < 90^\circ$)	$\frac{m \cos\vartheta}{F_z(2H_{inl.} - \sqrt{F_z}\, tg\vartheta)\, Q_c}\left(\frac{T_{env.} G_o}{\sqrt{F_o}}\right)^3 \geq 1.6 \cdot 10^5$

LEGEND

m - coefficient of air velocity variation in a jet;
n - coefficient of excess temperature variation in a jet;
G_o - mass air flow at the outlet of one air diffuser, kg/s;
Q_c - convective heat flow, W; v - air flow velocity, m/s;
$T_{env.}$ - absolute temperature of environmental air, K;
f - area of horizontal surfaces of heat sources, m^2;
F_o - free cross-section area of air diffuser, m^2; F_r -floor area of the room or its module, m^2; p - heat sources perimeter along which convective flows are replenished, m; p_r - room perimeter, m; H - room height, m; $H_{inl.}$ - height of air inlet location, m; h - room height calculated from the horizontal surface of a heat source, m; x, y - paths covered by inflow and convective jets up to the zone of their collision; b_o - width of air diffuser slot which forms a plane jet.

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