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IMPROVING THE EFFICIENCY OF AIR DISTRIBUTION IN A ROOM WITH A LINEAR SLOT DIFFUSER

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The article investigates the improvement of air distribution efficiency in a room when using a linear diffuser as an air distribution device. Linear diffusers allow to provide comfortable conditions in the room.

The paper analyzes some characteristics of the air flow formed when using linear diffusers. The influence of the geometric parameters of the diffuser on the quality of the microclimate is considered, in particular, such characteristics as jet boundaries and velocity profiles in the jet cross-sections are considered. Numerical modeling allowed to determine the optimal operating modes of such diffusers and evaluate their efficiency.

Experimental studies confirmed that linear diffusers contribute to a more uniform distribution of supply air. The results obtained can be used to optimize and improve ventilation systems in buildings, which will contribute to increasing energy efficiency and reducing operating costs.

Keywords: air distribution, flat air jet, air velocity, jet border, linear diffuser, air flow turbulence

Introduction

Modern regulatory requirements for the indoor environment (Kapalo et al., 2014) set high standards for the quality of ventilation and air distribution (Voznyak et al.,2022), uniformity of temperature (Myroniuk et al., 2024) and ensuring a comfortable microclimate (Borowski et al., 2023). In conditions of intensive use of premises, especially office, public and industrial, effective control of air flow movement becomes critically important (Voznyak et al., 2020). One of the important aspects for this is the uniformity of air distribution (Jaszczur et al., 2016) without the formation of stagnant zones (Sukholova et al., 2011) or excessive temperature drops (Voznyak and Myroniuk et al., 2022).

Ventilation systems with traditional air distribution devices (Voznyak, 2020) often do not provide the necessary uniformity of air distribution (Voznyak et al.,2023), avoid the formation of overheating or excessive cooling zones (Janbakhsh, and Moshfegh, 2014), as well as prevent local drafts (Srebric, and Chen, 2002). This leads to a decrease in comfort in the premises (Allmaras et al., 2012), deterioration of working conditions and even possible negative consequences for human health (Dovhaliuk et al., 2018), in particular the development of respiratory diseases and a general decrease in working capacity (Gumen et al., 2017). In addition, inefficient use of ventilation and air distribution systems causes increased energy consumption (Voznyak et al. 2023), which increases the costs of heating, air conditioning and ventilation (Voznyak, 2020).

Linear slot diffusers are one of the promising solutions for improving the efficiency of air distribution (Voznyak, 2022). Due to their design, they provide uniform and controlled air distribution (Sukholova et al. 2011), which helps to reduce local temperature fluctuations and reduce the risk of drafts (Srebric, and Chen, 2002). They allow to achieve higher energy efficiency of ventilation systems (Voznyak, 2020), as they ensure optimal mixing of air masses and help to reduce heat or cold losses.

Studies in the field of ventilation and air distribution (Janbakhsh, 2014) show that the use of linear slot diffusers allows to significantly improve the quality of the microclimate in rooms (Borowski et al., 2023). In particular, experimental and numerical simulations (Voznyak, 2020) show that such diffusers provide effective control over air flows (Gumen et al., 2017), which is important for maintaining comfortable conditions in rooms for various purposes (Sukholova et al. 2011).

Materials and Methods

The purpose of this article is to analyze the effectiveness of using linear slot diffusers in ventilation systems, determine the optimal parameters of their operation and assess their impact on the uniformity of air distribution in rooms, as well as to investigate the aerodynamic characteristics of a linear slot diffuser (LSD). The study uses numerical modeling methods (Srebric, and Chen, 2002) and experimental measurements (Voznyak, 2020), which allows us to substantiate recommendations for the design of ventilation systems using louvered slot diffusers to improve comfort and energy efficiency.

Today, many ventilation systems use louvered linear diffusers (Voznyak et al., 2022) with two or more slots as air outlet devices. Linear diffusers, when operating in supply ventilation, air conditioning and heating systems, form flat air jets (Borowski et al., 2023).

Such air jets are:

- Free (Voznyak, 2020), if such air jets have no obstacles in their development;
- Non-free (Voznyak, 2020), if their development is influenced by the surfaces of the premises;
- Isothermal (Voznyak et al. 2023), if the air jet temperature coincides with the air temperature in the room;
- Non-isothermal (Voznyak et al. 2023), (heated or cooled), if the temperature of the jet exiting the nozzle does not coincide (higher or lower) with the room temperature;
- Laminar (Sukholova et al. 2011) (criterion $Re < 2300$);
- Turbulent (Sukholova et al. 2011) ($Re > 10{,}000$).

Flat air jets, similarly to compact ones, have a jet core – this is a flow area with constant air velocity and temperature, a jet pole (JP), which is the vertex of the conditional outer boundaries of the jet passing through it and through the boundaries of the louvered linear diffuser (Kapalo et al., 2014; Voznyak et al. 2023; Sukholova et al. 2011).

It is reasonable to propose a hypothesis that the presence of several flat slots in the LSD causes the interaction of flat jets at the exit of the device, which leads to significant turbulence of the air flow.

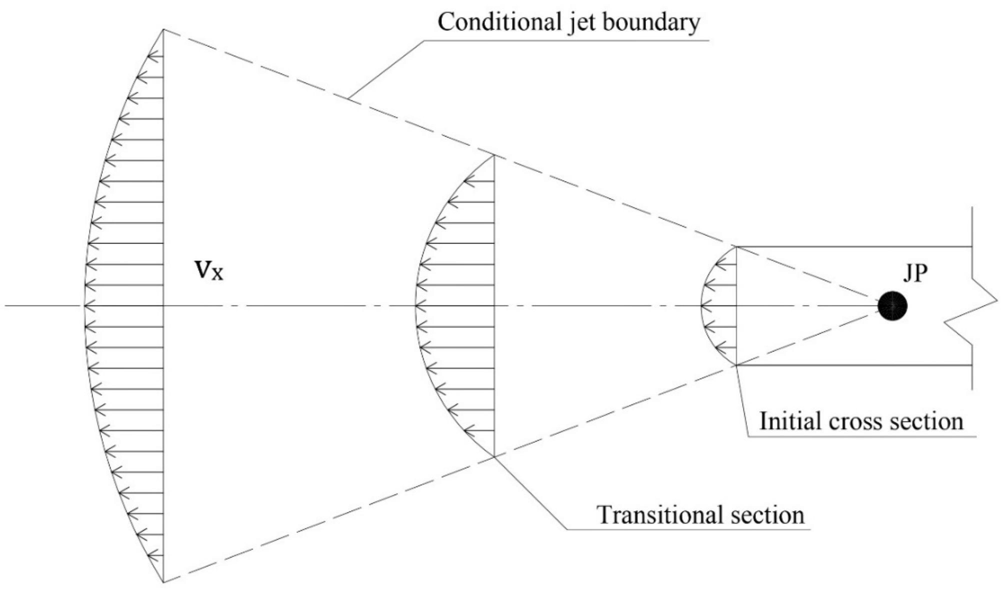


Fig. 1. Scheme of a free jet development

Results and discussion

The velocity v_y in any cross section "**x**" at a distance "**y**" from the axis of the plane jet is determined by the Schlichting's formula:

$$v_y = v_x \left[1 - \left(\frac{y}{y_b}\right)^{1,5}\right]^2 , \tag{1}$$

where v_x and v_y are axial and transverse air velocity respectively.

It is advisable to use relative values of velocities, axial $\overline{v}_x = v_x/v_o$ and in any cross section $\overline{v}_y = v_y/v_x$. In this case:

$$\overline{v}_x = \frac{0,48}{\frac{ax}{de}+0,145} , \tag{2}$$

where a = 0,078; d_e – equivalent nozzle diameter.

In non-isothermal flows, the relationship between gravitational and inertial forces at the moment of outflow is characterized by the Archimedes criterion Ar_o:

$$Ar_o = \frac{g\sqrt{F_o}\cdot\Delta\ t_o}{V_o^2\cdot T_{in}} , \tag{3}$$

where g = 9,81 m/s^2; F_o – nozzle area, m^2; Δt_o – excessive initial temperature, $\Delta t_o = t_o - t_{in}$, K; T_{in} – absolute indoor air temperature, K; V_o – initial speed, m/s.

Depending on the value of Ar_o, tidal jets are conventionally divided into non-isothermal-A, when the influence of gravitational forces on them is not significant, and non-isothermal-B, where the influence of gravitational forces is significant.

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

$$\Delta\ t_x = \frac{N}{x}, \tag{4}$$

where x – current longitudinal coordinate; N – thermal parameter:

$$N = \frac{0,54}{tg\alpha}\sqrt{\frac{T_{in}}{T_o}}\cdot\frac{1}{\sqrt[4]{\xi}}\cdot\Delta\ t_o\cdot\sqrt{F_o} , \tag{5}$$

where α – jet opening angle, α = 12º25' , and tgα = 0,22; ξ – local resistance coefficient, ξ = 1; T_o – absolute temperature at the nozzle outlet.

For convenience of calculations, the temperature damping coefficient is introduced ***n***:

$$n = \frac{0,54}{tg\alpha}\sqrt{\frac{T_{in}}{T_o}}\cdot\frac{1}{\sqrt[4]{\xi}}, \tag{6}$$

and axial excess temperature Δt_x :

$$\Delta\ t_x = n\cdot\Delta\ t_o\cdot\frac{\sqrt{F_o}}{x} . \tag{7}$$

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

$$\Delta\ t_y = \Delta\ t_x\cdot exp\left(-0,7\sigma_T\overline{y}^2\right), \tag{8}$$

where σ_T – turbulent Prandtl number, σ_T = 0,65 ÷ 0,7 for compact jets; $\overline{y}$ – current transverse coordinate, $\overline{y}$ = y/cx – experimental constant, c = 0,28.

Often use relative values of excess temperatures, axial $\Delta\ \overline{t}_x = \Delta\ t_x/\Delta\ t_o$ and in any cross section $\Delta\ \overline{t}_y = \Delta\ t_y/\Delta\ t_x$.

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

The experimental setup consisted of a laboratory fan, air ducts, a flexible insert, a diffuser with a wall opening angle α = 12º25' and the studied louvered linear slot diffuser. The experiments were conducted for different numbers of diffuser slots and different slot lengths. The height of the slots was recorded. The actual setup in laboratory conditions where the experiment and measurements were performed is shown in Fig. 3.

As a result of the conducted studies, the dependence of the relative transverse velocity can be displayed as follows (Fig. 4).

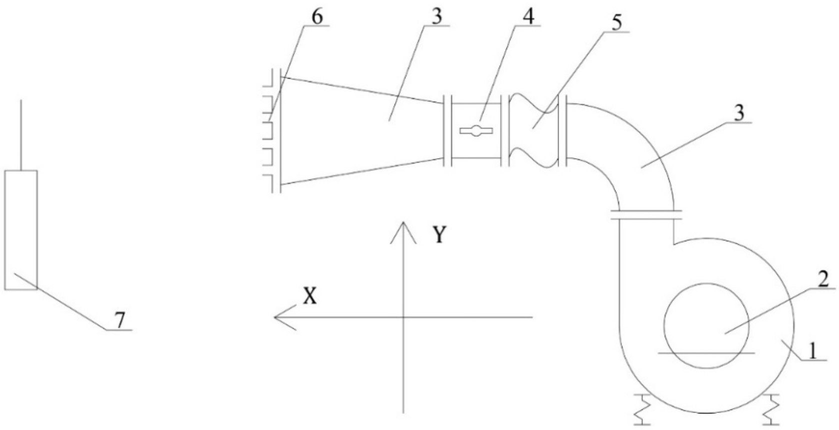
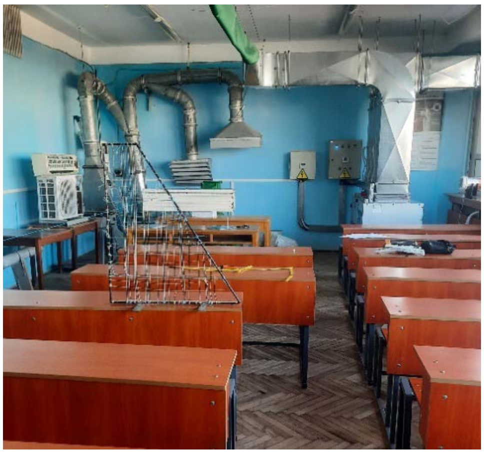


*Fig.2 Scheme of the experimental setup - 1 – centrifugal fan; 2 – electric motor; 3 – air duct; \
4 – control valve; 5 – flexible insert; 6 – linear slot diffuser; 7 – testo-405 thermal electrical anemometer.*

a

b



c

d

*Fig. 3. Photo of the experimental setup: a) – general view of the setup;
b) – linear slot diffuser with one open slot, mounted in the experimental setup;
c) – measurement process; d) – operation of the setup with different
combinations of open slots.*

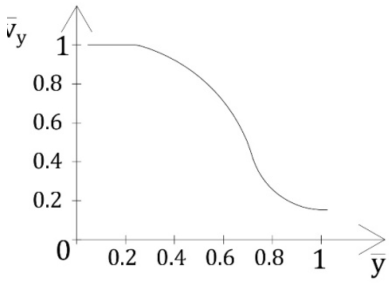


Fig.4. Dependence $\overline{v}_y = f(y)$) for a plane jet of a linear slot diffuser

Fig.4 shows that the air flow is properly turbulized, the velocity decay in the jet occurs intensively. Fig.4 shows the peculiarities of the velocity profile caused by the specifics of the device design.

Based on the measurements, it is possible to construct the boundaries of the jet in two projections Fig 5. The jet boundaries are plotted for A = 17 mm, B = 1000 mm.

The use of louvered linear diffusers allows you to significantly expand the supply air supply range with a single device.

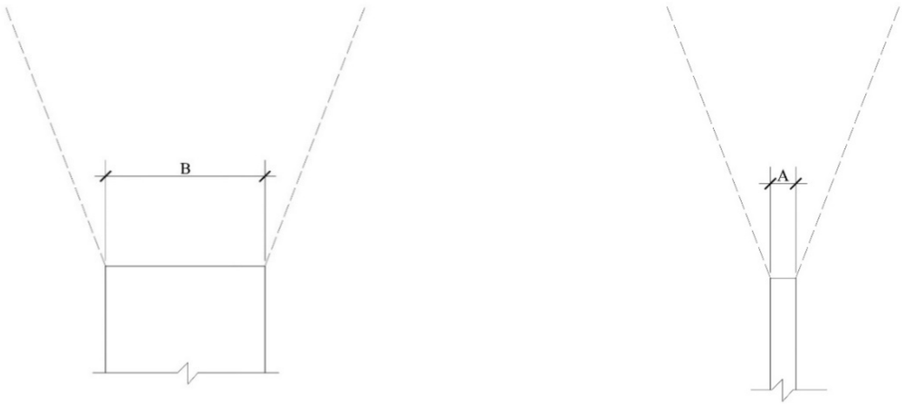


Fig.5. Jet boundaries: a) – plan; b) longitudinal profile.

Conclusions

1. The results obtained confirmed the proposed hypothesis that the interaction of flat jets at the outlet of the louvered linear slot diffuser leads to significant turbulence of the air flow

2. The interaction of jets at the outlet of the device leads to a sharper decrease in the axial velocity of the supply jet by 10 - 20% depending on the current coordinate compared to conventional air distribution grilles.

3. Louvered linear slot diffusers allow to ensure the supply of the required amount of supply air to a small volume room without creating drafts.

4. The design feature of the device causes a specific velocity profile in the cross-section of the air jet.

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ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ПОВІТРОРОЗПОДІЛУ В ПРИМІЩЕННІ ЛІНІЙНИМ ЩІЛИННИМ ДИФУЗОРОМ

У статті досліджується підвищення ефективності повіторозподілу в приміщенні при використанні в якості повітророздаючого пристрою жалюзійного лінійного щілинного дифузора. Враховуючи сучасні вимоги до вентиляційних систем, забезпечення рівномірного розподілу повітря, оптимального мікроклімату та енергоефективності є ключовими та визначальним завданнями при проєктуванні сучасних енергоефективних систем вентиляції. Жалюзійні лінійні щілинні дифузори мають низку переваг, зокрема здатність рівномірно розсіювати повітряний потік, покращувати рівень турбулентності та створювати комфортні умови у приміщенні без виникнення зон надмірного охолодження чи перегріву.

У цій статті проведено аналіз основних характеристик повітряного потоку, що формується при використанні жалюзійних лінійних щілинних дифузорів. Розглянуто вплив геометричних параметрів дифузора, швидкості подачі повітря в дифузор та розташування вентиляційних пристроїв на якість мікроклімату, зокрема розглянуто такі характеристики, як границі струмини та профілі швидкостей в перерізах струмини, що формуються жалюзійними лінійними щілинними дифузорами. Використання методів чисельного моделювання дало змогу визначити найбільш оптимальні режими роботи таких дифузорів та оцінити їх ефективність порівняно з традиційними системами подачі та розподілу припливного повітря.

Експериментальні дослідження підтвердили, що жалюзійні лінійні щілинні дифузори сприяють більш рівномірному розподілу температури, зменшенню ризику утворення протягів і покращенню загального рівня комфорту у приміщенні. Отримані експериментальні результати підтверджують теоретичні дані. Отримані результати можуть бути використані для оптимізації вентиляційних систем у житлових, офісних і промислових будівлях, що сприятиме підвищенню енергоефективності та зниженню експлуатаційних витрат.

Ключові слова: повітророзподілення, плоский струмінь, швидкість повітря, межа струменя, лінійний дифузор, турбулізація повітряного потоку