NUMERICAL SIMULATION OF LOCAL LOSS COEFFICIENTS OF VENTILATION DUCT FITTINGS

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ABSTRACT

The knowledge of the local loss coefficients is important for the accurate calculation of ventilation duct pressure loss. In practice, the pressure loss of ventilation duct is very often forecasted, what causes the wrong design of the ventilating fan. A large number of local loss coefficients exist, but the published data are different. The local loss coefficient can be estimated experimentally by the measurement on the real model, or with using of numerical simulation. The paper presents the using of CFD simulation for local loss coefficients of ventilation duct fittings (especially elbows and bends). The simulation results were compared with published data.

KEYWORDS

CFD simulation, local loss coefficient

INTRODUCTION

The local pressure losses (local resistance) are caused by the fluid flow through the duct fittings, which change the direction of the flow (elbows, bands, wyes, etc.) or affect the flow in the straight duct with constant cross-section (valves, stopcocks, filters etc.). The local pressure loss coefficient ξ for particular duct fitting can be determined purely by experiment (only one exception is Borda mouthpiece) and the data can be found in literature.

Since the experimental measurement of the local pressure loss coefficient on the real ductwork is expensive and time-consuming, it is possible to use advantages of the computer simulation modelling in CFD (computer fluid dynamics) software.

The numerical simulation results are compared with published data in the paper. Idelchik published an extensive work already in 1960, and his data are considered as correct. His work was edited also in USA (Idelchik, 1993). For example, Handbook of ASHRAE (2001) uses also the Idechik's data in chapter about the duct design. The next literature source is the German guidebook of heating and ventilation (Recknagel, 1996), where the different data of local loss coefficient are published. Also in Czech and Slovak literature it is possible to find these data. While the Czech literature is based on Idechik's values (Chysky and Hemzal, 1993), the Slovak literature (Ferstl, 2006) uses data from Recknagel guidebook (1996).

Presented analyses describe the local loss coefficient analytically so that it would be possible to use the results for calculation in practice.

The basic duct fittings as elbows and bends change the flow direction. In the straight duct the velocity and pressure profile are well balanced. When the fluid enters through the fittings the velocity and pressure profiles are disturbed (figure 1). The deformation of the velocity profile is caused by geometric condition of the duct fitting. The eddy zone can rise in the fittings, which influence the shape of the velocity profile (figure 1). After the fluid passes the fitting, the velocity profile tries to align. The fact mentioned above (deformation of the velocity profile) caused the local pressure loss.

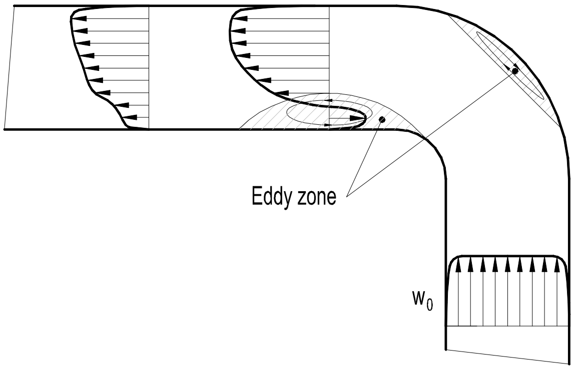


Figure 1 Velocity profiles in a duct with an elbow

RESEARCH METHODS

The simulation software CFD – Fluent vs. 6.2 was used for the calculations. The 3D model was created in the Gambit software. The number of the control volume is variable and, for the presented cases, it is between 500 000 and 2 000 000 cells.

The figure 2 shows the simulation experimental set-up. The fitting is placed between two straight ducts (3 m long on the inlet and 5 m long on outlet). The model is composed from three basic volumes: fitting, inlet duct and outlet duct.

The velocity in the duct *w* was chosen as constant 5 m/s for every analysed case. The presented results are valid for the turbulent flow. The model of turbulence k-ε RNG and standard wall function was used for calculations. The roughness height of the duct walls was zero for all cases, which corresponds to smooth walls.

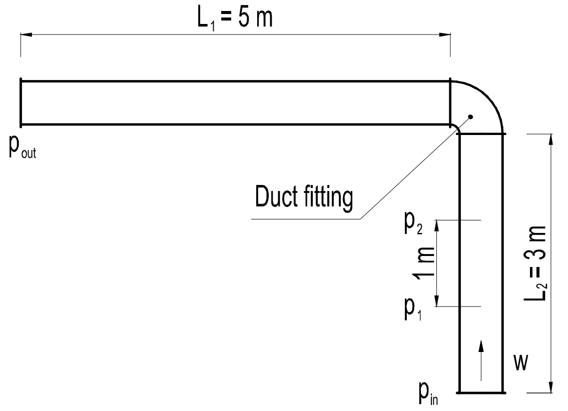


Figure 2 Experimental set up

Determination of local pressure loss coefficient ξ

The total pressure loss of the ventilation duct, shown in figure 2, is equal to difference between inlet and outlet pressure and also equal to sum of the friction and local pressure loss.

$$\Delta p = p_{in} - p_{out} = \Delta p_{fr} + \Delta p_{loc} \tag{1}$$

The specific pressure loss resulting from friction *F* can be obtained from 1 m straight sucking duct (figure 2)

$$F = p_1 - p_2 \tag{2}$$

The pressure loss resulting from friction is the function of the total length of the straight duct

$$\Delta p_{fr} = F(L_1 + L_2) \tag{3}$$

The local pressure loss can be estimated as a multiple of the local pressure loss coefficient ξ and dynamic pressure

$$\Delta p_{loc} = \xi \frac{w^2}{2} \rho \tag{4}$$

After substitution of (1) into (4) the local pressure loss coefficient can be determined as

$$\xi = \frac{2\left(\Delta p - \Delta p_{fr}\right)}{w^2 \rho} \tag{5}$$

For the convenience of engineering calculations, the total local loss coefficient is determined as the sum of the local resistance and friction coefficient (Idelchik 1993).

$$\xi = \xi_{loc} + \xi_{fr} \tag{6}$$

The examined types of the fittings

The paper deals with examination of the duct fittings, which changes the flow direction by 90°. The examined fittings are specified in the following description and also in figure 3.

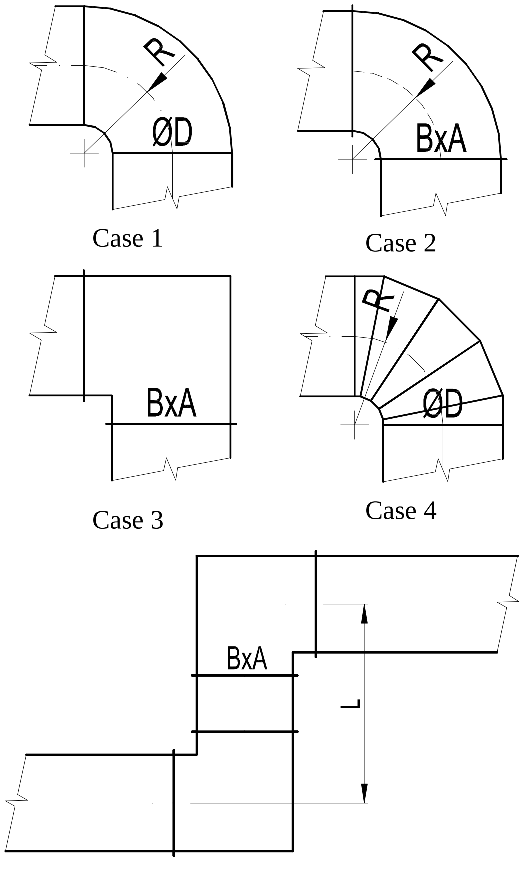
Case 1 – Round elbow 90°

Case 2 – Rectangular elbow 90°

Case 3 – Rectangular elbow with sharp corners 90°

Case 4 – Segmented round elbow 90°

Case 5 – Z-shaped elbow with sharp corners



Case 1

Case 2

Case 3

Case 4

Case 5

Figure 3 Schematic illustrations of duct fittings

RESULTS AND DISCUSSION

Case 1 - Round elbow 90°

The basic task, which is being analysed, is the round elbow (90°). The geometry of the elbow was characterized by the ratio *R/D*. The figure 4 shows the velocity contours for all analysed cases. The figure 5 presents the example of the velocity vectors for the ratio *R/D* = 0.5.

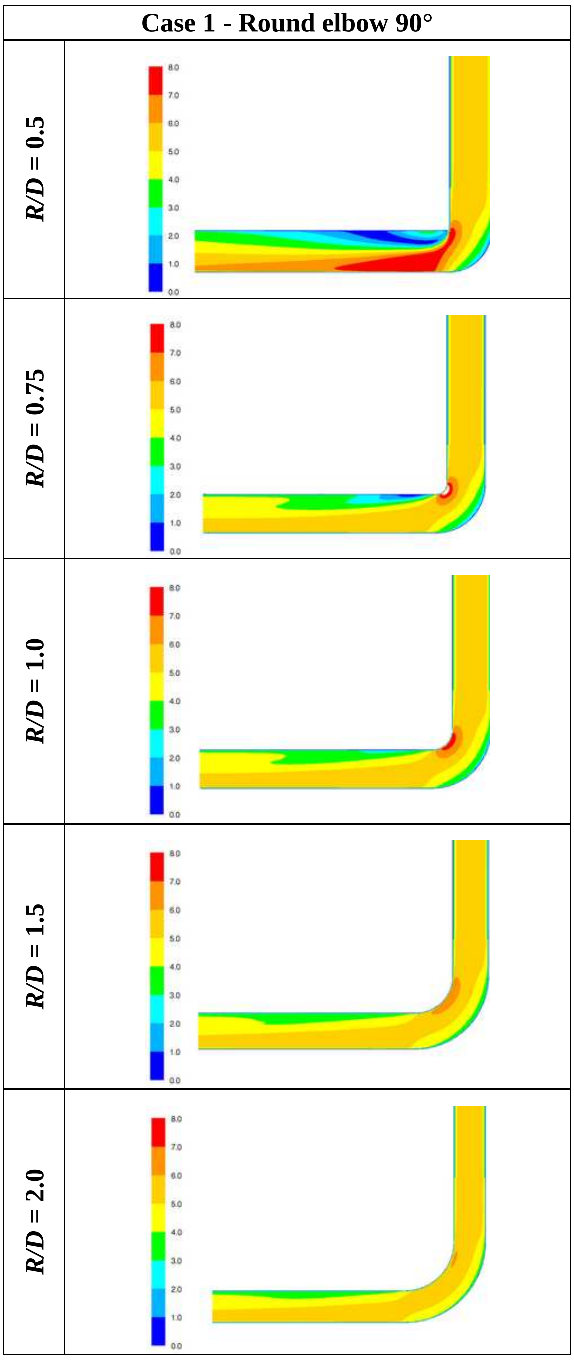


Figure 4 Velocity contours - Case 1

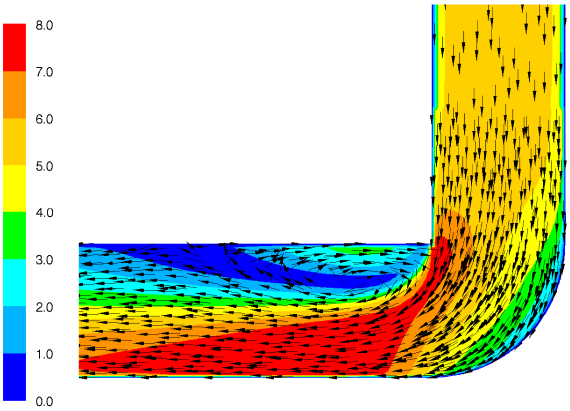


Figure 5 Velocity vectors – Case 1 (R/D = 0.5)

The results of the CFD simulation are present in figure 6. How it is seen the local pressure loss coefficients obtained by simulation are lower then the published data.

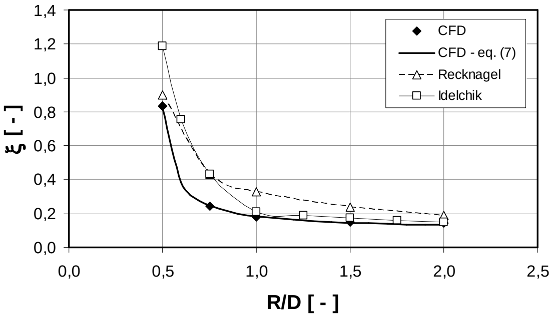


Figure 6 Results comparison – Case 1

On the basis of the numerical simulation results, the analytical dependence was found out.

$$\xi_1 = \frac{R}{D}\left[9.69\frac{R}{D} - 4.24\right]^{-1} \qquad (7)$$

Case 2 – Rectangular elbow 90°

The next basic case is the rectangular elbow (90°). The radius of the inner and outer edges is characterized by the ratio *R/B*. The local pressure coefficient ξ is also affected by the ratio of the duct high and width *A/B*.

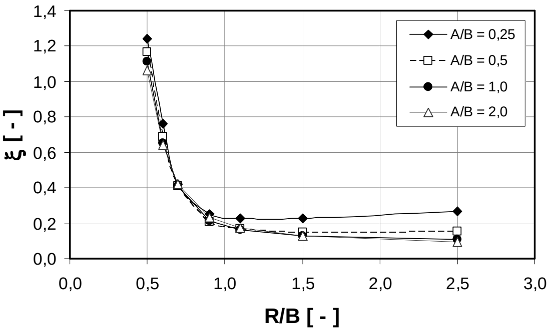


Figure 7 Results of simulations – Case 2

The results of the simulation are present in figure 7. The effect of the ratio *A/B* is visible. Especially for the higher values *R/B* > 1 and *A/B* > 1 the effect of the ratio *A/B* cannot be ignored. As it is seen in figure 7 (for the parameters *A/B* = 2 and *R/B* > 1) the higher *R/B* the higher local pressure loss coefficient ξ. It is caused by pressure loss resulting from friction, which is higher with higher *A/B*. The published data do not respect the mentioned fact as it is seen from the comparison of the results in figure 8.

On the basis of the numerical simulation results, the analytical dependence of the local loss coefficient on the geometric parameters of the fitting was found out

$$\xi_2 = C_1 \left(\frac{R}{B}\right)^{-1} + C_2 \exp\left(C_3 \left(\frac{R}{B}\right)^{-1}\right) \tag{8}$$

where

$$\begin{aligned} C_1 &= \frac{A}{B}\left(-0.069 - 3.458\left(\frac{A}{B}\right)^2\right)^{-1} \\ C_2 &= 0.092\left(\frac{A}{B}\right)^{-1} + 0.046 \qquad (9) \\ C_3 &= 1.247 + 0.177 \ln\left(\frac{A}{B}\right) \end{aligned}$$

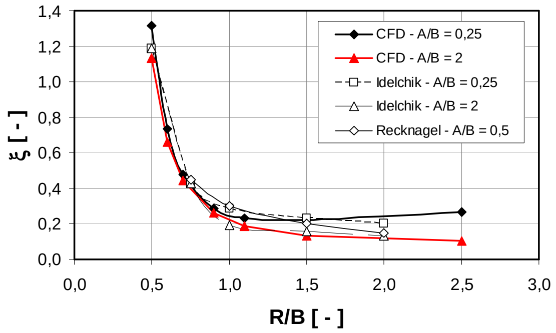


Figure 8 Results comparison – Case 2

Case 3 – Rectangular elbow with sharp corners

A very good agreement with Idelchik's (1993) data was obtained for the rectangular elbow with the keen-edged corners (figure 10). On the contrary, the ξ values published in German literature (Recknagel, 1996) are totally different. The sharp inner corner mainly affects the local pressure loss; therefore the relation between the coefficient ξ and the ratio *A/B* is practically straight. The dimension of the elbow defined by *A/B* has also effect on the local pressure loss, but how it is seen in figure 10, the effect is minimal.

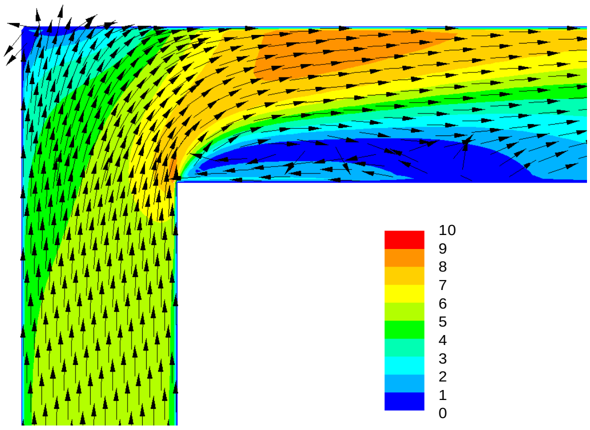


Figure 9 Velocity contour - Case 3

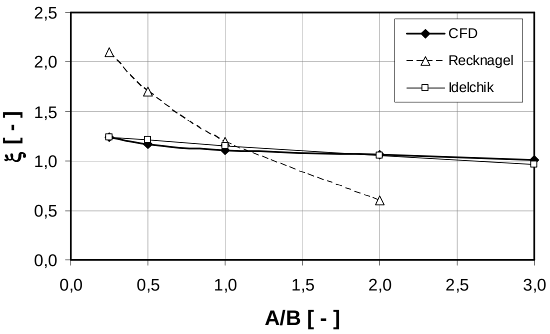


Figure 10 Results comparison – Case 3

On the basis of the numerical simulation results, the simple analytical dependence of the local loss coefficient on the ratio *A/B* was found out

$$\xi_3 = 1.11\left(\frac{A}{B}\right)^{-0.08} \tag{10}$$

Case 4 – Segmented round elbow 90°

The figure 11 presents the comparison of the published data of the local loss coefficient (Idelchik 1993, Recknagel 1995, Hemzal 1993) for simple (case 1) and segmented round elbow (case 4). The variability of the published data is evident in figure 11.

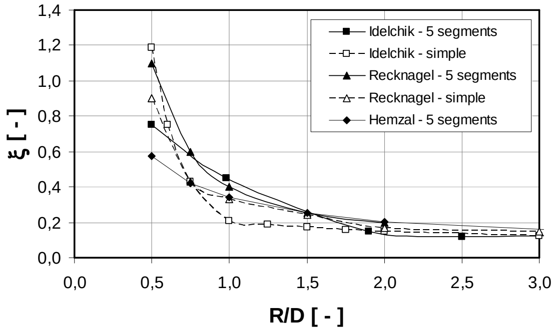


Figure 11 Comparison of the published data for simple round elbow and segmented round elbow

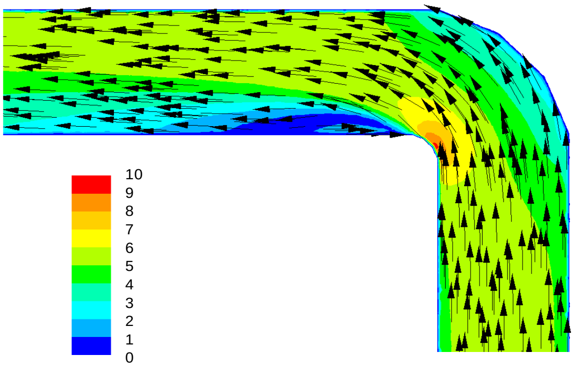


Figure 12 Velocity vectors and contour Case 4

The creation of the segmented elbow model in CFD software or in Gambit respectively is very complicated. Therefore the only one geometric case (R/D = 0.74) was simulated. The result of the simulation was compared with the simulation results obtained for Case 1 (figure 13).

The result of CFD simulation for the segmented round elbow (5 segments) corresponds with the result for the simple round elbow (Case 1) in principle.

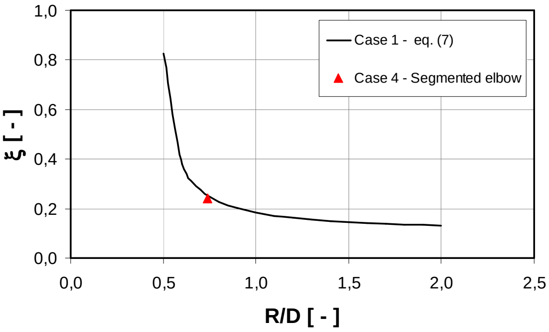


Figure 13 Results comparison – Case 4

Case 5 – Z-shaped elbow with sharp corners

The last case is composed from a pair of 90° elbows joined and it presents the Z-shaped elbow. The purpose of the study is to find the distance L, when it is possible to calculate the pressure loss coefficient as twice local loss coefficient of a single right-angle elbow $\xi_5 = 2\xi_3$. As it is seen in figure 10, the dependence $\xi_3 = f(A/B)$ is quite flat. Therefore the only one basic geometric case ($A/B = 1$) was analysed. The figure 15 shows the velocity contours for selected cases.

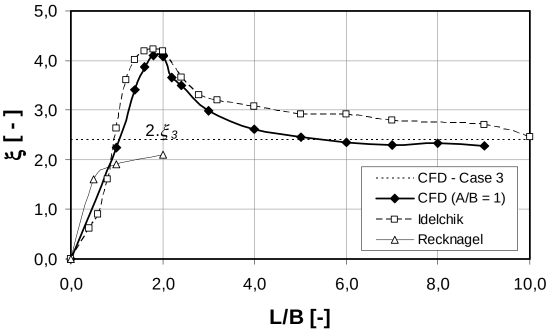


Figure 14 Results comparison – Case 5

The figure 14 presents the results of CFD simulation for the Z-shaped elbow. As it is seen the increase in the relative distance L/B between the axes of two single elbows first leads to a sharp increase of the total pressure loss coefficient and then, when the certain maximum is reached, to its gradual decrease to a value roughly equal to twice local loss coefficient of a single right-angle elbow (case 3).

In the figure 14 the dotted line presents the dependence $\xi_5 = 2\xi_3$. This simplified calculation can be used for the cases, when the distance $L > 2.5$ m ($L/B > 5$) is achieved.

The figure 14 also presents the comparison of the CFD simulation results with published data. In the area with lower L/B the results show good agreement with Idelchik’s (1993) data. For the $L/B > 3$ the results are little bit different. On the contrary, the data published by Recknagel (1996) seem to be incomplete and, especially for $L/B > 1$, the data show different trend. Using of these data for practical calculation cannot be recommended.

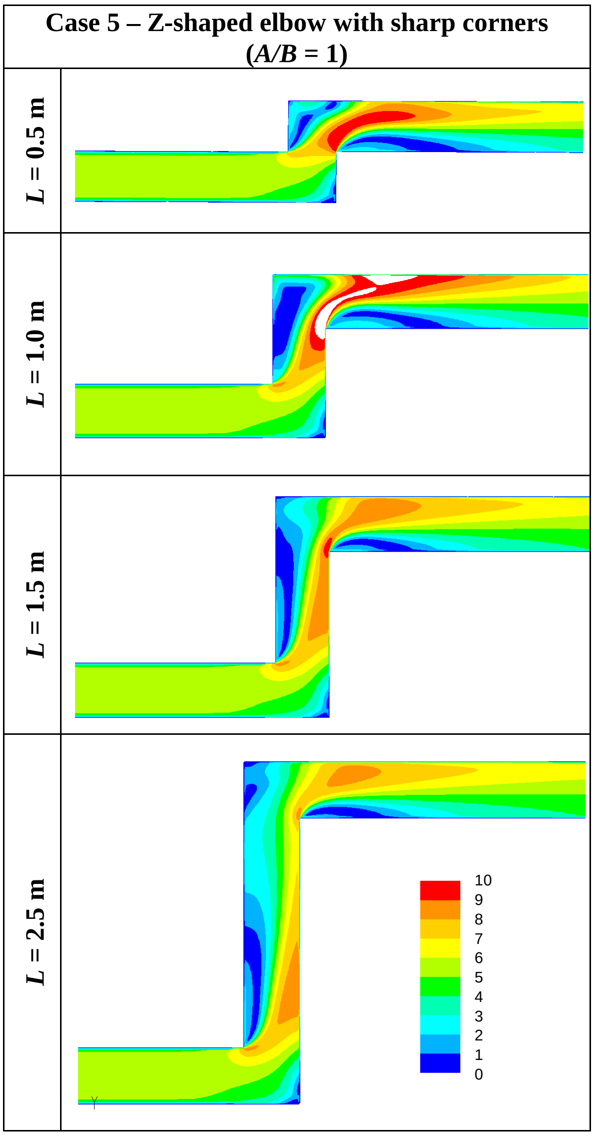


Figure 15 Velocity contours - Case 5

CONCLUSION

The paper presents the advantages of the CFD simulation using for analysis of local pressure loss coefficient (local resistance) of the duct fittings. In comparison with standard experimental methods on situ, the computer simulation doesn’t need expensive measuring device. The fast experiment caring out and simple obtaining of the results are also the advantage.

In the paper the basic duct fittings, which are used for change the flow direction as elbows and bends were analysed. The results of the simulation were compared with generally accepted published data. In this view the obtained results are very interesting. While the results published by Idelchik (1993) in his extensive work show the similar trend as the simulation results, some data published in German literature (Recknagel, 1995) cannot be recommended for practical calculation.

FUTURE WORK

The presented simulations were focused on elbows and bends only. The numerical simulation method in CFD allows carrying out other analyses. A similar method can be used for the other ventilation fittings like transitions, diffusers, cross, branches etc. The simulation analysis including the literature review will be continued in the next work.

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NOMENCLATURE

A	height of the duct [m]
B	width of the duct [m]
D	diameter of the duct [m]
F	specific friction pressure loss [Pa/m]
L	length of the duct [m]
p_{in}	inlet pressure [Pa]
p_{out}	outlet pressure [Pa]
Δp	total pressure loss [Pa]
Δp_{fr}	pressure loss resulting from friction (frictional drag) [Pa]
Δp_{loc}	local pressure loss (local resistance) [Pa]
R	radius of the curvature of the elbow axis [m]
w	air velocity [m/s]
ξ	local pressure loss coefficient [-]
ν	kinematic viscosity = $1{,}49.10^{-5}$ [m^2/s]
ρ	air density = 1,2 [kg/m^3]