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NUMERICAL MODELING OF THE FLAT AIR JET PHYSICAL PROPERTIES IN A ROOM

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The article presents the study results of air distribution in a room with a flat air jet. In particular, dynamic pressure, density and viscosity of air flow were considered. Aim of a paper is to numerically simulate these physical properties of a flat air jet in a room. A graphical representation of air jet parameters was obtained using package CFD Ansys FLUENT software. A hypothesis of applying Mendeleev – Clapeyron equation to moving air flow was considered. Flat air jets have been found to be effective in terms of velocity attenuation in indoor air distribution. The dependence of the tidal flat compressed air stream velocity on time and longitudinal current coordinate simultaneously is graphically presented. Their proper long-range allows for comfortable microclimate conditions using a minimum number of them. Convergence of experimental studies results and numerical modeling confirms adequacy of a theory of the experiment.

Keywords: flat air jet, molecular mass, volume, pressure, temperature, density.

Introduction

In premises for various purposes, air distribution occurs by free (Dovhaliuk and Mileikovskyi, 2018; Gumen et al., 2019), or compressed (Mileikovskyi and Tkachenko, 2021; Myroniuk et al., 2024) air supply jets. The purpose of these measures is to create a proper microclimate and air quality in the premises (Myroniuk et al., 2023; Spodyniuk et al., 2019). To achieve this goal, it is necessary to properly select air distribution devices and an air distribution scheme, ensuring energy efficiency and optimization of ventilation and air conditioning systems in general in the building (Tkachenko and Mileikovskyi, 2021; Vranay and Vranayova, 2020). Indoor air quality is considered in aspects related to the deficit of the required amount of air, exceeding the normalized velocity of the tidal air jets in the working ventilation zone (Voznyak et al., 2019; Voznyak et al., 2018) due to its insufficient attenuation.

The efficiency of ventilation systems, air conditioning ones in general (Shapoval et al., 2017; Kapalo et al., 2018) and air distribution systems in particular (Zhelykh et al., 2021; Lis and Spodyniuk, 2019) in premises is the main task of ensuring a comfortable thermal microclimate (Pietrucha T., 2017; Lee and Kim, 2022) and energy efficiency of HVAC systems. Conventional methods of air supply to premises do not provide proper air distribution. This usually leads to undesirable consequences: the presence of unventilated areas in the premises, excessive vortex formation, etc. To solve this problem, it is advisable to use flat tidal air streams. These air streams provide proper velocity attenuation, mix the air masses of the forward and reverse flows more intensively in the room and increase the quality index of air distribution system in working zone of a premise. Due to this, flat tidal air flows increase the efficiency of ventilation in the rooms of various purposes. The study of the parameters of the flat inflow compressed air jets allows us to identify the patterns of their motion and improve the theory of aerodynamics of the flat air flows. This creates an opportunity to improve aerodynamic efficiency in ventilation and air conditioning systems (Kapalo et al., 2019).

In this context, the situation is solved by numerical modeling (Almaras et al., 2012) of indoor air distribution, in particular by flat jets. Currently, numerical modeling of the physical properties of flat air jets in indoor environments is highly relevant.

Aim of this manuscript is to numerically simulate the physical properties of a flat air jet in a room as it flows out of a supply nozzle, in particular the dynamic pressure, density.

Materials and Methods

During the analytical description some assumptions, limitations, and simplifications were adopted:

– indoor air is considered a mixture of diatomic ideal gases;

– the air flow is flat, non-isothermal;

– initial air jet velocity: 5–10 m/s;

– volumetric air flow rate: 300–450 m^3/h;

– an air velocity has been measured by a device testo-405.

It is appropriate to accept simplification for air concerning the ideal gas in order to apply the Mendeleev – Clapeyron equation (1):

$$pV = \frac{mRT}{\mu}; \quad (1)$$

where V – air volume, m^3; p – full air pressure, Pa; m – air mass, kg; μ – air molecular mass, μ = 29 kg/kmol; R – universal gas constant, R = 8314 J/(kmol K); T – air temperature, K.

Considering μ = 29 kg/kmol, R of air 8314/29 = 287 J/(kg K).

It is advisable to hypothesize the application of the Mendeleev – Clapeyron equation for a moving air flow. To do this, let us divide both parts of equation (1) by time t [s] and express the total pressure p as the sum of static p_{st} and dynamic p_{dyn} ones. Therefore, the equation (2) is obtained:

$$\frac{(p_{st}+p_{dyn})V}{t} = \frac{mRT}{\mu t}; \quad (2)$$

Next, you should perform the following transformations: select in this equation the mass flow rate G [kg/s] and volumetric one L [m^3/s] instead of mass m [kg] and volume V [m^3], since $G = m/t$ and $L = V/t$. Therefore, the equation (3) is obtained:

$$(p_{st} + p_{dyn})L = \frac{GRT}{\mu}; \quad (3)$$

After dividing both parts of the equation (3) by the air volume flow rate, equation (4) is obtained:

$$p_{st} + p_{dyn} = \frac{\rho RT}{\mu}; \quad (4)$$

where ρ is the air density, kg/m^3.

Since values μ and R are constant, the relationship between three variable air parameters, i. e. pressure, temperature and density, is obtained from equation (4). If the air pressure is assumed to be constant, then the dependence of the density on the temperature is obtained from equation (5):

$$\rho = \frac{(p_{st}+p_{dyn})\mu}{RT}; \quad (5)$$

Air density for normal conditions (pressure p_{st} = 1013 hPa, temperature t = 0 ºC (273 K)) ρ = 1.29 kg/m^3. But for room ventilation conditions, room temperature is usually higher (t = 18 ºC for a cold season and $t = t_{ext}$ + (3–5) ºC for a warm one). Therefore for t = 18 ºC, ρ = 1.21 kg/m^3, that is, it is usually taken approximately for calculations ρ = 1.2 kg/m^3. An interesting aspect is the estimation of the error of such a hypothesis.

Since the temperature difference in the ventilation system at different points of the non-isothermal air jet does not exceed 3 ºC, it is reasonable to hypothesize that the air density does not change significantly, so this fact can be neglected. The results of calculations according to equation (5) show that the error is 0.08 %.

The verification of this hypothesis was performed using Ansys FLUENT software and confirmed by the results shown in Fig. 1.

It is appropriate to express another hypothesis regarding the total air pressure as the sum of static and dynamic ones. Since the air flow velocity is considered within the range of up to 20 m/s, the dynamic pressure is within the range of up to 240 Pa. In comparison with atmospheric static pressure of 100 kPa, the value of dynamic pressure of 240 Pa is 0.24 %. Therefore, this value can be neglected and the total pressure can be considered equal to the static pressure.

The verification of this hypothesis was also performed using Ansys FLUENT software and confirmed by the results shown in Fig. 2.

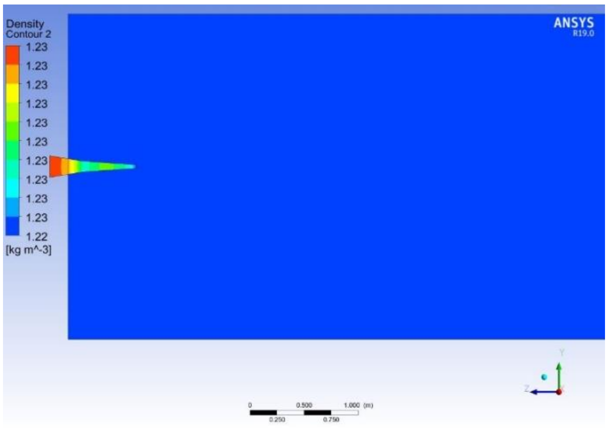

Fig. 1. Density distribution for an air jet

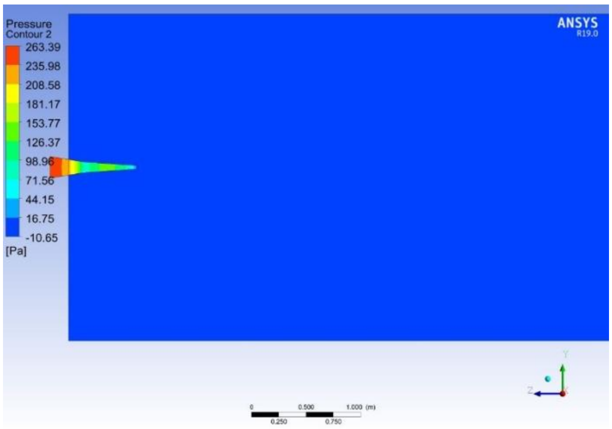

Fig. 2. Dynamic pressure distribution for an air jet

It would be interesting to consider a dynamic microclimate in which the parameters of the indoor air change periodically.

This primarily concerns the air velocity in the context of the aerodynamics of tidal air jets. Simplifying the problem, it is advisable to alternately take the initial excess temperature of the supply air stream as constant, and the initial velocity as variable, or, respectively, the excess temperature of the supply air stream as variable, and the initial velocity as constant.

Using a low velocity attenuation coefficient, air distribution with flat jets is advisable in small rooms.

Conclusions

1. Flat air jets are effective in terms of velocity attenuation in indoor air distribution; therefore it is advisable to use them when designing ventilation systems of office or industrial premises.

2. The dependence of the velocity of the tidal flat compressed air stream on time and the longitudinal current coordinate simultaneously is graphically presented.

3. Their proper long-range allows for comfortable microclimate conditions using a minimum number of them.

4. The hypothesis of applying the Mendeleev – Clapeyron equation to a moving air flow was considered and its experimental confirmation was obtained. Another hypothesis regarding the total pressure of a tidal flat compressed air flow as the sum of static and dynamic pressure was also confirmed.

5. Convergence of experimental results and numerical modeling confirms the adequacy of the theory of the experiment.

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ЧИСЛОВЕ МОДЕЛЮВАННЯ ФІЗИЧНИХ ВЛАСТИВОСТЕЙ ПЛОСКОГО ПОВІТРЯНОГО СТРУМЕНЯ У ПРИМІЩЕННІ

Для забезпечення належного мікроклімату та якості повітря у приміщеннях необхідно правильно вибрати повітророзподільні пристрої та схему розподілу повітря. У статті наведено результати експериментального дослідження розподілу припливного повітря в приміщенні плоским повітряним струменем, що витікає із припливної плоскої щілини. Зокрема, розглянуто такі характеристики повітряного потоку: динамічний тиск, густину та кінематичну в’язкість. Метою дослідження було числове моделювання вказаних фізичних властивостей плоского повітряного струменя у приміщенні, що витікає із припливного насадка. Результати теоретичних та експериментальних досліджень, а також числового моделювання подано у вигляді графічних та аналітичних залежностей. Графічне відображення цих параметрів повітряного струменя отримано за допомогою пакета програмного забезпечення CFD Ansys FLUENT. Розглянуто гіпотезу застосування рівняння Менделєєва – Клапейрона до рухомого повітряного потоку та одержано її експериментальне підтвердження. Виявлено, що плоскі повітряні струмені ефективні з погляду загасання швидкості припливного повітряного струменя у приміщенні. Подано графічну залежність швидкості припливного потоку плоского стисненого повітря від часу та поздовжньої поточної координати одночасно. Їх належна далекосяжність дає змогу створювати комфортні умови мікроклімату, використовуючи мінімальну їх кількість. Збіжність результатів експериментальних досліджень та числового моделювання підтверджує адекватність теорії експерименту. Підтверджено також іншу гіпотезу щодо повного тиску припливного стисненого повітряного потоку як суми статичного та динамічного тиску. Під час аналітичних та експериментальних досліджень прийнято певні припущення, обмеження та спрощення.

Ключові слова: плоский повітряний струмінь, молекулярна маса, об’єм, тиск, температура, густина.