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Enhancing of ventilation efficiency of premise due to linear diffuser

Orest Voznyak¹, Iryna Sukholova¹, Nadiia Spodyniuk^{2*} ,
Mariana Kasynets¹, Olena Savchenko¹, Oleksandr Dovbush¹ and
Oleksandra Datsko³

¹ Department of Heat and Gas Supply and Ventilation, Institute of Civil Engineering and Building Systems, Lviv Polytechnic National University, Lviv, Ukraine

² Department of Heat and Power Engineering, Education and Research Institute of Energetics, Automation and Energy Efficiency, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

³ Department of Civil Safety, Viacheslav Chornovil Institute of Sustainable Development, Lviv Polytechnic National University, Lviv, Ukraine

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ORIGINAL RESEARCH PAPER



ABSTRACT

This article is directed on increase of the premise ventilation efficiency by using linear diffusers. The aim of the work was to carry out theoretical research, experimental investigations and numerical modeling of the linear diffuser air dynamic characteristics, to obtain the graphs and analytical equations for determination of the linear diffuser necessary parameters and to increase of efficiency air distribution in the room. Graphs of air velocity dependence on current coordinate and plates angle have been created and approximated by empirical equations. There was established that air velocity decreases intensively with increasing current coordinate and decreases with increasing of the plates angle.

KEYWORDS

ventilation, air distribution, linear diffuser, air jet, air velocity, indoor climate

1. INTRODUCTION

Microclimate in the room [1–5] is supported by Heating, Ventilation, Air Conditioning (HVAC) systems [6–8]. HVAC systems maintain air temperature [9, 10], velocity [11], humidity [11], CO₂ concentration [12–14], noise level in the room [15] eliminate other pollutants [16]. Modern building should be energy effective concerning fuel and energy resources in general: building walls including their strength [17–23] HVAC systems [24–29], renewable energy sources [30–32] and exhaust air heat utilization [33–35], also creation of a dynamic indoor climate in the premise, energy audit, etc.

In ventilation technology to increase efficiency of air distribution, it can be proposed to use various air distribution devices instead of traditional ones [11, 36]. Due to the high coefficient of air velocity attenuation and too high air velocity in the room there it is necessary to substitute air distributors on more effective ones concerning aerodynamics of tidal air jet. These devices should have a low coefficient of air velocity attenuation.

Air velocity is one of the most important parameters affecting the feeling of comfort. Velocity fields formed in the working area of the room by air jets depend on the type of air distributors and their geometric shapes, the initial velocities and temperatures of the jet, as well as on the interaction with natural convection and exhaust air flows.

An effective air distributor is a linear diffuser - an ordinary rectangular elongated plate grid. Diffusers are round, semi-circular or square. They are used for air supply and extraction

*Corresponding author.

E-mail: n_spoduniuk@meta.ua



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and are installed in walls, ceilings and floors of premises. The air velocity of the flat air flow in the facade section is $3\text{--}10\text{ m s}^{-1}$. The length can reach 30 m or more (these long lattices are formed by combining several shorter lattices against each other).

Linear diffusers come with fixed rotary plates. When making diffusers, fixed plates can be placed with the desired angle of inclination. Diffusers of the adjustable type (with rotary plates) sometimes provide quantitative regulation of the air flow rate.

Use of diffusers will make it possible to supply more air at lower velocities to production premises, provide comfortable conditions for personnel, and increase labor productivity.

Areas of application of linear diffusers are industrial premises with low height. The linear diffusers as tidal devices should be located along premise at suitable height and exhaust ones – near any wall.

2. PREVIOUS RESEARCH AND PROBLEM STATEMENT

There are a number of general requirements regarding the comfort of the air velocity and temperature of the internal air in the working area: the values of these two parameters must change in space and time without causing a feeling of blowing; some parts of the human body (ankles, back of the neck) are the most sensitive to blowing; air temperature should change with altitude; elevated temperature is recommended at the level below the knees; for a feeling of “freshness” you need increased speeds at elevated temperatures (a change in air velocity by 0.15 m s^{-1} is equivalent to a change in temperature by 1°C).

The parameters of the indoor air at a certain point in the room (air temperature and velocity) are affected by the following factors: the velocity and direction of the flow of air jets from the linear diffuser; temperature difference of supply air and internal air in the working area; shape and location of the linear diffuser; placement of holes for extracting internal air; dimensions and configuration of the room; temperature of the surfaces of the walls, ceiling, floor, windows; location, shape and intensity of heat release sources; the level of internal air turbulence.

For uniform distribution of the air flow along the diffusers, they are connected to ducts or installed in the walls of pressure chambers. Flow control valves can be installed in the supply ducts of the diffusers or installed directly in front of the diffusers. In case of air inflow, effective ejection of a significant amount of internal air is ensured, due to which less air mobility in the working area is achieved. Some of the best types of diffusers are equipped with adjustable directional devices that change the width and range of the jets. These directional devices can be mounted in the diffuser and have the form of flow regulators. A valve in the diffuser neck is used to regulate the flow rate.

Ventilation ducts with a longitudinal slot are special. Aerodynamics of air jets is specific. Along the slit of constant cross-section, the velocity direction and static pressure in the duct changes, and the velocity fields are deformed. Static pressure increases from the slit to the wall in the transverse

direction. Obviously, due to the law of conservation of energy, the total pressure remains constant. In the longitudinal direction, the average air velocity in the duct decreases, as part of the air escapes through the slit. As a result, the dynamic pressure will decrease. Since the total pressure remains constant, the static pressure will increase. The increase in static pressure is used to overcome pressure losses. It is interesting to note the situation of equality of static pressure increase and its loss. In this case, the static pressure will remain constant, which results in the uniformity of the exit air velocity of the tidal air jet.

The linear diffuser forms a flat jet with an extremely large ratio of the slit length to its width ($l/b = 50\text{--}1,000$), which significantly exceeds the limit value $l/b = 10$ of traditional flat jets [37]. In this regard, it will be interesting to implement the calculated dependencies of traditional flat jets for a linear diffuser and make a corresponding comparison.

Mathematical models [38–40] are suitable, but they do not consider non-stationary mode.

An important factor is the confirmation of theoretical results by experiments [41] and numerical modeling [42–44]. Analyzing the methods of numerical modeling, the most convenient $k\text{--}\varepsilon$ model should be noted, which gives the maximum accuracy of the results.

3. THE PURPOSE OF THE ARTICLE

The aim of the work was to carry out theoretical research, experimental investigations and numerical modeling of the linear diffuser aerodynamic characteristics, to obtain the graphs and analytical equations for determination of the linear diffuser necessary parameters and to encrease of efficiency air distribution in the room.

4. INVESTIGATION OF THE FLAT AIR JET AERODYNAMIC CHARACTERISTICS

An air linear diffuser (Fig. 1) of constant section with a length l (m) has a perimeter P (m) and a cross-sectional area F (m^2).



Fig. 1. Linear diffuser

A slit of constant width δ is arranged along the air distributor. Air volume flow rate is L . Research objectives: assessment of the unevenness of the deviation of the velocities of the outflow of the air jet and the determination of the resistance of the air distributor.

Let's take the origin of coordinates at the damped end of the air distributor and direct the abscissa axis towards the air flow.

Let's draw two cross-sections in the air distributor at a distance x and $x + dx$ from the muffled end. Obviously, the decrease in air flow inside the air distributor from section $x + dx$ to section x is equal to the air flow flowing through the gap between these sections. Denoting the air velocity in the x section through w_x , and in the $x + dx$ section through $w_x + dw_x$, and the normal outflow velocity from the slot in the x section through v_x , can be written

$$Fdw_x = v_x \delta dx. \quad (1)$$

Passing to the derivative, can be received

$$w_x = \frac{\delta}{F} v_x. \quad (2)$$

Normal air velocity in the slot

$$v_x = \mu \sqrt{\frac{2\Delta p_x}{\rho}}. \quad (3)$$

Experimental studies of the aerodynamic properties of a linear diffuser were conducted at conditions and simplifications:

- air jet was isothermal;
- rotary plates angles of inclination were $\alpha = 45^\circ$ and $\alpha = 60^\circ$;
- slit length and width were respectively 1 m and 15 mm, so ratio of the slit length to its width is $l/b = 66.7$;
- the initial air velocity and air volume flow rate in the linear diffuser were respectively within the limits: $v_0 = 5\text{--}10 \text{ m s}^{-1}$ and $L = 270\text{--}540 \text{ m}^3 \text{ h}^{-1}$ ($0.075\text{--}0.150 \text{ m}^3 \text{ s}^{-1}$).

The results of the study at the rotary plates angles of inclination $\alpha = 45^\circ$ and $\alpha = 60^\circ$ are shown in Fig. 2.

Size less velocity is ratio axial velocity to initial one: $\bar{v}_x = v_x/v_0$.

Chart (Fig. 2) is constructed for two angles of rotary plate's inclination, but for other angles interpolation should be used. To increase the accuracy of the results, it is advisable to supplement the graphical method with an analytical one. For this need graphs (Fig. 2) were approximated by Eq. (4):

$$v_x = v_0 m \sqrt{\frac{\delta}{x}}, \quad (4)$$

where v_x is the axial air velocity, m/s; v_0 is the initial air velocity, m/s; x is the current coordinate, m; δ is the width of slit, m; m is the coefficient of air velocity attenuation.

Size less coefficient m is determined from Eq. (5) depending on rotary plate's angle of inclination:

$$m = 4 - 0.033\alpha, \quad (5)$$

where α is the angle of rotary plates inclination.

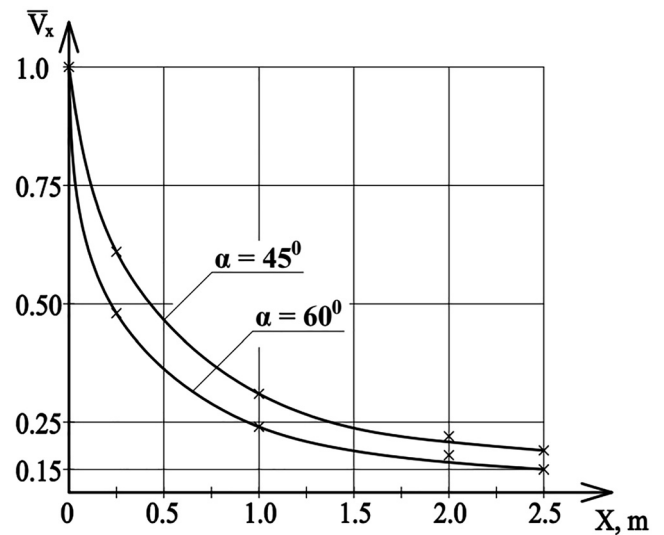


Fig. 2. Dependence of the axial size less velocity of the air jet on the current coordinate and angle of rotary plate's inclination

Due to Eq. (5) it is possible to determine coefficient of air velocity attenuation at any angle of rotary plate's inclination. After that it is suitable to use Eq. (4) for further calculation.

To compare the results, numerical simulation has been carried out in the ANSYS Fluent package ($k\text{--}\epsilon$ model). The current velocity of the air jet in frontal plane (Figs 3 and 4) flowing from the linear diffuser at the different initial air velocity and plates angle was determined. So does in profile plane (Fig. 5).

The results of the study proved that the air velocity in a flat jet of a linear diffuser is intensively attenuated, and the range under these conditions is adequate. The air velocity attenuation coefficient decreases when the angle of inclination of the rotary plates increases. This factor should be considered when optimizing the attenuation of the jet and its range.

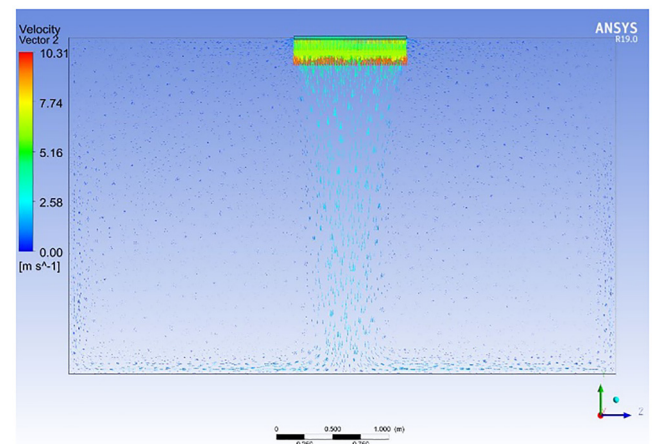


Fig. 3. Velocity distribution in frontal plane at $v_0 = 10 \text{ m s}^{-1}$ and plates angle of inclination 60°

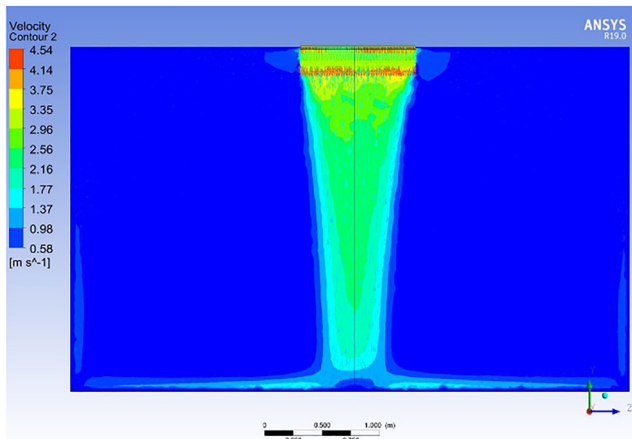


Fig. 4. Velocity distribution in frontal plane at $v_0 = 5 \text{ m s}^{-1}$ and plates angle of inclination 45°

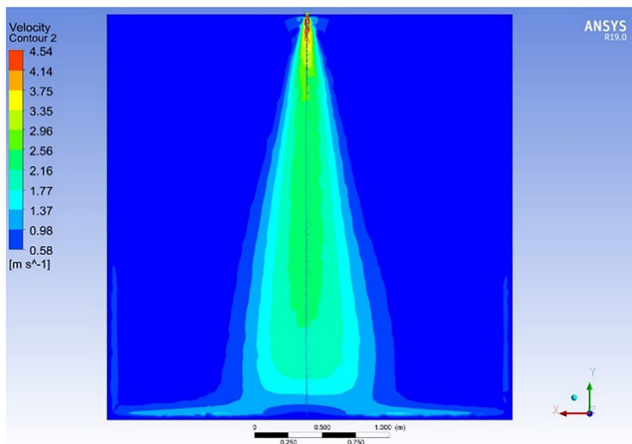


Fig. 5. Velocity distribution in profile plane at $v_0 = 5 \text{ m s}^{-1}$

The obtained results demonstrate satisfactory convergence and adequacy of the theory to experiment.

It would be interesting to research the acoustic characteristics of linear diffusers in future.

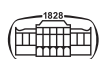
5. CONCLUSIONS

Graphs and analytical equations for determination of the linear diffuser air jet characteristics have been obtained. Also, two-factor dependence of the axial velocity of the air jet on the current coordinate and plate's angle was established. There was established that air velocity decreases intensively with increasing current coordinate and decreases with increasing of the plate's angle. Numerical modeling of the linear diffuser air dynamic characteristics demonstrates satisfactory convergence with experimental results. It was established that coefficient of air velocity attenuation of linear diffuser air jet is appropriate and satisfies comfort conditions in the room.

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