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AIR DISTRIBUTION EFFICIENCY WITH A LINEAR SLOT DIFFUSER IN NON-ISOTHERMAL CONDITIONS

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Abstract. Effective provision of a comfortable indoor climate is a key requirement for modern central air ventilation systems. These systems play an important role in creating a healthy and comfortable environment for living, working or relaxing. Taking into account modern architectural trends and design solutions, linear louver diffusers are becoming increasingly popular as air distribution devices. Their aesthetic appeal allows them to be harmoniously integrated into interior design, often making them central elements that emphasize the style of the room.

The design feature of linear louver diffusers lies in their specific structure: they have a small width with a significant length, which distinguishes them from traditional compact diffusers of round or square shape. This feature significantly affects the characteristics of the air jet formed by such diffusers. During the operation of ventilation systems in air conditioning or air heating modes, linear diffusers create unique air flows that differ from compact jets in their behavior, velocity and temperature distribution. These differences must be taken into account at the stages of design, adjustment and operation of ventilation systems in order to ensure their effective operation and achieve an optimal microclimate.

Data obtained from computer modeling and experimental studies play a key role in the development and optimization of ventilation systems with linear louver diffusers. Modeling allows you to predict the behavior of air flows in different conditions, taking into account the geometry of the room, the location of the diffusers and air parameters (temperature, humidity, flow rate). Experimental studies, in turn, confirm theoretical calculations and allow you to refine the parameters of the system. Thanks to an integrated approach that combines modeling and experiments, it is possible to achieve high efficiency of ventilation systems, minimize energy consumption and ensure a comfortable microclimate in the premises.

The use of linear louver diffusers also contributes to reducing noise exposure and uniform air distribution, which is especially important for residential and public spaces. Proper selection and adjustment of such diffusers allows you to avoid areas of air stagnation or excessive turbulence, which can negatively affect the comfort of users. Thus, taking into account the features of linear diffusers at all stages – from design to operation – is the key to creating effective and aesthetically attractive ventilation systems that meet modern requirements for comfort and energy efficiency.

Keywords: microclimate, thermal comfort, flat jet, air distribution; air flow turbulence.

Introduction. The requirements of current standards for the microclimate in rooms where people are located are strict and require ensuring a high level of ventilation and air distribution quality, the necessary temperature distribution and a comfortable microclimate [1, 2].

To ensure comfortable conditions in the room, air distribution devices operate in a non-isothermal mode for a significant part of the time, i.e. the temperature of the air supplied from the diffusers is different from the air temperature in the room [3, 4]. It is important in public and residential premises with constant operation of ventilation systems to correctly calculate and adjust the air distribution in such a way as to reduce the possibility of drafts in the rooms [5], to avoid the formation of stagnant zones and large differences in air temperature in the room [6].

One of the most effective and optimal solutions for small-sized rooms is the use of linear louver diffusers [7][9]. Such diffusers ensure uniform distribution of heated or cooled supply air, supply of a large amount of air [8, 9] with rapid attenuation of the axial velocity of the air in the jet [10, 11]. The use of linear slot diffusers allows for comfort in rooms [12], improve working conditions and efficiency, reduce [13] the cost of operating ventilation systems [14] and energy consumption [15].

Studies of air distribution devices confirm that it is the use of linear slot diffusers that allows for the best quality of air distribution in rooms and microclimate.

Analysis of the recent publications and research works on the problem. Many studies and scientific articles in the past and present concern the operating characteristics of ventilation systems and air distribution devices [16][26], which is very important for ensuring microclimate parameters in premises for various purposes [6], 17, 18]. Studies are carried out using numerical simulations and experimentally [19-21]. However, today a significant number of these studies concern vortex diffusers [3, 22]. The operating parameters of linear slot diffusers are insufficiently studied, but important because such diffusers are quite popular today [23, 24]. The studies described the characteristics of air flows under isothermal conditions.

Due to the lack of generalized calculation methods for linear louver slot diffusers available on the market, despite their similarity in appearance, they often have quite significant differences in technical characteristics [5].

Known studies conducted using mathematical modeling consider flat and vortex air jets, but do not describe rectangular ones, which are characterized by a small slot width and a relatively large length. These studies were conducted based on the analysis of several modeling approaches, in particular the k-ε model, since they allow for fairly high-quality numerical modeling [6].

Therefore, the study of the parameters and characteristics of linear slot diffusers and the formation of methods and determination of dependencies for their calculations, especially when operating in non-isothermal conditions, which are an approximation to the actual operating conditions, is important for energy-efficient and high-quality provision of the required microclimate parameters in rooms and safe operation of such equipment [12, 25].

For linear slot diffusers, calculation and modeling of the temperature distribution and attenuation in the jet is necessary, since these diffusers are used mainly in rooms of small volume and at short distances from the area where people are staying [26].

The purpose of the article is to analyze the effectiveness of using linear slot diffusers in ventilation systems operating in non-isothermal conditions and to investigate their aerodynamic characteristics.

Research methodology. Using the methods of physical and mathematical modeling of air flow motion based on jet flow equations, theoretical research methods were applied, thanks to which calculated dependencies were obtained for determining the parameters of the air flow and geometric parameters of the linear louver diffuser.

Using assumptions and simplifications, the results of experimental studies were also processed. Based on the theory of similarity and modeling of scales for the conversion of physical quantities and for visualization of the air flow structure and the structure of microjets, the results of these experimental measurements were processed. A planning matrix was constructed for planning a multifactorial experiment.

Presentation of research results. In ventilation systems of premises air distribution devices of various designs are used. These devices, depending on their structure and purpose, have common as well as significantly different operating characteristics.

Flat jets formed during the operation of louvered slotted linear diffusers are [3]:

– free, if such jets have no obstacles in their development;

– not free, if the development of the jet is affected by obstacles and surfaces of the premises;

– isothermal, the air temperature in the jet and in the room is the same;

– non-isothermal (heated or cooled), when the air temperature in the jet is different from the air temperature in the room.

Slotted linear diffusers have several flat slots and during their operation, the effect of interaction of several parallel flat jets occurs at the outlet of the device, which leads to turbulization of the entire air flow and a drop in temperature in the jet.

In non-isothermal flat jets, when heated air is supplied horizontally, there is a deviation of the jet upwards, when cooled air is supplied, there is a deviation downwards due to the influence of gravitational forces [24].

As a result of such a deviation of each flat microjet formed by each slot of the linear slot diffuser, rapid mixing of the flows occurs, as shown in Fig.1. This leads to a sharper decrease in the speed of the total jet formed by a diffuser of this type.

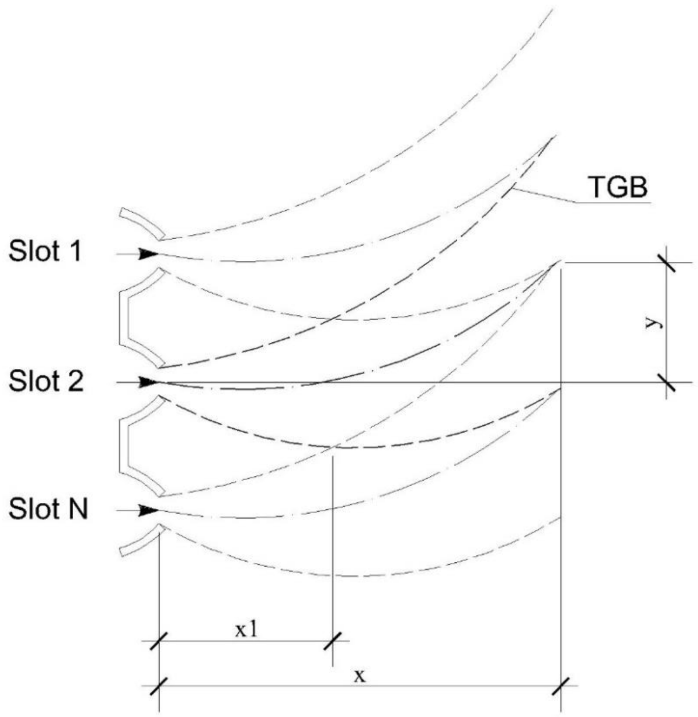


Fig. 1. Thermal limits of microjets of a linear louvered slot diffuser:
TGB – thermal jet boundary; x – current longitudinal coordinate; x_1 – coordinate of the start of mixing of microjets; y – the amount of deviation from the jet axis to the slit axis; Slot 1…Slot N – linear diffuser slots

The relationship between gravitational and inertial forces in non-isothermal jets and microjets at the moment of air leakage is characterized by the Archimedes criterion Ar_o:

$$Ar_o = \frac{g\sqrt{F_o}\cdot\Delta t_o}{V_o^2\cdot T_{in}}, \quad (1)$$

where $g = 9.81$ m/s^2;

F_o– nozzle area, m^2;

Δt_o– excessive initial temperature, $\Delta t_0 = t_0 - t_{in}$, K;

T_{in} – absolute indoor air temperature, K, t_{in} – indoor air temperature, °C;

V_0 – initial speed, m/s.

In non-isothermal jets discharged horizontally, the excess temperature $\Delta t_x = t_x - t_{in}$ is determined by the formula:

$$\Delta t_x = \frac{N}{x}, \quad (2)$$

where x – current longitudinal coordinate;

N – thermal parameter:

$$N = \frac{0.54}{tg\alpha}\sqrt{\frac{T_{\text{в}}}{T_0}}\cdot\frac{1}{\sqrt[4]{\xi}}\cdot\Delta t_o\cdot\sqrt{F_o}, \quad (3)$$

where α – is the jet opening angle, $\alpha = 12°25'$, and $tg\alpha = 0.22$;

ξ – local resistance coefficient, $\xi = 1$;

T_0 – absolute temperature at the nozzle outlet, K.

In calculations, to simplify them, the temperature damping coefficient during jet development is used n:

$$n = \frac{0.54}{tg\alpha}\sqrt{\frac{T_B}{T_0}} \cdot \frac{1}{\sqrt[4]{\xi}}, \quad (4)$$

then the axial excess temperature Δt_x:

$$\Delta t_x = n \cdot \Delta t_o \cdot \frac{\sqrt{F_o}}{x}. \quad (5)$$

Therefore, excess temperature $\Delta t_x = t_y - t_{in}$ in any cross section "x" at a distance "y" from the axis is determined by the formula:

$$\Delta t_y = \Delta t_x \cdot exp\left(-0.7\sigma_T \overline{y}^2\right), \quad (6)$$

where σT – turbulent Prandtl number, $\sigma_T = 0.65 - 0.70$;

$\overline{y}$ – current transverse coordinate, $\overline{y} = {}^{y}/_{cx}$ – experimental constant, $c = 0.28$.

The calculations use the relative values of excess temperatures, axial $\Delta\overline{t}_x = \Delta t_x/\Delta t_o$ тand in any cross-section $\Delta\overline{t}_y = \Delta t_y/\Delta t_x$.

Practical calculations of jets are performed using the formulas [24]:

$$\Delta\overline{t}_x = n \cdot \sqrt{\frac{\sqrt{F_o}}{x}} \cdot \frac{1}{k_n}, \quad (7)$$

where, k_n- the coefficient of non-isothermality, for plane jets, is 1.13 (for heated) and 0.82 (for chilled).

The research was conducted on the following experimental setup, which is schematically shown in Fig. 2.

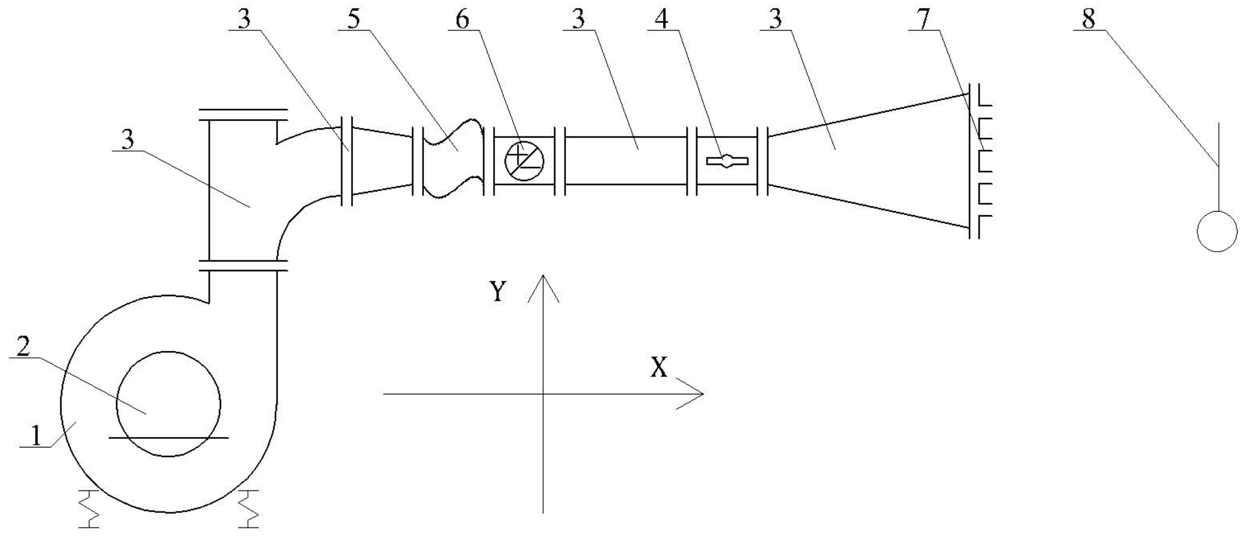


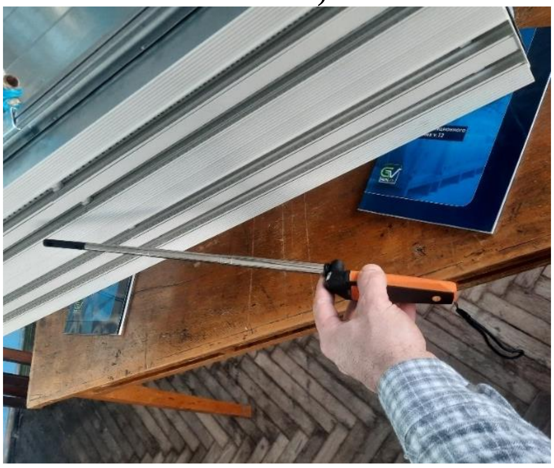
Fig. 2. Experimental setup (schematically):
1 – fan; 2 – electric motor; 3 – air duct; 4 – control valve; 5 – flexible insert; 6 – air heater/cooler; 7 – linear slot diffuser; 8 – testo-405i thermoelectroanemometer

The experimental setup consists of a fan, a regulating throttle to set the required flow rate, an air cooler and air heater, an air duct system that provides air supply and a linear louver diffuser, as well as instruments for measuring air velocity and temperature.

The studies were conducted for different numbers of slots of the linear louver diffuser and different slot lengths. The height of all slots was constant. The research process is shown in Fig. 3.

a)

b)



c)

d)

Fig. 3. Field studies:
a – linear diffuser louvers; b – general view of the experimental setup; c – measurement of isothermal jet parameters; d – visualization of the jet with smoke

After processing the experimental data, the following dependence of the drop in the relative jet temperature was obtained depending on the relative current coordinate Fig. 4.

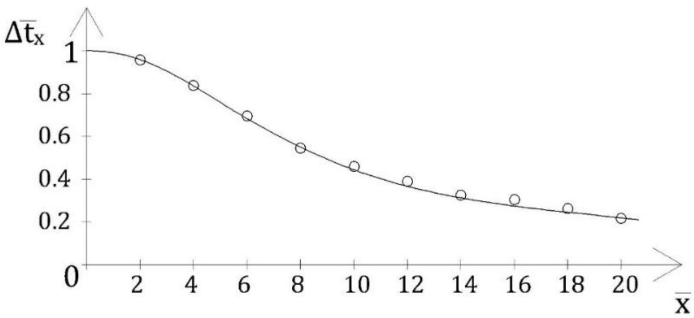


Fig. 4. Dependence of relative temperature on longitudinal coordinate $\Delta\bar{t}_x = f(\bar{x})$ for linear slot diffuser (° – experimental data)

According to the obtained results, which are shown in Fig. 3, it can be concluded that the heated or cooled air flow leaving the louvered linear diffuser is turbulized faster than the air distribution grilles. As a result, the velocity and temperature decay in the jet occurs faster and more actively. The value of the temperature decay coefficient for the linear louvered slot diffuser is equal to $n = 1.5 - 2.0$, which is significantly smaller compared to such a coefficient for a conventional air distribution grille, for which $n = 3.2$.

Conclusion. The obtained dependences of the velocity decay as a result of the conducted studies of non-isothermal flat jets formed in linear louvered slot diffusers allow to improve and expand the existing methods of calculating air distribution devices.

It has been confirmed that with the joint interaction of several flat jets formed in linear louvered slot diffusers, a 10 - 20 % sharper decrease in the air temperature in the jet is observed due to greater turbulence of the air flow.

The temperature attenuation coefficient for the linear slot diffuser $n = 1.5 - 2.0$ allows it to be used in ventilation systems with high air distribution conditions, without the occurrence of drafts in the premises.

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ЕФЕКТИВНІСТЬ ПОВІТРОРОЗПОДІЛУ ЛІНІЙНИМ ЩІЛИННИМ ДИФУЗОРОМ В НЕІЗОТЕРМІНИХ УМОВАХ

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Анотація. Ефективне забезпечення комфортного мікроклімату в приміщеннях є ключовою вимогою до сучасних центральних систем вентиляції повітря. Ці системи відіграють важливу роль у створенні здорового та комфортного середовища для проживання, роботи чи відпочинку. З урахуванням сучасних архітектурних тенденцій і дизайнерських рішень, лінійні жалюзійні дифузори набувають дедалі більшої популярності як повітророзподільні пристрої. Їхня естетична привабливість дозволяє гармонійно інтегрувати їх у дизайн інтер'єру, часто роблячи їх центральними елементами, що підкреслюють стиль приміщення.

Конструктивна особливість лінійних жалюзійних дифузорів полягає в їхній специфічній будові: вони мають малу ширину при значній довжині, що відрізняє їх від традиційних компактних дифузорів круглої чи квадратної форми. Ця особливість суттєво впливає на характеристики повітряної струмини, яка формується такими дифузорами. Під час роботи вентиляційних систем у режимах кондиціонування або повітряного опалення лінійні дифузори створюють унікальні повітряні потоки, що відрізняються від компактних струмин за своєю поведінкою, розподілом швидкості та температури. Ці відмінності необхідно враховувати на етапах проєктування, налаштування та експлуатації систем вентиляції, щоб забезпечити їхню ефективну роботу та досягти оптимального мікроклімату.

Дані, отримані в результаті комп'ютерного моделювання та експериментальних досліджень, відіграють ключову роль у розробці та оптимізації вентиляційних систем із лінійними жалюзійними дифузорами. Моделювання дозволяє прогнозувати поведінку повітряних потоків у різних умовах, враховуючи геометрію приміщення, розташування дифузорів і параметри повітря (температуру, вологість, швидкість потоку). Експериментальні дослідження, у свою чергу, підтверджують теоретичні розрахунки та дозволяють уточнити параметри роботи системи. Завдяки комплексному підходу, що поєднує моделювання та експерименти, можна досягти високої ефективності вентиляційних систем, мінімізувати енергоспоживання та забезпечити комфортний мікроклімат у приміщеннях.

Використання лінійних жалюзійних дифузорів також сприяє зниженню шумового впливу та рівномірному розподілу повітря, що особливо важливо для житлових і громадських приміщень. Правильний підбір і налаштування таких дифузорів дозволяють уникнути зон застою повітря чи надмірної турбулентності, що може негативно впливати на комфорт користувачів. Таким чином, врахування особливостей лінійних дифузорів на всіх етапах – від проєктування до експлуатації – є запорукою створення ефективних і естетично привабливих вентиляційних систем, які відповідають сучасним вимогам до комфорту та енергоефективності.

Ключові слова: мікроклімат, тепловий комфорт, плоский струмінь, подача повітря, турбулізація повітряного потоку.

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