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Influence of geometrical parameters on the flow characteristics of multi-pipe earth-to-air heat exchangers – experimental and CFD investigations

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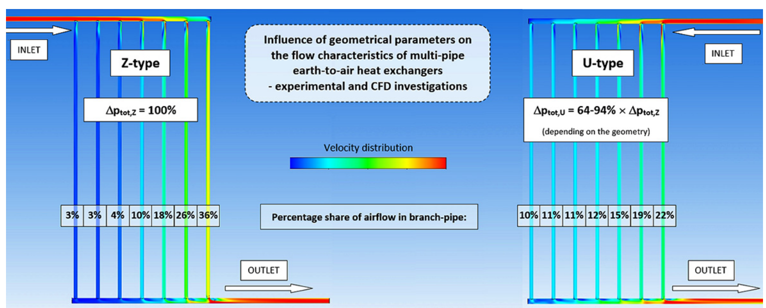
HIGHLIGHTS

- In multi-pipe exchangers airflow division between pipes can be non-uniform.
- The sensitivity analysis of geometrical parameters on the flow performance was done.
- U-type structures generate lower total pressure losses than Z-type structures.
- Airflow division uniformity in U-type structures is significantly better.
- Main pipe diameter to the parallel pipe diameter ratio has a significant impact.

GRAPHICAL ABSTRACT



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ABSTRACT

Efficiency of the earth-to-air heat exchangers depends not only on their thermal performance but also on the total pressure losses that are the cost of harvesting a geothermal heat. In this paper the sensitivity analysis of the flow characteristics to the change of multi-pipe exchanger geometry is presented. Experimental investigation and CFD simulation results present total pressure losses in the considered exchangers and airflows in each branch-pipes. Considered geometrical structures varies in the number of parallel pipes, pipes length, main pipes diameters and supply type. The experimental investigations were conducted on the exchangers models in a scale 1:4. To investigate the real size exchangers, validated CFD flow performance model was used. A costless modification of heat exchanger supply-type from Z-type to U-type structure (change in air inlet location) is verified as a simple method of decreasing total pressure losses by 6–36% and improving airflow division uniformity by 11–80%. It is shown that main pipes diameter that are 1.4 times bigger than parallel pipes diameter can result in diminished total pressure losses by 56–73% and improved airflow division uniformity by 6–59%. The least significant effect on the flow characteristics has the branch-pipe length. Total pressure losses of long branch-pipes exchangers can be 15–32% higher than for short ones and the airflow division uniformity can be 8–35% higher. Results can be used for choosing the proper geometry of multi-pipe earth-to-air heat exchangers from the flow performance point of view. Presented flow characteristics can be used in detailed analysis and energy assessment of exchangers cooperating with the mechanical ventilation system in building.

1. Introduction

Nowadays a great focus is given to the energy efficiency in every aspect of life. About 40% of primary energy in Europe is consumed by the buildings [1] (2012), what overlaps with data of U.S. Energy Information Administration [2] (2016). It explains the great interest in energy-efficient buildings over last 10 years. The trends of energy efficiency are supported by the rising energy prices forcing people to look

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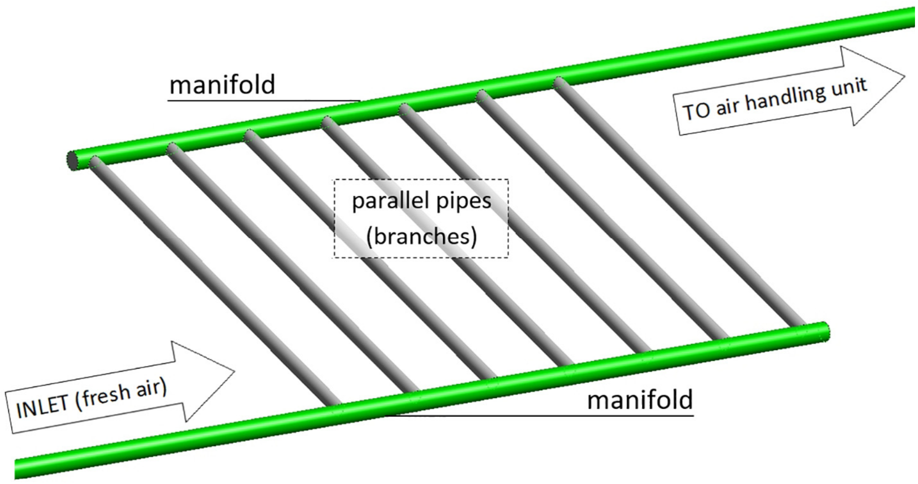

Fig. 1. Multi-pipe EAHE.

d – diameter of parallel pipes,
d_{main} – main pipes (manifolds) diameter,
n – number of parallel pipes,
L – length of parallel pipes,
type – supply type (Z or U),
β – connection angle between manifolds and parallel pipes,
V – airflow.

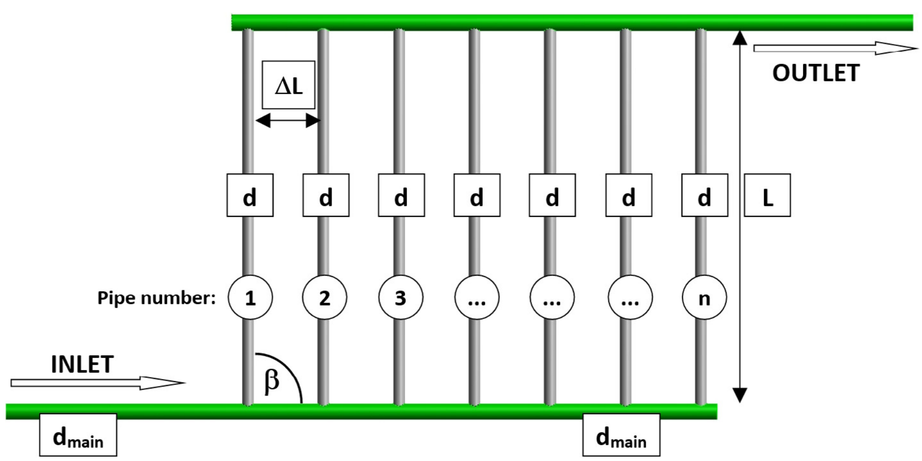

Fig. 2. Multi-pipe EAHE geometrical parameters (Z-type structure).

for energy savings and are shaped by the legal requirements. Thanks to the very good insulation standards in the modern buildings, the share of energy needs for fresh ventilation air heating in the total energy demand for heating rises and achieves a value of about 40–60% in the single family buildings and even more than 80% in a special buildings with huge demand for fresh ventilation air, such as the laboratory buildings. An answer to the constantly increasing share of heat demand for ventilation in total heat demand of the building is an application of heat recovery from exhaust air. One of the most popular method of heat recovery is usage of a plate-type heat exchangers in an air handling unit (mechanical ventilation systems). Efficiency of such systems in cold and moderate climates depends, among the others, on a phenomenon of heat exchanger frosting, which increases a pressure drop, decreases total flow rate and can even fully block the airflow. Review of the most popular defrosting methods is presented in [3]. To avoid frosting fresh ventilation air can be preheated in the winter by the earth-to-air heat exchanger (EAHE) using the renewable energy source – geothermal energy – instead of electricity. This is possible due to the fact that ground temperature at a depth of about 2 m is quite stable during the year and for Central European climate varies from about 4 °C to 10 °C [4]. As a result, in the summer, fresh ventilation air can be pre-cooled by the EAHE, what can decrease the energy consumption also for cooling the building. Authors of the article [5] are of the opinion that over-sizing the heat recovery unit is less costly method of improving the energy efficiency than installing the pipes into the ground but also confirm that EAHE, even with a short pipes, can drastically reduce the frosting time of the heat recovery unit what is considered to be crucial in some applications. These advantages of EAHE have recently gained significance in the Europe because of the legal requirements [6] which require higher efficiency of the heat recovery units in the ventilation systems and make the energy class of the system dependent also on the amount of energy needed for defrosting.

The latest extensive reviews of the recent advancements in earth-to-air heat exchangers are presented in papers [7,8], containing basic