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CHARACTERISTICS OF THE OPERATION OF A LINEAR SLOT DIFFUSER IN SEMILIMITED CONDITIONS

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The effective operation of ventilation systems depends on how its components are correctly calculated and selected accordingly. However, it happens that the actual and calculated parameters of operation often differ, especially in cases where linear louver diffusers are used. Such a difference in characteristics arises from the fact that, usually, formulas and nomograms for the selection of linear diffusers are built for conditions when the jets are free, in actual operating conditions the jets are not free.

This article considers the influence of the enclosing structures of the room on the jet formed by a linear louver diffuser. Such devices have a small width with a significant length of the air outlet slots, which affects the characteristics of the jet. Such features of the operation of these diffusers must be taken into account at the stages of design, operation, and adjustment to ensure optimal microclimate parameters.

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

Introduction

Today, there are many studies describing the development and characteristics of free jets (Chemerynskyi & Voznyak, 2025) and non-free jets (Borowski et al., 2023). Free jets are those that are not affected by the surrounding enclosing structures and other obstacles (Voznyak, Bokhan et al., 2025). Non-free jets are those that are significantly limited by the surrounding enclosing structures of the room or other objects located in it and are also affected by adjacent jets or air flows (Voznyak, Chemerynskyi et al., 2025). The first case concerns rooms of considerable size and large volume compared to the size of the jet formed by the supply device. The second case, on the contrary, occurs in rooms of very small size and volume. Both cases are not common. The most common are semi-free jets, which occur during the operation of ventilation systems in rooms. Semi-free jets are formed when they are partially affected by enclosing structures, other obstacles and adjacent jets and air flows. Such an impact causes deformation of the jet development and its transverse and longitudinal velocity fields, as well as curvature of the jet axis. This in turn affects the microclimate parameters and comfortable conditions in the premises (ASHRAE, 2023).

The position of the supply and exhaust openings relative to the surrounding obstacles and in relation to other supply and exhaust devices (Cao et al., 2011) is important for the correct development of jets of linear louver diffusers (Alkhalaf et al., 2024), since unlike conventional round jets, jets in a linear diffuser have a specific structure (Yu et al., 2003). The considerable length with a small width of the air outlet slots of a linear louver diffuser causes a sharper impact in comparison. And the efficiency and correctness of such a diffuser depends significantly on its location relative to surrounding obstacles.

The most studied air flow pattern to date are compressed jets (Eraslan et al., 2023), which develop according to a dead-end pattern, that is, a pattern where the supply and exhaust openings are located in the same plane. In this case, the initial volume of air, having reached the opposite plane, turns around and moves in the opposite direction towards the main flow.

Today, there are many studies (Borowski et al., 2019) of the characteristics of the development of jets formed by a linear louver diffuser in rooms for various purposes, in particular, work has been studied even in operating rooms (Both et al., 2017; Park, 2013; Keshtkar & Nafteh., 2016) using the CFD modeling method (Law & Valdez, 2014; Voznyak et al., 2025; Yau et al., 2018).

In ventilation systems, flow patterns of non-free jets are also quite common, when the exhaust openings are located on the opposite side of the room from the supply opening (Chow & Wong, 1994). With such a scheme, the air volume is removed from a confined space and does not participate in the movement towards the supply flow (Sheng et al., 2023). When choosing and designing a method for organizing air distribution, the specifics of the room, its purpose, structural and architectural features, location and dimensions of sources of heat, moisture and harmful gases, the level of requirements for maintaining the necessary design parameters of the microclimate should be taken into account (Vozniak et al., 2015). This approach allows you to obtain optimal indoor air conditions and the most efficient use of energy resources (Voznyak et al., 2020; Voznyak et al., 2023).

Materials and Methods

To determine the regularity of development and semi-compressed jets, studies of axisymmetric jets with a dead-end and flow pattern of air volume movement were conducted (Li et al., 2017), as well as with partial influence of the surrounding walls of the room and obstacles (Erdogan et al., 2024; Zhang et al., 2025). Studies were also conducted to determine the influence of the location of the exhaust and supply devices on the development of jets.

The air was released through the slots of a linear diffuser in the amount of one to four and with a slot length of 1.0 m. In the studied diffuser, the slot width was 17 mm. The release was carried out into a limited laboratory room that also had obstacles in the way of the development of the jet boundary.

Parameter value $\frac{\sqrt{F_{csr}}}{d_{hd}}$, which characterizes the relative dimensions of the inlet opening, in the experiment was 220; 110; 73 and 5,

where F_{csr} – cross-sectional area of the room in which the semi-compressed jet develops, m^2;

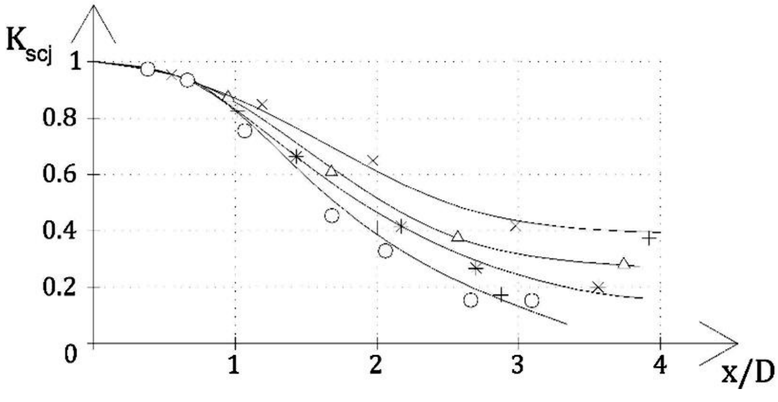
d_{hd} – hydraulic diameter, m.

Based on the research results, graphs of velocity fields in the jets of a linear louver diffuser at different relative distances from the diffuser were constructed ($\frac{x}{D} = 1; 2; 3$ and 4) and determining the air flow rate in the jet.

It has been proposed (Voznyak, 2010) to take into account the difference in the rate of decrease of axial velocities in free and semi-compressed jets by introducing a compression coefficient in terms of velocity $K_{scj} = \frac{v'_x}{v_x}$, where v'_x – velocity at a specific point of a compressed jet, $\mathrm{m/s}$; v_x – velocity in a defined precise free jet, m/s.

Similarly, the coefficients for the flow rate in a semi-compressed jet are introduced.

The values of the compression coefficients of semi-compressed jets developing in rooms where there is a partial influence of surrounding enclosing structures and other obstacles according to the dead-end scheme, obtained on the basis of field studies, are shown in Fig..



Compression ratio of semi-compressed jets
*rectilinear air movement scheme x – 5; Δ – 73; * – 110; ○ – 110; dead-end air flow pattern + (–220)*

It is obvious that in cases where the maximum flow rate in a semi-compressed jet significantly exceeds the initial air flow rate in a linear louver diffuser, the influence of the air flow pattern in the room will be insignificant. As can be seen from Fig. 1, for axisymmetric jets, the pattern of their development does not actually affect the value of the compression ratio at the values of the parameter $\frac{\sqrt{F_{csr}}}{d_{hd}} = 220$. Conversely, at a relatively small relative flow rate in a semi-compressed jet, the influence of the jet motion scheme has a significant effect and this influence increases with an increase in the relative size of the inlet openings of the linear louver diffuser.

Results and discussion

Let us analytically establish the difference in the values of the compression coefficients at the speed of dead-end and flowing semi-compressed jets (Borowski et al., 2021). The longitudinal velocity components in a semi-compressed jet are smaller than in a free jet by the amount of the "velocity shift", which is the same in each cross section, but varies from section to section. The friction that occurs during the movement of air near the limiting surfaces and existing obstacles and the thickness of the near-wall boundary layer are not taken into account. The analytical reflection of these prerequisites is the equation:

$$v' = v - v_{vs}, \tag{1}$$

where v – velocity in an arbitrary coordinate of a free jet, $\mathrm{m/s}$; v_{vs} – velocity on the axis of the free jet, $\mathrm{m/s}$.

According to equation (1), the value of the compression ratio for a dead-end or flowing jet can be determined from the equation:

$$K_{scj} = K_{scj}^{ef,df} = \frac{v'_x}{v_x} = 1 - \frac{v_x^{ef,df}}{v_x}, \tag{2}$$

where K_{scj}^{ef} – velocity compression ratio for jets developing according to a dead-end pattern; K_{scj}^{df} – velocity compression ratio for jets developing according to a flow diagram; v_x^{ef} – velocity shift in a semi-compressed jet developing in a dead-end pattern, $\mathrm{m/s}$; v_x^{df} – velocity shift in a semi-compressed jet developing along a flow pattern, $\mathrm{m/s}$

The magnitude of the velocity shift is determined from the continuity equation, which implies that the total air flow rate in each cross-section of the jet in a dead-end scheme is zero, and in a flow-through scheme of air movement it is equal to the transit (initial) air flow rate.

For axisymmetric jets, the continuity equations can be shown in the following form:

$$2\pi \int_0^{\frac{D}{2}} \left(v - v_x^{ef}\right) y dy = 0, \tag{3}$$

$$2\pi \int_0^{\frac{D}{2}} \left(v - v_x^{df}\right) y dy = \frac{\pi\, {d_{hd}}^2}{4} \cdot v_0, \tag{4}$$

where v_0 – air outlet speed from linear louver diffuser, $\mathrm{m/s}$.

After solving equations (2, 3 and 4), we get that:

$$K_{scj}^{ef} - K_{scj}^{df} = \left(\frac{d_{hd}}{F_{csr}}\right)^2 \cdot \left(\frac{v_0}{v_x}\right). \tag{5}$$

After substituting into equation (5) the formulas for determining the axial velocity of axisymmetric jets (Voznyak, 2010) and some transformations, we obtain a formula for determining the difference and value of the compression coefficients in terms of the velocity of dead-end and flowing semi-compressed jets:

$$K_{scj}^{ef} - K_{scj}^{df} = \frac{\pi}{4} \cdot \frac{d_{hd}}{\sqrt{F_{csr}}} \cdot \frac{x}{\sqrt{F_{csr}}} \cdot \frac{1}{m}, \tag{6}$$

where m – coefficient of change of velocity in a free jet.

As follows from formula (6), the influence of the semi-compressed jet development scheme is directly proportional to the initial compression ratio and distance from the linear louver diffuser and inversely proportional to the velocity change coefficient m.

Calculations using formula (6) confirm the results of experimental data.

Conclusions

In actual operating conditions, linear louver diffusers form mainly semi-compressible or compressible jets, which in turn develop according to a dead-end or flow pattern. A method is presented, confirmed by experimental data, for calculating compression ratios for the correct selection and prediction of the level of comfortable and energy-efficient operation of linear louver diffusers and ensuring the required microclimate.

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ХАРАКТЕРИСТИКИ РОБОТИ ЛІНІЙНОГО ЩІЛИННОГО ДИФУЗОРА В НАПІВОБМЕЖЕНИХ УМОВАХ

Ефективна експлуатація систем вентиляції залежить від багатьох факторів. Важливо, наскільки правильно система та її компоненти розраховані й підібрані. Від точності цих розрахунків залежить стабільність роботи всієї системи та комфорт мікроклімату. Проте під час проєктування та підбирання обладнання для невеликих приміщень фактичні параметри роботи часто відрізняються від розрахункових. Це особливо стосується лінійних жалюзійних дифузорів. Відмінність між теоретичними та реальними характеристиками струмин виникає через те, що більшість формул і номограм створені для умов вільного розвитку струмин. А у реальних умовах на їхній рух впливають огороджувальні конструкції, меблі, планування та інші перешкоди.

У статті розглянуто вплив конструкцій приміщення на повітряні струмини від лінійного жалюзійного дифузора. Ширина таких пристроїв невелика за значної довжини щілин, що відрізняє їх від традиційних квадратних чи круглих решіток. Ця особливість визначає геометрію та швидкісні характеристики повітряного потоку й безпосередньо впливає на ефективність розподілу повітря. Ці чинники необхідно ураховувати під час проєктування, монтажу й експлуатації систем вентиляції. Правильний вибір і розташування лінійних дифузорів забезпечують рівномірний розподіл повітря, зменшення зон дискомфорту та підтримання оптимального мікроклімату.

Практика показує, що ігнорування впливу огороджувальних конструкцій може спричинити небажані течії, протяги чи застійні зони. Це не лише погіршує комфорт перебування людей, але й знижує енергоефективність системи. Тому дослідження взаємодії повітряних струмин із конструктивними елементами приміщення – важливе завдання, яке дає змогу оптимізувати роботу обладнання, підвищити його ефективність і забезпечити сучасні вимоги до комфорту та енергоощадності.

Ключові слова: мікроклімат, тепловий комфорт, плоский струмінь, напівстиснений струмінь, розподіл повітря; турбулентність повітряного потоку.