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Improving of ventilation efficiency at air distribution by the swirled air jets

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Pollack Periodica • An International Journal for Engineering and Information Sciences

17 (2022) 1, 123–127

DOI: 10.1556/606.2021.00419

Received: March 20, 2021 • Revised manuscript received: October 4, 2021 • Accepted: October 9, 2021
Published online: December 3, 2021

ORIGINAL RESEARCH PAPER

ABSTRACT

The article is devoted to decision of actual task of air distribution efficiency increase due to swirled air jets application. The aim of the paper is investigation of swirled air jets, analytical dependencies obtaining for determination of the air velocity attenuation coefficient, aerodynamic local resistance coefficient and noise level from the twisting plates inclination angle; optimization of the twisting plates inclination angle of the air distributor. It has been established that increase of the angle results in the air velocity attenuation coefficient increase and results in decrease of the noise level and resistance coefficient of air distributor. The optimum angle of the plates is determined considering aerodynamic, noise and energy aspects and equals 36°.

KEYWORDS

air distribution, swirled air jets, twisting plates, air flow

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1. INTRODUCTION

The effectiveness of human work depends largely on how the sanitary-hygienic parameters of the indoor climate [1, 2] meet the physiological needs [3, 4]. The energy efficiency of the indoor climate system should be ensured [5, 6]. In small-sized premises with many people there is a need to supply a significant amount of inflow air [7]. For this purpose, an air distributor is proposed which provides a high intensity of the air velocity attenuation of the inflow stream with the formation of a swirled air jet [8]. It is obvious that creation of a dynamic indoor climate [2] is also advisable in the closed spaces [9, 10]. It means periodic change of air temperature or air velocity in the working area of the room.

The noise appearance factor at jet's flowing out from air distributing devices [11] is necessary to take into account in designing ventilation and air conditioning systems [12, 13]. Basically, noise generation at air jet's leakage from outlet depends on its constructive realization and air jet flow velocity. As a result noise influences on the environment [11], solution of this problem is very significant.

2. PREVIOUS STUDIES AND PROBLEM STATEMENT

Analysis of previous studies has shown that a comfortable state of a person must be considered together with many factors: air temperature [14], air velocity [2, 3], humidity, temperature of the room surfaces [15, 16], noise level [17], thermal resistance of clothing, the CO_2 concentration in the room [18, 19], etc. Air distribution schemes are considered and

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analyzed for being most appropriate to be used indoors, taking into account the attenuation of inflow air jets [20, 21]. It is substantiated that more efficiency can be achieved using swirled air jets [22], that can leakage from the air distributor at the different angles of the twisting plates inclination [10].

It is known [23, 24], that decrease of air velocity attenuation coefficient is a desirable factor. It demands of intensive turbulence [25, 26] of air flow and results in increase of aerodynamic local resistance [27–29].

The noise factor is important under leakage from the air supply devices, when it is designed ventilation and air conditioning systems in rooms. Generation of noise by air-forming nozzles depends largely on its design performance and the flow rate of the air jets. There are known acoustic characteristics of the different air distributors [11]. However, it is possible to use air-distributing units in ventilation and air conditioning systems, which creates a swirled inflow air jet in an accompanying flow [30, 31].

There are suitable mathematical models [32–34] so that to create an adequate hypothesis and to answer the questions: which are acoustic characteristics of the air jet at these conditions, which is a noise level created, air velocity attenuation coefficient and an aerodynamic local resistance coefficient?

3. THE AIM OF WORK

The aim of the paper is investigation of swirled air jets, which flow out from the air distributor at the different angles of the twisting plates inclination; analytical dependencies obtaining for determination of the air flow characteristics; dependency determination of air velocity attenuation coefficient, aerodynamic local resistance coefficient and noise level from the angle of the twisting plates inclination; optimization of the angle of inclination of air distributor twisting plates.

To achieve the goal, it should be to carry out the theoretical and experimental research, concerning determination of the air velocity attenuation coefficient, aerodynamic local resistance coefficient and noise level from the angle of inclination of twisting plates.

4. MATERIALS AND METHODS

In this work there is considered the air distributor (Fig. 1), which provides leakage of swirled air jet. In the application of this device, the variation of the flow rate and the angle of inclination of the twisting plates is provided (Fig. 1).

Consequently, it is necessary to carry out experimental studies and to establish numerical dependency of air velocity attenuation coefficient, aerodynamic local resistance coefficient and noise level from the angle of inclination of the twisting plates. The experimental research of the air distribution by swirled air jet has been carried out under such conditions and simplifications:

Fig. 1. Natural model of the air distributor with twisting plates

- the air jets are isothermal;
- the air flow rate in the experiments was within: $L = 200–500\,m^3\,h^{-1}$;
- angles of twisting plates were 15°, 30°, 45°, 60°, 75°, 90°;
- initial velocity of air in nozzles for supply was in the range of: $v_0 = 2–10\,m\,s^{-1}$.

Air velocity has been measured by thermal electrical anemometer Testo-405 using a coordinate system with a grid of points 5 × 5 cm. Due to measured initial and current air velocities it has been determined air velocity attenuation coefficient from Eq. (1):

$$m = \frac{v_x x}{v_0 \sqrt{F_0}}, \tag{1}$$

where m is the air velocity attenuation coefficient; v_0, v_x is the initial and current air velocity, m s^{-1}; x is the running coordinate, m; F_0 is the air outlet space area, m^2.

Level of sound capacity has been measured by the UNI-T UT-352 sound level meter. The results of acoustic properties investigations are presented in Fig. 2. This graph shows dependence of air jet leakage noise level from angle of inclination of air distributor twisting plates.

This graph (Fig. 2) is approximated by Eq. (2) for determining of the unitless noise level $\overline{L}$ depending from the angle of inclination α of the twisting plates:

$$\overline{L} = 1 - 0.03\sqrt{\alpha}, \tag{2}$$

where $\overline{L}$ is the unitless noise level as relation of current to maximal noise level; α is the angle of inclination of twisting plates, deg.

As it is known [35, 36], in order to provide normative values of air velocity in the working area it should be

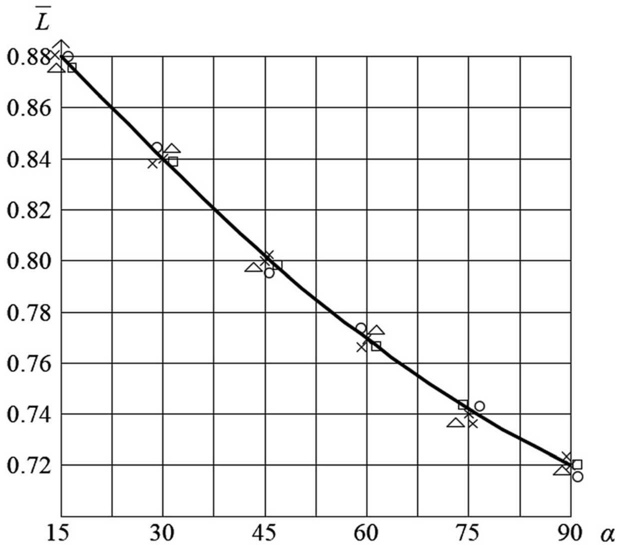

Fig. 2. Chart of the unitless noise level $\bar{L}$ dependence from the angle of inclination of the twisting plates

possible to reduce the velocity attenuation coefficient m. This is achieved by decreasing of the twisting plates angle, but at the same time it significantly increases both devices aerodynamic resistance and the noise level.

Based on the experimental results, graphs (Fig. 3) are designed.

In Fig. 3 the research results of velocity attenuation coefficient m and an air distributor aerodynamic local resistance coefficient ζ of the air distributor depending from the angle of inclination α of the twisting plates are presented. Velocity attenuation coefficient m is presented in the left ordinate axis and aerodynamic local resistance coefficient ζ of an air distributor – in the right axis. These graphs (Fig. 3) are approximated by Eqs (3) and (4) for determining of the attenuation coefficients m depending from the angle of inclination α of the twisting plates:

$$m = 0.02\alpha - 0.24, \tag{3}$$

and for determination of the aerodynamic local resistance coefficient ζ of the air distributor is shown hyperbolic, Eq. (4):

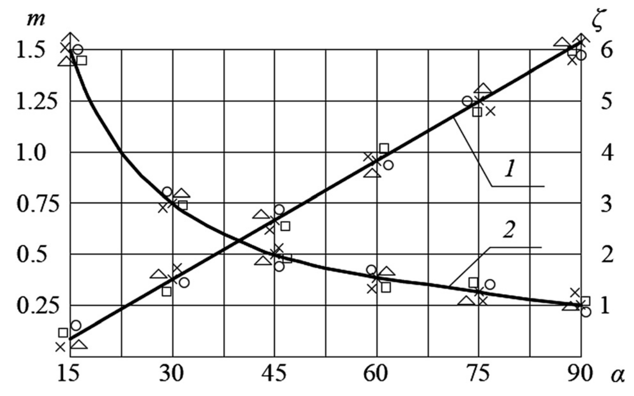

Fig. 3. Graph for determining of the angle of inclination α of the swirling plates: 1) attenuation coefficient of air jet velocity m; 2) the coefficient of local resistance ζ

$$\xi = \frac{90}{a}. \tag{4}$$

Taking into account the priority fraction $\beta = \zeta_{\max}/m_{\max}$, the numerical value of the empirical constant is obtained as $C = 90/\beta$, i.e., $C = 22.5$.

Consequently, in terms of velocity attenuation, it is effective to use the device at smaller angles of the twisting plates, where the velocity attenuation coefficient is minimal. But at the same time, in terms of aerodynamic resistance and the noise level, the situation is completely opposite. Therefore, it is quite logical to see the optimization problem of determining the optimal angle of inclination of the twisting plates, which would satisfy the appropriate requirements, particularly the velocity attenuation m of the air jet (material content of the system), the aerodynamic resistance ζ (energy intensity of the system) and the noise level (acoustic properties).

To solve this problem, it is proposed to introduce an additional function ψ, which combines these values and represents their sum: $\psi(\alpha) = m(\alpha) + \xi(\alpha) + \overline{L}(\alpha)$, taking into account the priority fraction β and the empirical constant $C = 22.5$. This representation is correct, since all of these quantities are unitless, depend on the same argument (the angle of inclination of the twisting plates α) and are given by analytical expressions Eqs (2)–(4).

Graphically, additional function ψ is presented in Fig. 4, but in analytical form in Eq. (5):

$$\psi = 0.02\alpha - 0.24 + \frac{22.5}{a} + 1 - 0.03\sqrt{\alpha}. \tag{5}$$

Along with the graphical method of determining the optimal angle of inclination also the analytical method has been applied. To do this, it was differentiate the Eq. (5), equate the derivative to zero, and obtain the Eq. (6), which is unreasonable to solve by an algebraic method.

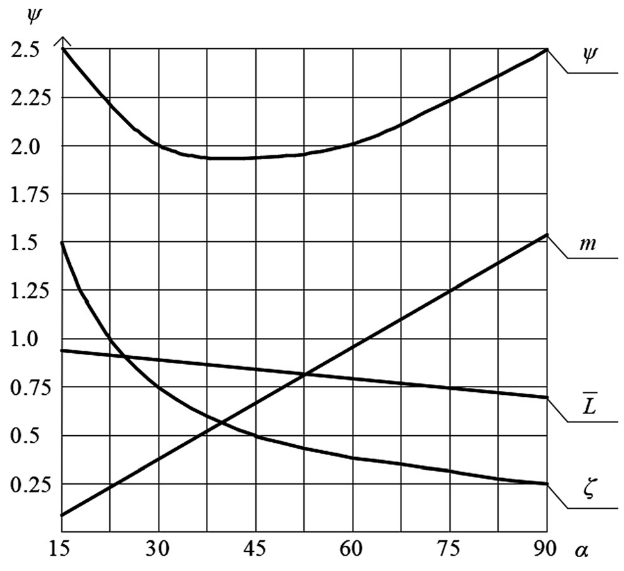

Fig. 4. Graph for determining of the optimal angle of inclination α of twisting plates taking into account all characteristics: attenuation, acoustic and resistant

$$0.02\alpha^2 - 0.015\alpha^{1.5} - 22.5 = 0. \qquad (6)$$

Instead, an iteration method is proposed, for which it was obtained the solution $\alpha_0 = 36°$. Consequently, it was obtained graphically $\alpha_0 = 35°$ and analytically $\alpha_0 = 36°$. So, the results are completely acceptable.

5. CONCLUSIONS

The air distributor is proposed, which provides increase of air jet velocity attenuation, intensity.

Application of the proposed air distributor substantially increases the quality of air distribution for supplying a significant amount of air into small-scale premises.

It is possible to carry out control of air distribution selection taking into account limited noise level for particular capacity of incoming outlet based on the obtained dependences.

It should be noted that the aerodynamic local resistance coefficient and a noise level are the highest at angle of twisting plates $\alpha = 15°$ and there are the lowest at angle of twisting plates $\alpha = 90°$.

It has been determined that in order to achieve an increase of the air velocity attenuation, it is necessary to reduce the angle of inclination of the twisting plates; its optimum value is $\alpha_0 = 36°$.

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