Use of a supply ventilation system as an air curtain

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Abstract. Recently, for a number of reasons, retail and office premises on the first floors of the building, which have a separate entrance to the street, have gained wide popularity. These rooms must have supply ventilation to maintain the required microclimate parameters. The article proposes, in addition to fulfilling its main function, to use general exchange ventilation as an air curtain in these types of premises. Due to the supply of air above the doorway with certain parameters, in some cases, it is possible to abandon the thermal air curtain as a separate energy-intensive device. The implementation of this task is supposed to be carried out by organizing the necessary air exchange scheme, without increasing its required performance. The article presents the results of the study, which make it possible to assess the possibility of using the proposed technical solution for the most standard case. In particular, an adapted calculation of the air distribution grille is presented to fulfill the stated purpose.

1. Introduction

All over the world, the level of requirements for the parameters of the air environment in rooms for various purposes is constantly increasing. Formation of comfortable parameters of the environment in habitable premises is the main function of life support systems. Open doors, windows and other openings lead to significant heat loss and are the main cause of drafts in the room. Air-thermal curtains help to solve several problems at once related to maintaining the microclimate and energy consumption of the building as a whole. They are designed to separate zones with different air temperatures on different sides of open openings of working windows, entrance doors and gates. By supplying a high-speed air flow, they form a kind of curtain that prevents warm air from escaping outside and does not let cold air into the room. When the curtain is used in a room with an open opening, the internal thermal comfort is improved, drafts disappear, heat losses are significantly reduced, and, consequently, heating costs.

In summer, in areas with a warm climate, the air curtain is also energy efficient, since it significantly reduces the cost of air conditioning.

In the modern world, the problem of energy conservation is very relevant, which makes scientific and technological progress require the introduction of new energy-efficient technologies, constant replenishment of scientific ideas, as well as fundamental research. Energy saving implies the efficient (rational) use of energy in all links: from the extraction of primary energy resources to the consumption of all types of energy by end users. Thus, the improvement of heating and ventilation systems aimed at reducing the energy consumption spent on creating and maintaining the required microclimate in the premises, is a very urgent task [1, 2].
Having carried out a comprehensive analysis of the operation of air-thermal curtains, we can confidently assert that they do not always meet modern energy saving requirements, due to the use of an electric heater for heating the supplied air [3].

Today, along with large retail and office buildings, small offices and trade organizations, often located on the ground floor of knowledge, have gained high popularity. These premises, as a rule, have a separate entrance and are equipped with a supply and exhaust general ventilation system [4], [5]. The main feature of these premises is not high attendance, therefore, the work of a separately installed heat curtain will be, although effective, but impractical. The operating mode of general ventilation is constant, since it is aimed at maintaining the required parameters of the microclimate [6].

Considering all of the above, a new promising technical solution appears, which consists in using a supply-side general ventilation system as an air curtain in small public spaces. By organizing the necessary air exchange in the room, general ventilation can function as a heat curtain, which will increase the energy efficiency of engineering systems and reduce the overhead costs of maintaining the premises.

2. Materials and methods

2.1. Materials

To use the proposed direction, it is first of all necessary to consider the existing methods for calculating the general ventilation system and air curtain.

Ventilation of premises is a prerequisite for work. The calculation of the required air exchange in the premises under consideration should be based on the type of room and the number of people working there [6]. The performance of the supply and exhaust ventilation system in this case is determined by the minimum amount of outdoor air per person. For one person, the air exchange rate ranges from 20-60 m³/h. This average value varies markedly depending on the purpose of the room. In practice, as a rule, 60 m³/h per person is sufficient for a permanent stay at the workplace and 30 m³/h for each person for a temporary stay (less than 2 hours) [6], [7].

As for the calculation and design of air curtains, today there are a lot of works that are devoted to this issue [8-21]. However, most of them are considering industrial use cases that have a number of features.

2.2. Methods

To select the heat output of the air curtain, it is necessary to know the total time during which the entrance doors will be open, the specific flow of cold air, and the dimensions of the doorway.

The specific flow of cold air is determined by the formula:

\[ j_{ex} = \mu_{ex} \cdot (2 \rho_e \cdot \Delta p_{ex})^{0.5} \]  (1)

where \( \mu_{ex} \) – the coefficient of air consumption at the inlet without taking into account the action of the air curtain and the influence of the figure of a person passing through the inlet;

\( \rho_e \) – he density of the outside air;

\( \Delta p_{ex} \) – the calculated pressure difference determined by the formula:

\[ \Delta p_{ex} = 0.5 \cdot (H_{bu} + 2h_{g} - h_{d}) \cdot (\gamma_{ex} - \gamma_{in}) \]  (2)

where \( H_{bu} \) – the height of the building from the ground surface to the top of the staircase, m;

\( \gamma_{ex} \) and \( \gamma_{in} \) – specific gravity of air, at the design temperature of outdoor and indoor air.

It has been experimentally established that the equivalent time \( z_{in} \) for a single passage of a person through single doors is 2 s, through double doors 1.5 s and through triple doors 1-1.2 s.

Knowing the number of people passing through the entrance for 1 hour, you can determine the total
amount of cold air:

\[ G_{ex} = 0.9 \cdot j_{ex} \cdot A_{ex} \cdot z_{in} \cdot N_{ex} \]  

(3)

where \( j_{ex} \) – the specific flow of cold air, kg/(s m\(^2\));

\( A_{ex} \) – door area, m\(^2\);

\( z_{in} \) – equivalent time of door opening;

\( N_{ex} \) – the number of people passing through the entrance in 1 hour.

Heat consumption for heating cold air is found by the formula:

\[ G_{ex} = 0.9 \cdot j_{ex} \cdot A_{ex} \cdot z_{in} \cdot N_{ex} \]  

(4)

where \( c \) – the heat capacity of air, J/(kg °C);

\( t_{in} \) – internal temperature, °C;

\( t_{ex} \) – outside temperature, °C.

The amount of air \( G_{z} \), kg/h, heated to \( t_{z} \), to create an air-thermal curtain, is determined by the formula:

\[ G_{z} = \frac{Q_{ex}}{c \cdot (t_{z} - t_{ex})} \]  

(5)

The volumetric flow rate of the supplied air at a temperature \( t_{z} \) of heated air [9]:

\[ L_{z} = \frac{G_{z}}{\rho_{z}} \]  

(6)

The above dependencies determine the amount of supply air required to compensate for heat losses due to opening the outer doors. However, when designing an air curtain, in our case, the determining parameter will be the air flow rate, which will prevent the flow of cold air.

In some works, [10] there is evidence that a sufficient condition for the operation of an air curtain is the passage of the outer boundary or axis of the jet through a certain point and finding the value of the average air velocity at the “end of the jet” within 2-3 m/s. At the same time, it is considered that such a balance of heat in the door opening is automatically observed, in which there is no heat loss with the air leaving outside, and with the incoming cold air. In our opinion, this approach is not entirely accurate, but we can use it, taking into account the specifics of the serviced object: a small area of the doorway, short-term opening of doors.

3. Results

A special place in the issue under consideration will be occupied by the method of supplying and distributing air to achieve the goal. The air distributor must fulfill the condition of maintaining the minimum required speed at the end of at least 2-3 m/s, and also fit harmoniously into the interior of the room. Since the doors in most cases for this type of premises have a small width (up to 1.5 meters, usually 0.8-1.1 m), it is most preferable to carry out air distribution using a ready-made standard air distribution device: a supply grille [23]. When calculating and selecting the most suitable grille, it is necessary to use the theory of movement of supply ventilation jets [24]. In our case, a flat jet will take place. Plane jets are formed when they flow out of elongated rectangular holes with a side ratio \( a_0/b_0 > 5 \), where \( a_0 \) and \( b_0 \) are respectively the sizes of the larger and smaller sides of the grating. For plane jets \( x < 6a_0 \) we have:
\[ V_x = \frac{m_1 \cdot V_0 \cdot \sqrt{b_0} \cdot K_c \cdot K_b \cdot K_n}{\sqrt{x}} \]  

(7)

\[ \Delta t_0^{\text{max}} = \frac{n_1 \cdot \Delta t_0 \cdot \sqrt{b_0} \cdot K_b}{K_c \cdot K_n} \]  

(8)

where \( V_x \) – the maximum air velocity in the main section of the jet at a distance \( x \) from the grate, m/s;

\( m_1 = m/2.45; \)

\( m \) – lattice speed coefficient;

\( n_1 = n/2.45; \)

\( n \) – the temperature coefficient for a flat section of the jet;

\( F_0 \) – area of the calculated section of the section;

\( b_0 \) – the width of the design section of the lattice;

\( V_0 \) – exit speed from the grid;

\( \Delta t_0 \) – the temperature difference;

\( K_c \) – coefficient of constraint;

\( K_b \) – the coefficient of interaction;

\( K_n \) – non-isothermal coefficient;

\( x \) – the distance from the lattice to the point under consideration, m.

In our case, we will have a non-isothermal jet with a small value of \( \Delta t_0 \) = 3, according to [6], the supply air temperature in public premises should be no more than 3 °C above the calculated supply air temperature.

Since when designing a supply-side general-exchange ventilation system with the function of a heat curtain, it is first of all necessary to know the required speed at the outlet from the air distribution device, then from formula (7) we express the parameter \( V_0 \), setting the speed \( V_x = 2\text{-}3 \) m/s:

\[ V_0 = \frac{V_x \sqrt{x}}{m_1 \cdot \sqrt{b_0} \cdot K_c \cdot K_b \cdot K_n} \]  

(9)

However, this dependence is suitable only for a rough estimate, since it includes the non-isothermal coefficient \( K_n \) with the participation of the parameter \( V_0 \). In our and similar cases, it is quite possible to use this dependence, since there is an insignificant temperature difference between the ambient temperature and the supply air temperature, which leads to a minimal effect of gravitational forces.

Knowing the velocity in the section of the grating \( V_0 \), we can determine the air flow required to supply \( G \), m³/s:

\[ G = F_0 \cdot V_0 \]  

(10)

Let's make a calculation for the most typical conditions with the following initial data:

- room height \( h = 3 \) m;
- the width of the doorway \( c = 0.8 \) m;
- air temperature in the room \( t_w = 19 \) °C;
- supply air temperature according to [6] 22 °C, temperature difference \( \Delta t_0 = 3 \);  
- air speed at the end of the jet \( V_x = 2 \) m/s;
- let us set the air speed at the outlet from the grating \( V_0 = 5 \) m/s;
- the lattice is of the AMN type with dimensions 0.8x0.1 from the manufacturer's catalog [23] (Figure 1). The area of the calculated cross-section of the accepted lattice according to the catalog is \( F_0 = 0.073 \) m².
When calculating, we will take the scheme of supply air supply from top to bottom with conical compact jets (Figure 2).

There are two approaches to calculating non-isothermal jets. The first approach is based on the complex parameter \( H \)-geometric characteristic [13], which has the dimension of length and depends on the design parameters of the distributor (coefficients \( m, n, F_0 \)) and the conditions at the outlet \((V_0, t)\).

The second approach is based on the dimensionless characteristic of the jet - the current Archimedes criterion [23], at a certain distance from the air distributor, which also depends on the above parameters and on the considered jet length.

The geometric characteristic \( H \) for a flat jet is determined by the formula:

\[
H = \sqrt{h_0 \cdot T_n^2 \cdot \left( \frac{m \cdot V_0^4}{n \cdot \Delta t_0 \cdot g} \right)^{\frac{3}{2}}}
\]  

(11)

where \( T_n \) – the ambient temperature, K;
\( g \) – acceleration due to gravity 9.81 m/s^2;
for our case for the chosen lattice \( m = 6, n = 5.1 \).

When heated air is supplied, when its temperature is higher than the average air temperature, gravitational forces arise due to the difference in air densities, which reduce the range of the jet. This fact is taken into account by the non-isothermal coefficient \( K_n \), which for our case is defined as:

\[
K_n = \sqrt{1 - \frac{x}{H}}
\]  

(12)

Since in our case the temperature difference is insignificant \( \Delta t_0 = 3 ^\circ C \), and the velocity \( V_0 \) is sufficiently high, the value of the non-isothermal coefficient becomes insignificant due to its tendency in the unit \( Kn = 0.99 \) (Figure 3, 4), which allows using the dependence (9).

After making calculations, we got the value \( V_x = 2.12 \) m/s, which corresponds to the initially specified condition. We plotted the dependence of \( V_x \) on \( V_0 \) under the given conditions for the listed conditions (Figure 5).
For a speed $V_0 = 5 \text{ m/s}$ according to the diagram [23], the sound pressure level for this grille will be 46 dB, which is below the permissible 60 dB for this type of room.

4. Discussion
Consideration of the problem posed in the article is carried out using existing methods and data, however, some of them may be subject to criticism. In particular, there is evidence that the calculation of the required speed $V_x$ is not entirely accurate [22], so the authors plan to continue research in this direction. However, today this direction is very promising and the use of this technical solution is very attractive from the point of view of energy saving in engineering systems.
5. Summary
The article discusses the possibility of using general supply ventilation to prevent cold air from entering when opening doors in public premises. The implementation of this task is supposed to be carried out by organizing the necessary air exchange scheme, without increasing its required performance. Thus, general ventilation will simultaneously perform two functions: maintaining the required microclimate parameters and act as a heat curtain. The article deals with the most typical case for a public space of a small area, however, for a wider application of this technical solution, further research is needed.

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