Numerical Study of the Influence of the Inlet Geometric Parameters on the Jet Characteristics

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Abstract. Calculation of air distribution in premises is one of the main stages when designing ventilation and air conditioning systems of a building. The microclimate quality and the efficiency of ventilation and air conditioning systems depend on the accuracy and correctness of the calculations. The purpose of this study is to assess the influence of the distance between the inlet and the 45-degree turn on the jet characteristics. The basic geometric and kinematic characteristics of the jet flowing from the opening located at various distances from the 45-degree turn were obtained. The change in the deflection of the outflow angle and the kinematic coefficient of the inlet opening were obtained.

Keywords: Jet flow · Numerical method · Computational fluid dynamics · Fluent · Air distribution · Flow characteristics

1 Introduction

Calculation of air distribution in the premises is one of the main stages when designing ventilation and air conditioning systems of a building. The microclimate quality and the efficiency of ventilation and air conditioning systems depend on the accuracy and correctness of the calculations. It should take into account the need for rational use of resources and compliance of the supplied air parameters with regulatory requirements. By changing the feed angle, one can provide the required microclimate parameters without additional equipment, and thereby optimize the costs of ventilation and air conditioning.

This is especially important in rooms with increased heat generation, where one has to use air exchange schemes with the supply of jets directly to the working area.

Many works consider an urgent issue of the influence of the geometric and kinematic parameters of the supply jet on the air distribution in rooms for various purposes. The results of a numerical experiment using the CFD software package are presented in [1–6]. The choice of a numerical model for various cases of air distribution is considered in [2–7]. The detailed studies of the air distribution scheme “from top to bottom” in a flat and spatial setting are presented in [8–13]. In the articles [2, 3, 13], the velocity fields in an air jet supplied by recirculation air diffusers were obtained numerically. The authors [14–16] carried out a series of studies on vortex zones and the local resistance coefficient (LRC) of exhaust openings.

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The works [17, 18] study the influence of the geometric characteristics of the inlet located at different distances from the 90-degree turn of an air duct. The geometric and kinematic characteristics of jet as a function of distance were obtained. However, due to the limited room space, the air in the working area must be supplied at other angles rather than 90°.

For geometrically complex air distributors, the kinematic coefficient is not constant along the length of the main jet section [19]. So, it becomes necessary to take into account the unevenness of velocity profiles in jets, formed during an outflow from nozzles with different geometry and direction [20].

The purpose of this work is to determine the influence of the distance between the inlet and a 45-degree turn on the jet characteristics.

To achieve this purpose, the following tasks were set:

- To study numerically the jet outflow from the inlet located at different distances from the 45-degree turn.
- To determine the patterns of change in geometric and kinematic characteristics as a function of the distance from the air duct turn.

2 Materials and Methods

The study was carried out numerically using the Fluent software package. The standard k-e turbulence model was adopted as in [17, 18]. Standard near-wall functions were used to model the near-wall boundary layer.

Figure 1 shows the geometry of the studied area. The jet is fed from an inlet opening with a width of $b_0 = 0.2$ at a constant velocity $u_0 = 3$ m/s. The inlet is located at a distance $l = 0...2$ m after the air duct turns at the angle $\alpha = 45°$. The considered area has the following dimensions: $b = 8.0$ m, $h = 4.0$ m, $h_1 = 0.7$ m.

We adopted the following boundary conditions:

- AB (feed opening) – Velocity inlet: velocity is uniform and directed along the normal to the boundary: $u_0 =$ const; $k = 0$; $\varepsilon = 0$;
- FG, GH, HI, IK (free flow boundaries) – Pressure Outlet: excess pressure $\Delta p = 0$; velocity is directed along the normal to the boundary - u - $= u_n$, $dk/dn = 0$, $d\varepsilon/dn = 0$;
- AF, FE, BC and CD (impermeable walls) Wall: $u = 0$, $(du_n)/dn = 0$; d/dn are derivatives along the normal to the boundary.

As a result of the solution, the basic geometric and kinematic characteristics of the jet flowing from the opening located at different distances between $\bar{l}$ and the 45-degree turn were obtained.

The results are presented in dimensionless form:

- $\overline{u_x} = u_x/u_0$; $\overline{u_y} = u_y/u_0$; $\overline{u_{av}} = u_{av}/u_0$ are the longitudinal and transverse components and mean velocity, respectively;
- $\overline{P_{st}} = P_{st}/P_D$ is the static pressure;
- $\bar{x} = x/b_0$; $\bar{y} = y/b_0$ are the geometric parameters.

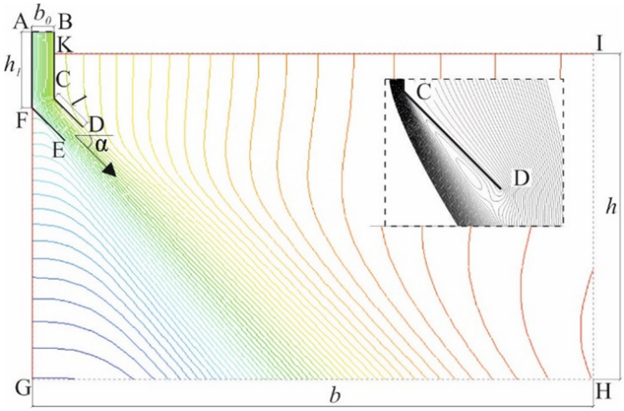

Fig. 1. Geometry of the considered area and streamlines

3 Results and Discussion

Figure 1 shows the streamlines of jet flowing out from the inlet located after a 45-degree turn. In the previously considered case [17, 18], a vortex region was shown, which had a significant influence on the jet characteristics. The jet flattened only at a distance of $\bar{l} > 3.0$ from the turn. In case of a 45-degree turn, a vortex zone is also formed along the upper wall CD, due to which the jet breaks off and the outflow angle changes. In this case, the vortex region affects the jet only at a small distance from the turn $\bar{l} < 1.0$.

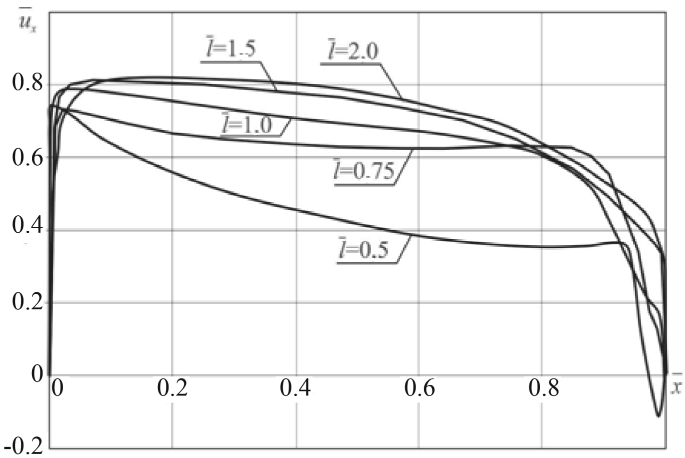

Fig. 2. Longitudinal velocity component

Figures 2 and 3 show graphs of changes in dimensionless longitudinal and transverse velocities, respectively. Since the jet is directed at an angle of 45 degrees, the longitudinal and transverse velocities are comparable at all lengths. At the length of $\bar{l} = 0.5$ velocities

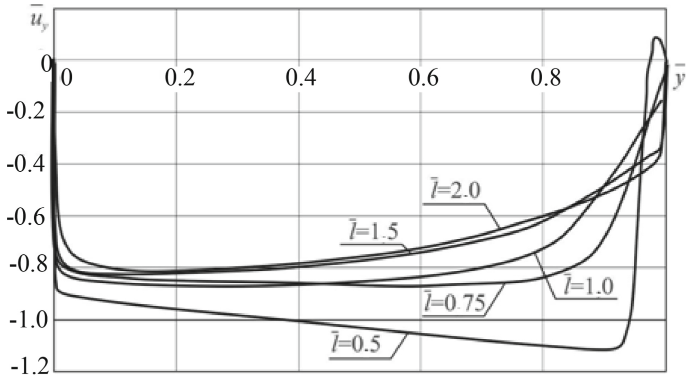

Fig. 3. Transverse velocity component

change the signs, which indicates the presence of a vortex zone at the upper wall of the duct. Further, the velocity profile is practically flattened, there is no vortex zone. At a distance of $\bar{l} > 1.5$, the profiles of the longitudinal and transverse components of velocity become equal, the disturbances generated during the turn do not have an influence. A greater distance between the inlet and the turn does not affect the change in the jet characteristics.

The maximum velocity in the jet sections was used to determine the angle at which the outflow from the inlet opening occurs. Table 1 shows the deflection of the jet outflow angle from 45°:

$$|\Delta\alpha| = \alpha - 45, ^\circ \tag{1}$$

Table 1. The deflection angle

$\bar{l}$, m	0.5	0.75	1.0	1.5	2.0
Δα, °	14.3	11.5	3.8	5.5	5.3

Figure 4 shows a graph of changes in the deflection angle from the jet axis. It also shows the relationship between the angle of jet deflection from the horizon when the inlet is located after the 90-degree turn. Due to the strong influence of the vortex zone after the 90-degree turn, the jet deflects more from the axis and this influence remains significant up to $\bar{l} = 0.4$. In case of a 45-degree turn, the influence of the vortex zone ends already at $\bar{l} = 0.2$. Further, the deflection angle approaches 0 and remains constant. In the area $\bar{l} < 0.2$, the angle change can be described by the following formula:

$$\alpha = 23.834 l^{(-3.106)} \tag{2}$$

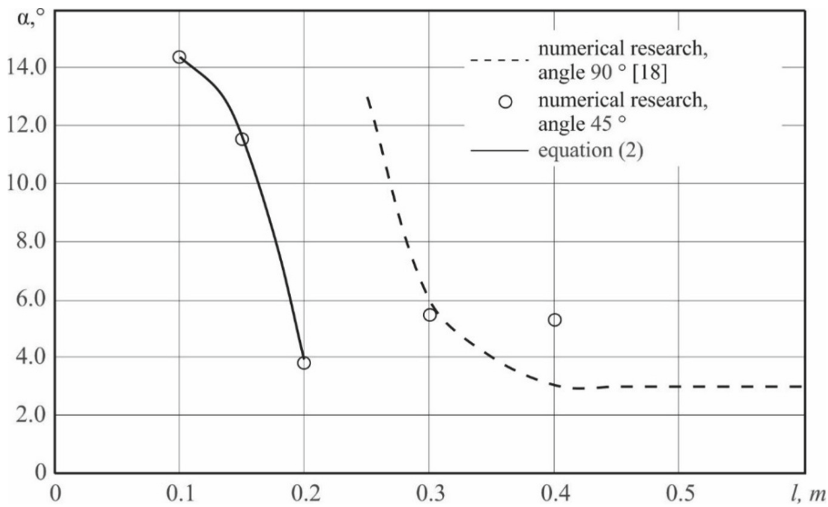

Fig. 4. Jet axis deflection angle

Figure 5 shows the change in average velocity at the jet axis for various distances $\bar{l}$ from the turn. The solid line in Fig. 5b shows the change in the average velocity calculated using the following equation:

$$u_m = \frac{mu_o\sqrt{b_0}}{\sqrt{\eta}}, \tag{3}$$

where $\eta = x \cdot \cos\alpha$ is the dimensionless distance from the center of the outflow along the jet axis.

The change in average velocity at various distances from the turn can be described by Eq. (3). For $\eta < 2$ the results obtained numerically and using Eq. (3) have a significant discrepancy, since this formula is suitable only for describing the change in velocity in the main section of the jet. For $\eta < 2$ the flow is aligned and the main section is formed. The coefficient m for the inlet located after the 45-degree turn of the air duct depends on the distance $\bar{l}$ and it is in the range of 1.45–1.65 (Table 2).

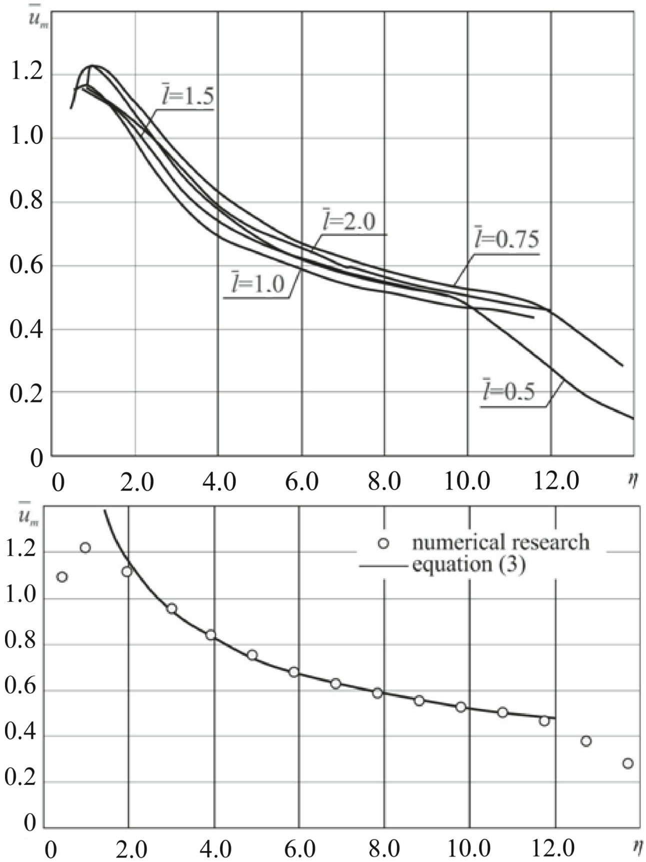

Fig. 5. Average velocity on the jet axis

Table 2. Kinematic coefficient of the inlet opening

$\bar{l}$, m	0.5	0.75	1.0	1.5	2.0
m	1.55	1.65	1.45	1.5	1.6

4 Conclusions

The main geometric and kinematic characteristics of the jet flowing from the inlet located after the 45-degree turn of the air duct were obtained numerically. As a result of the turn, a vortex zone is formed on the upper wall of the air duct, which affects the outflow jet parameters and along its length only at $\bar{l} < 1.0$. It was shown that the jet outflow angle had a deflection from 45°. The change in the average velocity in the main section of the jet is well described by the well-known formula for a free jet. In this case, the kinematic coefficient of the inlet opening is not constant and depends on the distance from the turn.

References

1. Shopayeva, A., Safiullin, R.: CFD-modeling of flow in confluence nodes of ventilation units of multi-storey buildings. IOP Conf. Ser.: Mater. Sci. Eng. (2020). https://doi.org/10.1088/1757-899X/890/1/012157
2. Kocharyants, K.V.: Numerical simulation of air distribution by fair overlaying jets. Selection of turbulence model. Vestnik grazhdanskih inzhenerov **57**, 128 (2016)
3. Naumov, A.L., Kapko, D.V., Brodach, M.M.: Ventilation systems with local recirculation diffusers. Energy Build. 85 (2014). https://doi.org/10.1016/j.enbuild.2014.09.050
4. Ivanov, N.G., Zasimova, M.A.: Large eddy simulation of airflow in a test ventilated room. J. Phys. Conf. Ser. **1038**, 12136 (2018). https://doi.org/c
5. Zasimova, M.A., Ivanov, N.G., Markov, D.: Numerical modeling of air distribution in a test room with 2D sidewall JET. I. Foundations for eddy-resolving approach application based on periodical formulation. St. Petersbg. State Polytech. Univ. J. Phys. Math. **13** (2020). https://doi.org/10.18721/JPM.13305
6. Zasimova, M.A., Ivanov, N.G., Markov, D.: Numerical modeling of air distribution in a test room with 2D Sidewall JET. II. LES-computations for the room with finite width. St. Petersbg. State Polytech. Univ. J. Phys. Math. **13** (2020). https://doi.org/10.18721/JPM.13306
7. Ricci, A., Kalkman, I., Blocken, B., Burlando, M., Repetto, M.P.: Impact of turbulence models and roughness height in 3D steady RANS simulations of wind flow in an urban environment. Build. Environ. **171** (2020). https://doi.org/10.1016/j.buildenv.2019.106617
8. Nguyen, Ch.K., David, D., Kuznik, Fr.: Full-scale experimental study of ceiling turbulent air jets in mechanically ventilated rooms (2017)
9. Xie, H., Zhang, S., Guan, X.: Shanghai Ligong Daxue Xuebao/J. Univ. Shanghai Sci. Technol. **39**, 81 (2017). https://doi.org/10.13255/j.cnki.jusst.2017.01.014
10. Teodosiu, C., Ilie, V., Teodosiu, R.: Appropriate CFD turbulence model for improving indoor air quality of ventilated spaces. Math. Model. Civil Eng. **10**, 28 (2015). https://doi.org/10.2478/mmce-2014-0020
11. Mularski, J., Arora, A., Saeed, M.A., Niedźwiecki, Ł., Saeidi, S.: Impact of turbulence models on the air flow in a confined rectangular space. Eng. Sci. Technol. (2020). https://doi.org/10.37256/est.212021627
12. Teodosiu, R., Niculiţă, L., Teodosiu, C.: Computational fluid dynamics based modeling of a linear heat source. Environ. Eng. Manag. J. **13** (2014). https://doi.org/10.30638/eemj.2014.216
13. Tabunshchikov, Y.A., Shkarpet, V.E., Kapko, D.V., Brodach, M.M., Kochariantc, K.V.: Installing local recirculation air diffusers during building deep renovation reduces energy consumption of ventilation systems. Energy Procedia (2016). https://doi.org/10.1016/j.egypro.2016.09.149
14. Ziganshin, A.M., Batrova, K.E., Logachev, K.I., Mingazeeva, D.N.: Numerical modelling of energy efficient exhaust orifices and hoods in ventilation and air conditioning systems in buildings and facilities of thermal power plants. IOP Conf. Ser.: Earth Environ. Sci. (2019). https://doi.org/10.1088/1755-1315/288/1/012134
15. Logachev, K.I., Ziganshin, A.M., Averkova, O.A., Gol'tsov, A.B.: Reducing power consumption of local exhaust ventilation systems. J. Phys.: Conf. Ser. (2020). https://doi.org/10.1088/1742-6596/1683/4/042015
16. Logachev, K.I., Ziganshin, A.M., Averkova, O.A., Logachev, A.K.: A survey of separated airflow patterns at inlet of circular exhaust hoods. Energy Build. **173** (2018). https://doi.org/10.1016/j.enbuild.2018.05.036
17. Kareeva, J., Bliznyakova, K., Ashadullina, D., Zakieva, R.: Influence of geometrical parameters of air inlet hole on the kinematic characteristics of jet. IOP Conf. Ser.: Mater. Sci. Eng. (2020). https://doi.org/10.1088/1757-899X/890/1/012164

18. Kareeva, J.R., Varsegova, E.V., Bliznyakova, K.A., Zakieva, R.R.: Study of the influence of geometric parameters of the inlet opening on jet characteristics. Izv. KazGASU [News KSUAE] **54**, 104 (2020)
19. Kocharyants, K.V., Denisikhina, D.M.: Constancy of the kinematic coefficient during outlet from modern air distribution devices. Naychnoe obozrenie. **10**, 40 (2017)
20. Posokhin, V.N., Varsegova, E.V., Ziganshin, A.M.: About the numerical determination of the characteristics of the supply nozzle. Izv. KazGASU [News KSUAE]. **39**, 173 (2017)