

Ductwork Pressure Loss Determination Utilizing Building Information Model

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Abstract. Building design created as an information model contains not only information formed during building geometry creation but also additional information filled in by a designer. The data can be used further as well as applied in building geometry analyses. One of these are analyses of pressure loss in air-handling units. Such analyses take the advantage of both created geometric parameters, and basic physical variable. These analyses can be carried out directly in BIM software without external calculations needed. The main aim of this article is to describe utilization of information in building model leading to obtain pressure loss in air-handling units.

1. Introduction

Building created as a building information model provides plenty of opportunities. Information contained in model are as comprehensive as the designer is. The model contains fundamental geometric information which become the standard in civil engineering. On the other hand, building information model can contain complementary information. These complementary information are especially physic origin and can be utilized for building analysing which is important for sustainable building design. Project design phase is a building life cycle phase when the most important decisions are made, and changes occur. The decisions are important for further realization and building using phase especially because of expenditure. Over time decisions converge to an optimal solution.

In some cases, the building can be analysed directly into the modelling software with no external applications or other methods needed. Commercial software already provides analysing tools utilizing physical models. However, most of the analyses are not possible to be utilized directly in modelling software and one of them is ventilation ductwork pressure loss analysis. The analysing tools are influenced by building national standards requirements. Although physical equations are general, its interpretation and utilizing depends on national habits and standards. That is the reason why inconsistency is in the analysing tools between countries. The solution can be to develop national standard analysing tools with the use of BIM data in building design phase. [1]

2. Ventilation ductwork pressure loss

One of the requirements for proper ventilation ductwork design is a fan power sufficient to supply air into every room. [2] Ductwork pressure loss is needed to be calculated for designing the fan. Pressure



losses are caused by air friction against the duct walls [3]. The pressure loss on straight duct sections is very small. On the other hand, in places where flow direction is changed (elbows, reductions, other ventilation fittings), the pressure loss is considerable. For pressure losses in duct fittings (excluding straight pieces of duct) we use the term local pressure loss.

Local pressure losses are expressed as a pressure drop by the difference of static pressures at the beginning of the fitting and at its end. This is based on Bernoulli's equation

$$\rho \frac{v_1^2}{2} + p_1 + \rho gh = \rho \frac{v_2^2}{2} + p_2 + \rho gh + p_z, \quad (1)$$

where ρ is the air density, v is the mean velocity in a given cross-section, p is the static pressure, h is the height difference between the measured cross-section and the reference plane and p_z is the pressure loss caused by friction.

It is assumed that the system is airtight, and the mass flow is therefore constant. If the duct cross-sectional area is constant, the mean flow velocities in different parts of the duct are equal. In the case of air ducts, the effect of gravity on the flow is often neglected. With this simplification, the pressure drop of the duct fitting can then be expressed as equation

$$p_z = p_2 - p_1 \quad (2)$$

This pressure drop can also be expressed in terms of mean velocity as

$$\Delta p = \xi \rho \frac{v^2}{2}, \quad (3)$$

where ρ is the air density, v is the flow mean velocity and ξ is the pressure loss coefficient.

The pressure loss coefficient is based on the duct fitting type and depends especially on the nature of the flow (Reynolds number) and the fitting geometry. The pressure loss coefficient values can be found in tables [3-5] or (less often) in the form of mathematical equations [3, 6-7].

For pressure loss calculation on straight ducts sections is used equation

$$\Delta p = \lambda \cdot \frac{l}{D} \cdot \frac{\rho v^2}{2}, \quad (4)$$

where λ is the friction factor, l is the length of the straight duct section, D is the duct hydraulic diameter, ρ is the air density, v is the flow mean velocity.

The Colebrook-White equation is often used for the friction factor calculation

$$\frac{1}{\sqrt{\lambda}} = -2 \log \left(\frac{2.51}{Re \sqrt{\lambda}} + \frac{\varepsilon}{3.7 D} \right), \quad (5)$$

where ε is the absolute roughness of the duct material, D is the duct inner diameter and Re is the Reynolds number. In addition to the Colebrook-White equation, its approximation equations are also often used. These equations express the friction factor explicitly [6].

To select the sufficient fan power, it is necessary to calculate the total ductwork pressure loss. That means to sum the pressure losses of all fitting types and straight duct sections on the ductwork. The designer is forced to consider various geometric parameters and types of individual fittings to select

the appropriate pressure loss coefficient. However, this process can be automated utilizing a ductwork model in building information model.

3. Building information model

Plenty of software that provides modelling buildings as BIM, also allows to model building services. The mere geometry of a given duct section expressed by parametric values can serve as an input variable in the calculation of the pressure loss.

Some software, such as Autodesk Revit, allow to analyse ventilation ducts directly in the application's user interface. Using mentioned software, it is possible to analyse the ventilation ducts for pressure loss by means of several methods. For straight duct sections it is possible to choose from a couple of approximation equations (specifically the Haaland equation and the Altshul-Tsaal equation) and the Colebrook-White equation (5) to obtain the friction factor. The internal calculation also considers the nature of the flow according to the value of Reynolds number (software distinguishes between laminar and turbulent flow). The total straight duct sections pressure loss is determined using the modelled geometry and specified amount of supplied air.

The duct fitting pressure loss is calculated according to equation (3) utilizing the mass flow and the pressure loss coefficient. The pressure loss coefficient is obtained in several possible ways: by the input of user-entered coefficient value for each entity (each duct fitting) or by the user duct fitting pressure loss input directly to each entity and or by obtaining the coefficient value from ASHRAE table [8] which is automatically assigned to each entity according to the fitting type.

Automatic fitting detection in Revit and finding the pressure loss coefficient in the ASHRAE table may seem like the best choice for the designer. But this method has some disadvantages. The first is the inability to edit the table (inability to edit the coefficient values and parameters) [9] and the second is the imperfect searching for duct fitting type. The table consists of geometric parameters of a defined duct fitting type, according to which Revit finds the appropriate coefficient value. The problem occurs when the geometric parameters of the duct fitting do not correspond exactly to the tabular values of the geometric parameters. In Czechia, duct fittings are often made-to-measure and that is the reason why there is no appropriate value in ASHRAE table. In these cases, the table is unable to interpolate intermediate parameter values. The exact type of fitting is often difficult to detect (for example, the difference between smooth radius elbow and mitered elbow).

The solution of these imperfections can be free access to tabular values and the possibility of editing them. The ability of interpolation is also needed or the utilizing of mathematical equations expressing coefficient values depending on geometric parameters and more accurate detection of duct fitting type.

4. Complex pressure loss solution in BIM

The data use from the building information model for the purpose of determining the ductwork pressure loss can be utilized by several ways. When using commercial software, information can often be accessed with an external application using API (Application Programming Interface). As a result, plenty of parameters that are part of the software information model can be utilized as input variables to the physical models created in the source code of the external application.

An alternative to creating an external application may be to process IFC file. IFC file is an interchangeable format containing the fundamental parameters of the information model. This file contains number of parameters that can be used to analyse duct fitting pressure loss. The advantage is the versatility of this file. Commercial BIM tools can work with this type of file. However, the

disadvantage is the limitation in the number of parameters contained in the file. In particular, the physical parameters with the duct fitting type are missing.

In both cases, it is possible to use geometric parameters and process them further. The main part of the analytical tool is its physical model (physical equations), according to which the calculation runs. In the case of pressure loss, the key factor is local pressure loss, its values often vary in the literature. They are most often written in tabular form. These coefficient values are currently often obtained by numerical methods, but with some simplifications they may differ from the actual measured values on a real ductwork. Tabular values may be unsuitable for use in automated calculation, as their values need to be interpolated and there is a risk that the entered parameters will be out of the range of values in the table. In such a case, it seems more appropriate to use approximation equations describing the dependences of the magnitude of the coefficient of local pressure losses on the geometric parameters of the duct fitting. For many duct fittings, the approximation equations have not yet been determined or are determined based on numerical analyses, not real ductwork experiments.

5. Results and discussions

Laboratory experiment to determine pressure losses on the ductwork is time consuming but corresponds most to the real state of the ductwork in the building. From the values measured in this way, it is possible to compile equations, which can be used in the automation of pressure loss calculations in the building information model. An example of an automatic pressure loss calculation could be an external application / add-on for Revit that calculates pressure losses for fundamental duct fittings, which are elbows and transitions for round and rectangular pipe cross-sections. On the internet, this application called Revit Ductwork Pressure Loss Calculator is located on the GitHub web hosting in the form of an open-source add-on for the Revit application. It is an externally accessing application that uses the internal parameters of the Revit software to determine the type of duct fitting and then assigns the appropriate pressure loss coefficient to each fitting utilizing geometric parameters. The coefficient is assigned from two different sources. One source is a tabular value according to the ASHRAE table from 2001 and the other is mathematical equation reflecting the dependence of the coefficient on the geometry. For these purposes, the laboratory experiment research established analytical equations depending the coefficient of local pressure losses on 45° and 90° elbows geometry parameters. The equations are incorporated into the application and can be found in the Table 1.

The advantage of the application is the possibility of its user editing. Editing tabular values, including the values of their parameters, is user-friendly without the need to intervene in the source code, as these values are stored in a text file. It is therefore possible to adapt the coefficient values to designer experience or preferences. The mentioned application has the potential in Revit software to be developed into an automatic tool for the analysis of pressure losses for the Czech (and or international) environment. The application development consists mainly in adding other duct fittings to the source code, which the algorithm would consider and thus contain a satisfactory number of fittings over time. Other elements suitable for inclusion in the calculation could also be the effect of elbows that are placed downstream nearly each other with small or no duct straight part. This advanced analysis can lead to more accurate results of pressure losses. For two consecutive elbows, the tabular values are often unsatisfactory, and the analytical expression of the coefficient-geometry dependency is not common. For this purpose, rectangular cross-section elbows with different aspect ratios of cross-sections and different values of axial rounding and different sizes of the straight intermediate part between the elbows were analysed. The result is the equation that can be incorporated into an analytical tool that utilizes information in a building model. The equations of pressure loss dependence are given in the following Table 1.

Table 1. Dependency of pressure loss coefficient on the geometry (W is width of the rectangular duct cross-section, H is height of the rectangular duct cross-section, L is length of intermediate straight section).

| Ductwork type | Dependency of pressure loss coefficient and duct fitting geometry |
|----------------|---|
| Elbow 1 × 45° | $\xi = -12,970 \left(\frac{W}{R}\right)^2 + 31,350 \frac{W}{R} - 18,490$ |
| Elbow 1 × 90° | $\xi = -5,606 \left(\frac{W}{R}\right)^2 + 14,210 \frac{W}{R} - 8,470$ |
| Elbows 2 × 45° | $\xi = 0,043 \left(\frac{H}{W}\right)^{-2,441} - 0,015 \left(\frac{L}{W}\right)^3 + 0,072 \left(\frac{L}{W}\right)^2$ |
| Elbows 2 × 90° | $\xi = 0,432 \left(\frac{H}{W}\right)^{-1,248} - 0,007 \left(\frac{L}{W}\right)^3 + 0,032 \left(\frac{L}{W}\right)^2$ |

Table 2. Measurement errors, equation validity intervals, residual sum of squares and level of significance (W is width of the rectangular duct cross-section, H is height of the rectangular duct cross-section, L is length of intermediate straight section).

| Ductwork type | Absolute error | Validity interval | Residual sum of squares (RSS) | Level of significance α |
|----------------|--|--|-------------------------------|--------------------------------|
| Elbow 1 × 45° | $a = -12,970 \pm 0,350$ $b = 31,350 \pm 0,830$ $c = -18,490 \pm 0,480$ | $\frac{W}{R} = (1,0244; 1,3548)$ | 0,339 | 0,95 |
| Elbow 1 × 90° | $a = -5,606 \pm 0,38$ $b = 14,210 \pm 0,900$ $c = -8,470 \pm 0,523$ | $\frac{W}{R} = (1,0244; 1,3548)$ | 0,395 | 0,95 |
| Elbows 2 × 45° | $a = 0,043 \pm 0,004$ $b = -2,441 \pm 0,068$ $c = -0,015 \pm 0,001$ $d = 0,072 \pm 0,005$ | $\frac{H}{W} = (0,254; 1,000)$ $\frac{L}{W} = (1,476; 3,952)$ | 8,578 | 0,95 |
| Elbows 2 × 90° | $a = 0,432 \pm 0,030$ $b = -1,248 \pm 0,043$ $c = -0,007 \pm 0,004$ $d = 0,032 \pm 0,016$ | $\frac{H}{W} = (0,254; 1,000)$ $\frac{L}{W} = (1,476; 3,952)$ | 30,390 | 0,95 |

6. Conclusions

The building information model stores a substantial amount of information that can potentially be used. The more information the model contains, the more practical utilizing ways there are. Utilizing the BIM model for analytical tasks is an advanced feature of design software and offers considerable potential, which allows us to make competent decisions based on analysis and data at a time when we can influence the shape of the building with a minimum of costs. By simply using the already existing parameters and supplementing the physical calculating, it is possible to automate and to streamline building analysing. In this way, we can also maximize the use of available information in the model. In addition to the benefit rapid transfer of all created information about the building, BIM also offers the potential for application in the physical construction field.

The ductwork pressure losses determination is necessary for the design of ventilation system in a building. This process can be lengthy and complicated. The fundamental variables for the calculation, which are the coefficients, often differ and are not uniform for the Czech environment. In this respect,

the unification of values or mathematical dependencies can be a step towards standardizing this analysis and at simplifying, refining, and speeding it up. With simple automation processes, we can save a considerable amount of time and thus design buildings efficiently in the context of current needs.

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