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Influence of the Cross-sectional Shape on the Pressure Drop at 90 Degree Elbow Duct Fittings

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Abstract

Most of the calculations of pressure losses for HVAC (heating, ventilation, and air conditioning) fittings in networks are based on data, from sources which are over 60 years old. A large part of existing-literature data for pressure drop coefficients are also only valid for high Reynolds numbers, i.e. larger than 200000. This Reynolds number range is often not applicable for HVAC systems. Therefore, new and adequate studies are needed to achieve efficient ventilator operation and avoid energy waste.

The objectives of this paper are to present a comparison between the updated data and the literature and to show the Reynolds number dependency of the pressure drop by means of CFD simulations. The results of the simulation study illustrate the influence of the cross-sectional shape (circular, rectangular, oval and ellipse) on the pressure drop at 90° fittings for different radiuses of curvature r over diameter D ratios r/D. The results show that fittings with circular cross sectional shape do not have the lowest pressure losses.

The investigation concerns circular ducts with a diameter D = 300 mm within the velocity range 2-8 m/s as standard case. The dimensions of the other cross-sectional shapes have been determined in such a way that the volume flow rate remains the same as those for the circular fittings of the standard case.

Keywords - Pressure drop; Energy efficiency; HVAC Fittings; CFD

1. Introduction

The pressure drop of HVAC fittings was subject of many investigations until the middle of the 20th century. Unfortunately not much has been done since this time. But the arrival of new technology such as numerical simulation can help to update the available databases and go much further in the research possibilities. In the building technology field for example, there is a lack of information for the pressure loss coefficient of HVAC fittings the corresponding to the domain of Reynolds number under 200000. Indeed most researches present pressure loss coefficients values acceptable for Reynolds number equal and greater than 200000 ([1], [2]).

In this paper by the means of simulations, the velocity dependency of the drop pressure for 90° bend fitting is shown. And the influence of the cross-sectional shape on the drop pressure for the same type of bend is also investigated.

The following shapes are considered: circular as standard, horizontal rectangle (RH or Rec_Hor), vertical rectangle (RV or Rec_Ver), oval (O) and ellipse (E). The choice of the dimensions is detailed in fig. 3. The volume flow rate of the circular area is kept as standard because of the will to present a practical use of the data and later on to put the data in relation with the power demanded by a building fan.

a. Pressure loss coefficient definition

The pressure drop in a HVAC network is presented as followed and detailed in fig. 1:

$$\Delta P = \frac{1}{2}\rho u^2(\lambda\frac{l}{d} + \sum\zeta_i) \qquad (1)$$

ρ	Density	kg m^{-3}
u	Average velocity	m s^{-1}
λ	Duct friction coefficient	
l	Length of duct	m
D	Inner diameter of the duct	m
ζ_i	Pressure loss coefficient of fittings	

While in straight duct the pressure drop ΔP_R is linear and generated by wall friction phenomenon, the pressure drop generated by a HVAC fitting is characterized by the so called pressure loss coefficient ζ:

$$\zeta = \frac{\Delta P}{\frac{1}{2}\rho u^2} \qquad (2)$$

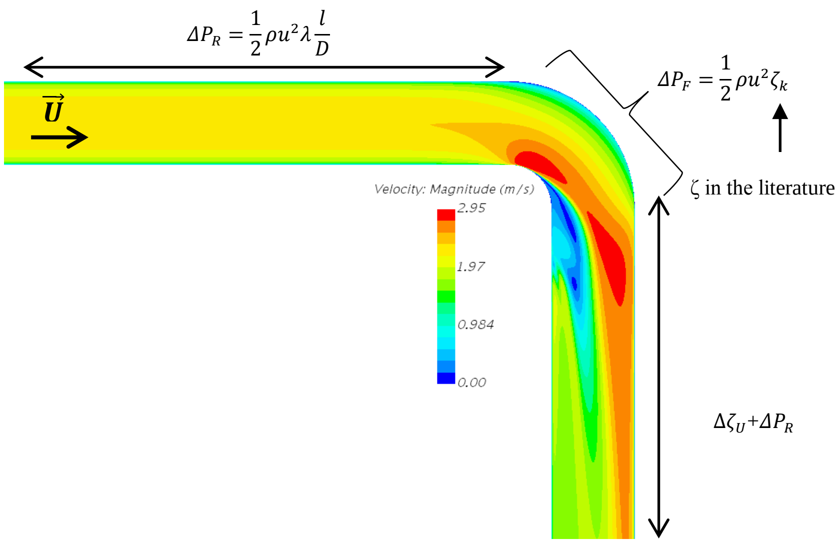
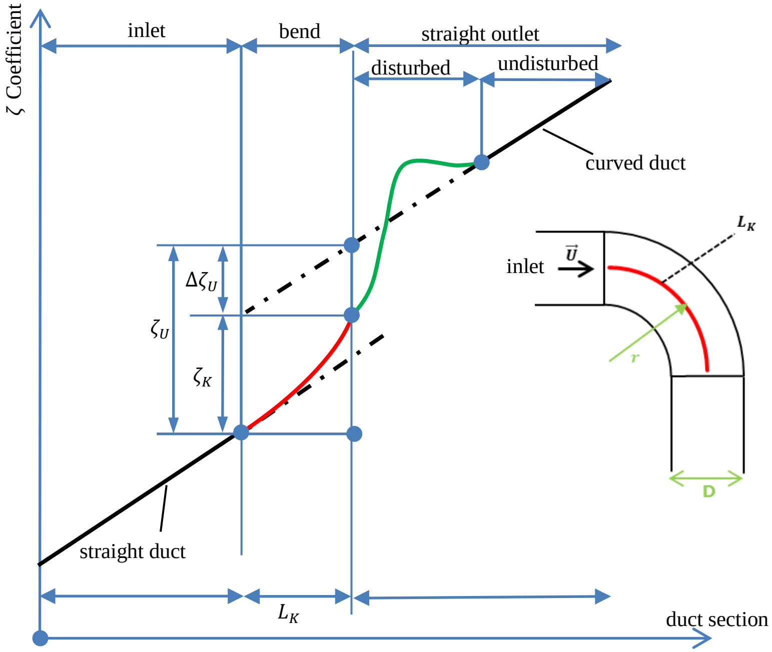


Fig. 1 Description of the pressure drop in a HVAC network

The ζ loss coefficient is a useful characteristic number to compare and evaluate the pressure drop of HVAC fittings regardless of their form and size.

Another important aspect is the entire value of the pressure loss coefficient. As explicitly shown in fig. 2, on the one hand there is a pressure drop caused in the fitting mainly due to flow separation and secondary flows ζ_k and on the other hand there is a pressure drop due to the disturbed flow downstream the bend, ([3]). But it turns out that most of the data sources neglect the later one, because its value can be very small. Since the goal is to determine precisely the pressure drop, the pressure drop of a fitting ζ_U will always be considered as the whole sum of these two losses.



ζ_U: Total bend pressure loss coefficient, $\zeta_U = \zeta_k + \Delta\zeta_U$
ζ_k: Actual ζ- loss coefficient of the bend
$\Delta\zeta_U$: Additional ζ – loss coefficient as a result of disturbed flow after the bend in the straight duct

Fig. 2 Description of the pressure loss coefficient for a fitting

2. Simulations

a. Preparations

The computational fluid dynamics tool Star CCM+ 10.06.010 from CD-adapco is used to perform several simulations in order to obtain the pressure loss coefficient of different area forms and different radius curvatures for the 90° bend fittings (fig. 3)

The adopted simulation model is the steady SST (Menter) *k-ω* because of its suitability for problems in which the wall influences are dominant ([4], [5]).

The investigation deals with fitting with smooth walls, i.e. the wall roughness is neglected as a parameter.

As mentioned before, the circular shape is chosen as reference with a diameter of $D = 300$ mm. The selected velocities are 2, 4, 6 and 8 m/s, corresponding to a Reynolds number range from 3.86×10^4 to 1.56×10^5. The volume flow rates are derived from those velocities and are utilized to acquire the "equivalent velocities" for the other cross-sectional forms. The dimensions of those cross-sectional forms are calculated by applying the equivalent diameter formula (3):

$$d^* = \sqrt[5]{\frac{32}{\pi^2}} \sqrt[5]{\frac{A^3}{P}} \tag{3}$$

Where A is the cross-sectional area of a shape and P is the perimeter. The equivalent diameter gives an equivalent circular shape from non-circular form so that in straight duct there is the same drop pressure per meter as in the equivalent circular shape. It was decided to choose $L_x = 2 \times l_x$ and $d^* = 300$ mm, the values of L_x and l_x are then deduced.

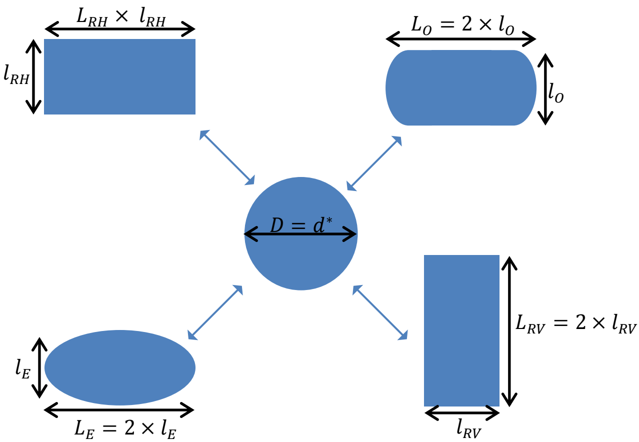


Fig. 3 Details about the different shape dimensions

The selected curvature radiuses are $\mathrm{r} = \mathrm{D}, \mathrm{r} = 3/4\mathrm{D}$ and $\mathrm{r} = 2/3\mathrm{D}$. Those radiuses of curvature are the most used as HVAC fittings essentially because they are much cheaper than the bigger ones.

3. Results and discussions

Fig. 4 presents the values of ζ_U for each radius curvature in relation to the equivalent velocity. Overall, except for the vertical rectangle, all other cross-sectional forms present smaller ζ_U than the circular shape ones. Plus the oval and horizontal rectangular shapes provide the lowest pressure drops. Also it can be clearly seen that ζ_U is becoming smaller as the velocity grows. For instance, ζ_U of the circular shape gets smaller from U=2 m/s to U=8 m/s by 15% for r=2/3D and by 23% for $r = D$. Furthermore an overall decrease of ζ_U as the radius of curvature is growing bigger can be noticed.

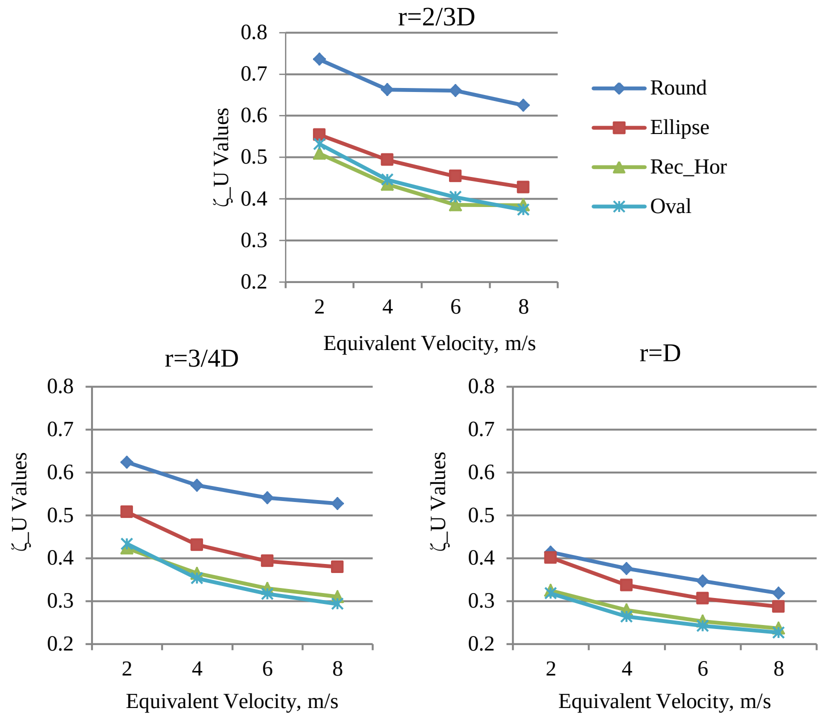


Fig. 4 ζ_U values for the different curvature radiuses and shapes in dependence on the velocity

To evaluate the discrepancy with the actual database, a more practical comparison is carried out. First, the ζ_U values are extracted for the selected curvature radiuses and velocities from the software tool Plancal Nova 9, which is a well-known software and used by planning engineers to determine the pressure drop of a HVAC network. And

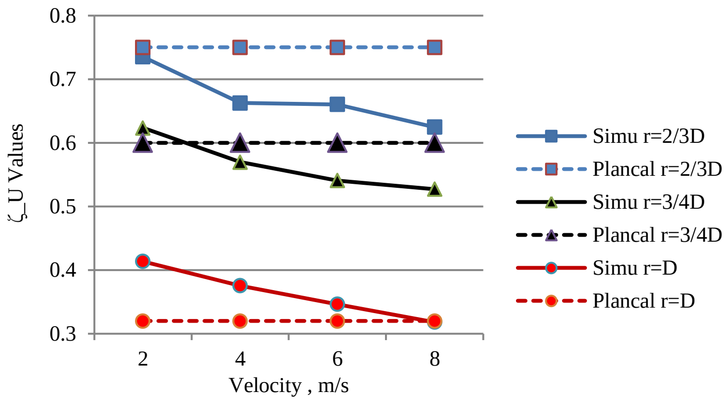


Fig. 5 Comparison of the ζ_U values between the simulations and Plancal for the circular shape and the different radiuses of curvatures and shapes in dependence on the velocity.

then those ζ_U values are compared with the simulation results. Additionally, Plancal bases its calculations on the norm VDI 2087. Fig. 5 illustrates this observation for the circular shape. The ζ_U values from Plancal (dashed lines) are constants and most of them tend to diverge from the simulated ζ_U loss coefficients (solid lines).

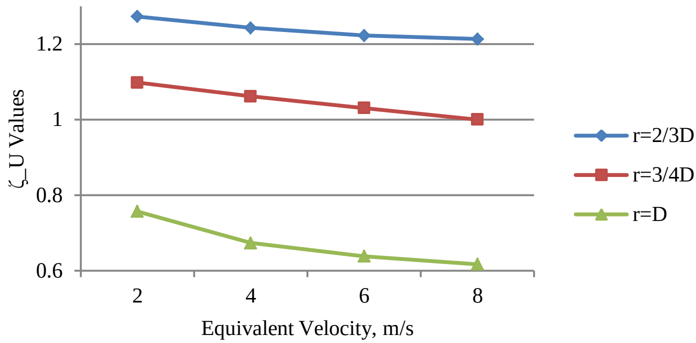


Fig. 6 ζ_U Values for the rectangular vertical shape for the different radius curvatures in dependence on the velocity

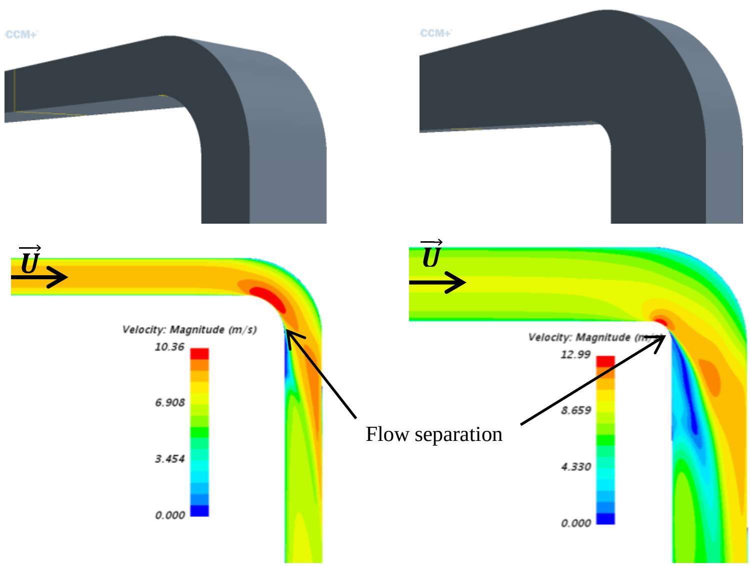


Fig. 7 Flow separation for bends of the rectangular vertical and horizontal shapes, equivalent velocity is 8 m/s and $r = D$

The rectangular vertical shape constitutes a particular case since its ζ_U values are much higher than those of the other forms, fig 6. For example, a comparison with the rectangular horizontal shape illustrates that, for all the velocities and radiuses of curvature studied, the ζ_U values of the rectangular vertical shape are from 133% to 222% larger. An explanation of this huge discrepancy can be the immense flow separation occurring in the rectangle vertical bend fitting, fig 7.

4. Conclusion

Using numerical simulation tools the impact of the cross sectional-shapes was observed. While the rectangular vertical shape provides the highest pressure loss coefficient, the rectangular horizontal and the oval forms generate lower loss coefficients than the circular shape.

It was illustrated as well that the velocity (and accordingly the Reynolds number) dependency of the pressure drop of 90° HVAC fitting with different radiuses of curvature for Reynolds Number under 200000. This means that there is a miscalculation regarding the drop pressure of HVAC network. A 15% or 20% mistake in the estimation of the pressure loss for one fitting may be considered as small, but most of the HVAC networks of buildings are made of dozens and sometimes hundreds of fittings. This estimation error can become considerable and cannot be neglected. The direct consequence is a false configuration of the fans, leading to energy waste. Further works shall be done for bigger radiuses of curvature and other fittings as well.

For the sake of quality and precision, the experiments are still going on. It is planned to show the results in a near future.

Acknowledgement

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