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Validation of CFD model for simulation of multi-pipe earth-to-air heat exchangers (EAHEs) flow performance

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A R T I C L E I N F O

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A B S T R A C T

In this paper the experimentally obtained flow characteristics of multi-pipe earth-to-air heat exchangers (EAHEs) were used to validate the EAHE flow performance numerical model prepared by means of CFD software Ansys Fluent. The cut-cell meshing and the k-ε realizable turbulence model with default coefficients values and enhanced wall treatment were used. The total pressure losses and airflow in each pipe of multi-pipe exchangers was investigated both experimentally and numerically. The results show that airflow in each pipe of the multi-pipe EAHE structures is not equal. The validated numerical model can be used for a proper designing of multi-pipe EAHEs from the point of view of the flow characteristics. The influence of EAHEs geometrical parameters on the total pressure losses and airflow division between the exchanger pipes can also be analyzed. Usage of CFD for a designing process of EAHEs can be helpful for HVAC engineers (Heating Ventilation and Air Conditioning). It can also be helpful for optimizing the geometrical structure of multi-pipe EAHEs in order to save the energy and decrease operational costs of low-energy buildings.

1. Introduction

1.1. Application of earth-to-air heat exchangers

In the contemporary low energy buildings about 40% to even 60% of the heat for the building is used to heat up the fresh ventilation air. To reduce the energy demand for buildings, mechanical ventilation systems with heat recovery from exhausted air are commonly used. In cold and moderate climates, when the outside temperature is lower than about −5 °C, the plate-type heat exchangers in air handling units are frequently freezing, which decreases the energy savings. To avoid this problem, the earth to air heat exchangers (EAHEs) can be used as a part of the energy efficient mechanical ventilation systems with heat recovery for any kind of buildings. EAHE enables additional energy recovery thanks to the accumulative properties of the ground and a quite stable ground temperature. For central Europe climate quite stable ground temperature occurs at a depth of about 2 m and varies from 4 °C to 10 °C depending on the ground thermal properties (mainly thermal diffusivity), ground cover and season [1]. The pipe-type EAHE consists of pipes buried in the ground. Fresh air flows through the pipes and heats up in the winter, preventing the air-to-air heat exchanger in an air-handling unit from freezing (heat gains), or cools down in the summer (cool gains).

The principle of pipe-type EAHE operation for extreme winter conditions of central Europe is presented in Fig. 1. For some parts of transitional periods (spring, autumn), the usage of EAHE is not economically justified and the wall inlet (fresh external air) is used instead of EAHE inlet.

1.2. Multi-pipe earth-to-air heat exchangers

In buildings such as factories, markets [2], green houses [3], offices or swimming pools, for high demand of the fresh air, multi-pipe (registry type) heat exchangers are used to decrease total pressure losses and to decrease the area necessary for system installation. This consists of two main pipes (manifolds, d_{main}) and many parallel pipes (d) with the same length L (Fig. 2).

A proper designing of such exchangers is more complicated than that of single pipe structures, because much more parameters have to be taken into account. For the estimated calculations, the equal airflow division between all of parallel pipes is assumed but experimental investigations revealed the weakness of this assumption [4]. In Fig. 3 the example of percentage share of the flow rate in each pipe in the total flow rate of multi-pipe EAHE is presented, showing the airflow non-uniform division between parallel pipes.

There are many papers focused on the issue of mathematical modeling of EAHEs operation [5–15]. Majority of those mentioned take into account one-pipe structures of exchangers and focus attention on

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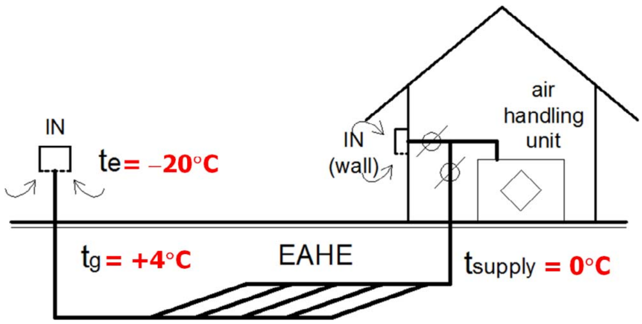

Fig. 1. Principle of pipe-type EAHE operation for extreme winter conditions of Poland, temperature: e – external, g – ground, supply – after the EAHE.

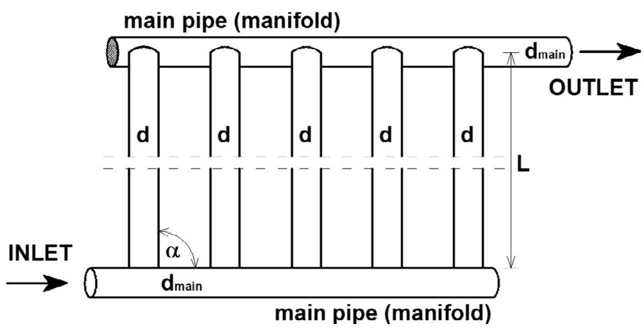

Fig. 2. Schema of the multi-pipe EAHE.

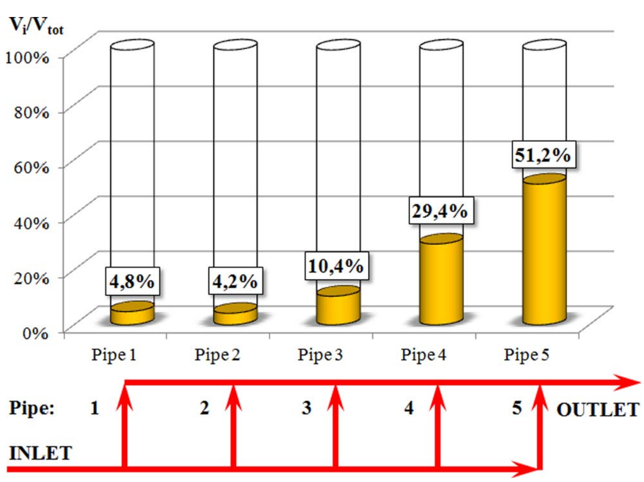

Fig. 3. Percentage share of flow rate in each pipe in the total flow rate of multi-pipe EAHE: 5 pipes 90°, L = 76d, d_{main} = d.

EAHEs thermal performance. In the article [16] one can read that the simple payback time of EAHE in the Italian climate can be 5–9 years. Performance evaluation and the life cycle cost analysis of EAHE were also conducted in the New Delhi (India) [17]. EAHE coupled to a photovoltaic system was investigated in Greece [18]. EAHE performance for greenhouses was investigated in Turkey [3]. The potential of EAHE for low energy cooling of buildings in Algeria was analyzed in [19]. The EAHEs were also studied in France [20]. An exception for papers solely focused on the thermal performance is the CFD model of registry type EAHE suggested in [6]. The model was validated by using measurements of inlet and outlet air temperature. Measuring results of pressure losses and airflow division between parallel pipes, i.e. experimental EAHE flow characteristics, were not presented. Also the numerical analysis for multi-pipe heat exchangers described in [14] is focused on the EAHE thermal performance and does not take into consideration the airflow division between parallel pipes. To the best knowledge of the authors, measuring results of pressure losses and airflow division between parallel pipes were not presented in the open literature.

2. Scope, experimental investigation and CFD model

2.1. Scope of investigation

In this work attention is drawn only to the EAHEs flow characteristics (flow performance). Thermal performance of the EAHEs is not a field of this work. Numerical flow performance model built with CFD code (Ansys Fluent software) is validated for typical 5-pipe heat exchangers of various parallel pipe length (L) and various main pipe diameters (d_{main}) with a constant branch-pipe diameter (d). In the model the total pressure losses and airflow in each pipe of multi-pipe EAHE are taken into account and compared with experimental results. EAHEs structures investigated in this paper:

1) d_{main} = d, L = 76d,
2) d_{main} = 2.3d, L = 76d,
3) d_{main} = d, L = 271d.

Those values were chosen from the typical range of use to show the influence of geometrical parameters d_{main} and L on the flow performance.

2.2. Experimental investigation

The experimental investigations of EAHEs models in scale 1:4 were conducted to measure the total pressure losses of EAHE and to measure the airflow in each parallel pipe. The most important data of the experimental set-up are shown in Fig. 4 and summarized in Table 1. Commercial polypropylene smooth pipes were used to build the heat exchangers models. View of the experimental set-up is shown in Fig. 5.

A simple and non-invasive method for airflow measurement was implemented to avoid interaction of the measuring tools with airflow in the pipes. The airflow in each pipe V_i of the exchanger was calculated based on pressure losses Δp_i at the measuring sector of each branch L_i (rearranged Darcy-Weisbach formula, Eq. (1)). The same method was used for total airflow V_{tot} calculations (Eq. (2)).

$$V_i = 3600\cdot\left(\frac{2\Delta p_i\cdot d_i^{1.25}}{0.3164\cdot\rho\cdot L_i\cdot\upsilon^{0.25}}\right)^{\frac{1}{1.75}}\cdot\frac{\pi\cdot d_i^2}{4} \tag{1}$$

$$V_{tot} = 3600\cdot\left(\frac{2\Delta p_{C-D}\cdot d_{main}^{1.25}}{0.3164\cdot\rho\cdot L_{C-D}\upsilon^{0.25}}\right)^{\frac{1}{1.75}}\cdot\frac{\pi d_{main}^2}{4} \tag{2}$$

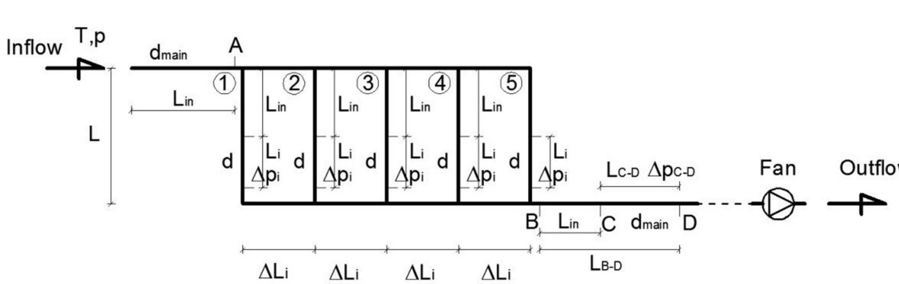

Fig. 4. Schema of the experimental set-up.