CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 3

Heiselberg, Per Kvols

Experimental investigation of the effect of connection angle between main and parallel pipes in multi-pipe earth-to-air heat exchangers on the total pressure losses

Łukasz Amanowicz[#1], Janusz Wojtkowiak[#2]

[#]*Department of Civil and Environmental Engineering, Institute of Environmental Engineering, Poznan University of Technology, Pl. Marii Skłodowskiej-Curie 5, 60-965 Poznan, POLAND*

[1]lukasz.amanowicz@put.poznan.pl

[2]janusz.wojtkowiak@put.poznan.pl

Abstract

The total pressure losses in multi-pipe earth-to-air heat exchangers (EAHEs) depends on many geometrical parameters. One of the most important is the connection angle between main and parallel pipes. Sometimes the choice of EAHE angle is associated with the available space, but in many cases different angles can be used. In this paper the influence of the connection angle between main and parallel pipes on the total pressure losses was investigated experimentally using several models of multi-pipe heat exchangers with angles: 90, 45 and 2x45 degrees. The results show that the connection angle significantly affects the total pressure losses in multi-pipe earth-to-air heat exchangers and consequently – the energy efficiency of mechanical ventilation system.

Keywords - mechanical ventilation; multi pipe earth-to-air heat exchangers; pressure losses

1. Introduction

In the energy efficient buildings the percentage share of energy for heating and cooling of fresh ventilation air in total energy demand of the building constantly increases. In the air-tight and well insulated buildings mechanical ventilation systems with heat recovery and earth-to-air heat exchangers (EAHEs) are used to diminish the energy demand for heating and cooling of fresh ventilation air [4]. Multi-pipe EAHEs are used for buildings such as offices, gyms and others, where large airflows are needed. This kind of exchanger is especially popular for greenhouses [6, 7, 8] and markets [5]. The energy efficiency of such systems depends not only on the efficiency of heat recovery in the air handling unit, but also on the heat and cool gains of EAHE and on the energy used by fans or blowers providing fresh air. The electrical energy for EAHE fan is directly proportional to the total pressure losses of EAHE and increases the primary energy needs of the building.

2. The aim and the scope of the paper

In this paper the influence of connection angle between main and parallel pipes of multi-pipe earth-to-air heat exchangers was experimentally investigated. Heat exchangers models with 5 and 7 parallel pipes in a scale 1:4 and geometries presented in the Figs. 1 to 3 and in Table 1 were used. Connection angles: 90, 45 and 2x45° were considered. For 5 pipe EAHEs main pipes diameters d_{main} = 1.0 d and 1.54 d were considered. The main pipe diameter d_{main} = 1.54 d was considered for 7 pipe exchangers. The influence of different main pipes diameter was investigated in the conference paper [2].

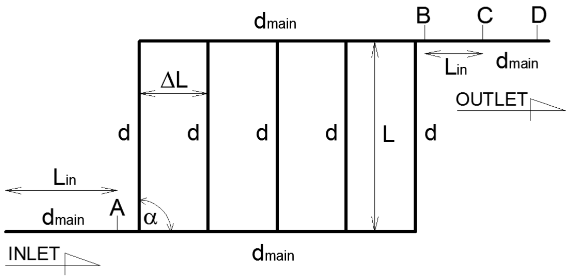

Fig. 1 Schema of the exchanger with angle of connection main and parallel pipes 90°

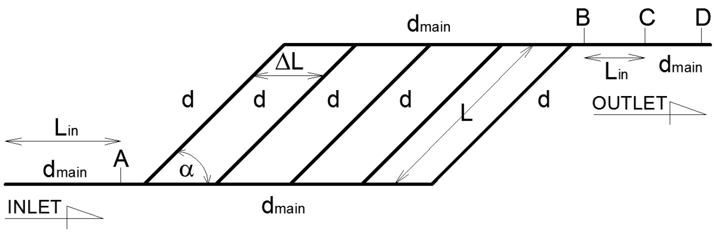

Fig. 2 Schema of the exchanger with angle of connection main and parallel pipes 45°

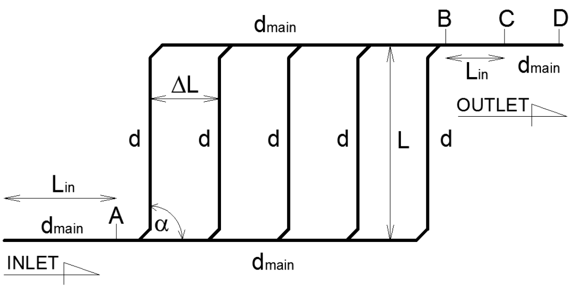

Fig. 3 Schema of the exchanger with angle of connection main and parallel pipes 2x45°

Table 1. The most important geometrical parameters of EAHEs models

Symbol	Description	Value [m]	Relative Value [-]
α	Angle of main and parallel pipes connection	90°, 45°, 2x45°	-
d	Internal diameter of branch parallel pipes	0.0461	1.0 d
d_{main}	Internal diameter of main pipes, accordingly: DN50 and DN75	0.0461 0.0710	1.0 d 1.54 d
L	Length of branch pipe	3.50	76.0 d
L_{in}	Length of inlet (developing) sector	1.50	32.5 d
L_{C-D}	Length of measuring sector of main outlet pipe	1.35	29.3 d
L_{B-D}	Length of outlet pipe	2.85	61.8 d
ΔL	The distance between parallel pipes	0.28	6.1 d

3. Measurements and experimental setup

The detailed description of the experimental setup was presented in [1] and [2]. The experiment was conducted using earth-to-air multi-pipe heat exchangers models built on polypropylene pipes, typically used for EAHEs construction. The view of the exchanger with the connection angle 90° and 2x45° is presented in the Fig. 4.

Fig. 4 The view of the exchanger model with the connection angle 90° (left photo) and 2x45° (right photo)

The theory of similarity in fluid mechanics [9] was used both for designing of the models and for experimental results interpretation. The total pressure losses and total airflow were measured for various airflow rates. An original non-invasive method of airflow measurement based on friction pressure losses Δp_{CD} of smooth pipes (a friction factor calculated from Blasius equation) at the measuring sector of fully developed flow L_{CD} was used. Total airflow was calculated from Eq. (1). The accuracy of the total airflow V_{tot} measurement was estimated to be ± 3% with the 95% confidence [3].

$$\dot{V}_{tot} = 3600 \cdot \left(\frac{\Delta p_{CD} \cdot d_{main}^{1.25}}{0.3164 \cdot \rho \cdot L_{CD} \cdot \upsilon^{0.25}} \right)^{\frac{1}{1.75}} \cdot \frac{\pi \cdot d_{main}^{2}}{4} \qquad [m^3/h] \qquad (1)$$

w_{main} - average velocity of air at the inlet of main pipe, [m/s]
ρ - density of air, [kg/m^3]
ν - air kinematic viscosity, [Pa s]

Total pressure losses of the exchanger were calculated from Eq. (2), assuming the fully developed flow at the L_{CD} sector and diminishing the pressure losses between points A and D by the friction pressure losses between points B and D (the sector of developing flow).

$$\Delta p_{tot} = \Delta p_{AD} - \Delta p_{CD} \cdot \frac{L_{BD}}{L_{CD}} \qquad [Pa] \qquad (2)$$

4. Results

The results of investigation are shown in dimensionless form in Figs. 5 to 7 as the total pressure loss coefficient vs. Reynolds number. Pressure loss coefficients k was calculated as the total pressure losses Δp_{tot} divided by the air dynamic pressure p_d from Eq. (3). Reynolds number was calculated from Eq. (4). As one can see in Figs. 5 to 7 values of k coefficient varies not significantly in a wide range of Reynolds number. It enables calculation of the average values of k coefficient from Eq. (5) for a convenient comparison of different structures of EAHE. Average values of total pressure losses coefficients are presented in Table 2. The accuracies of k coefficient calculation is estimated to be ±6%, with the 95% confidence.

$$k = \frac{\Delta p_{tot}}{p_d} = \frac{2 \cdot \Delta p_{tot}}{\rho \cdot w_{main}^2} \qquad [-] \qquad (3)$$

$$Re = \frac{w_{main} \cdot d_{main}}{\nu} \qquad [-] \qquad (4)$$

$$k_a = \frac{k_{min} + k_{max}}{2} \qquad [-] \qquad (5)$$

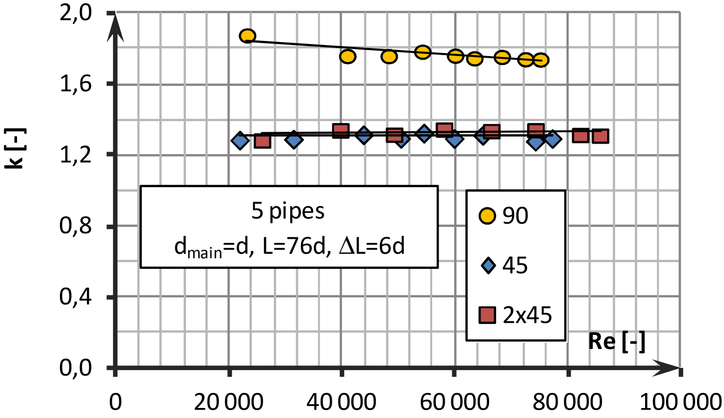

Fig. 5 Total pressure loss coefficient vs. Reynolds number for EAHEs with 5 parallel pipes and different angles of connection between main and parallel pipes, d_{main}=d

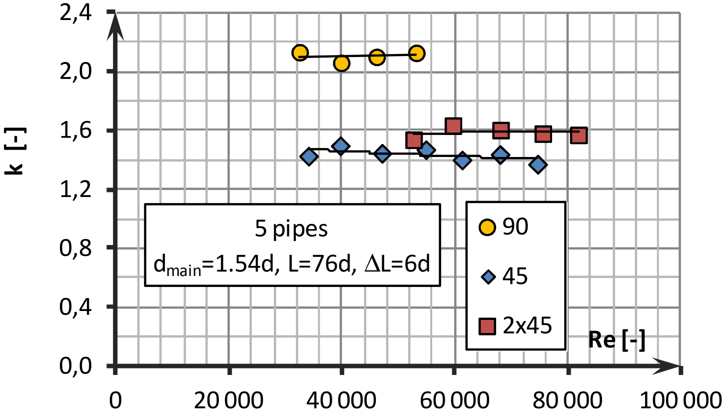

Fig. 6 Total pressure loss coefficient vs. Reynolds number for EAHEs with 5 parallel pipes and different angles of connection between main and parallel pipes, d_{main}=1.54d

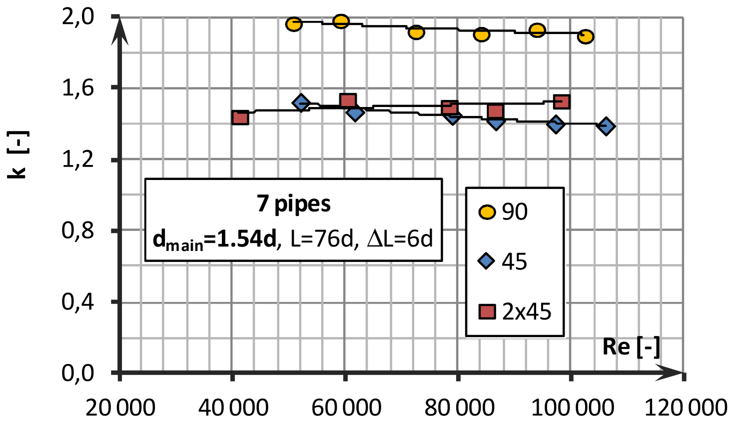

Fig. 7 Total pressure loss coefficient vs. Reynolds number for EAHEs with 7 parallel pipes and different angles of connection between main and parallel pipes, d_{main}=d

Table 2. The average values of total pressure losses coefficients

Number of pipes	d_{main}/d [-]	Angle of connection	k_a [-]
5	1.0	90°	1,83
		45°	1,32
		2x45°	1,32
	1.54	90°	1,90
		45°	1,44
		2x45°	1,59
7	1.54	90°	2,10
		45°	1,46
		2x45°	1,49

The percentage differences in pressure losses between EAHE structures of different main and parallel pipes angle connection were calculated from Eq. (6) and are presented in Table 3.

$$\Delta_{x-y} = \frac{k_{a\,x} - k_{a\,y}}{k_{a\,x}} \cdot 100\% \qquad [\%] \qquad (6)$$

Table 3. The percentage differences in pressure losses of structures with different connection angles between main and parallel pipes

Exchanger structure	Δ_{90-45} [%]	$\Delta_{90-2x45}$ [%]	$\Delta_{45-2x45}$ [%]
5 pipes, d_{main}/d = 1.0	28	28	0
5 pipes, d_{main}/d = 1.54	24	16	-10
7 pipes, d_{main}/d = 1.54	30	29	-2

5. Conclusions

The following conclusions can be drawn from the presented results:

- for investigated structures, exchangers with the connection angle 45° generated 24% to 30% lower pressure losses than exchangers with the angle 90°,
- for investigated structures exchangers with the angle 2x45° generated 16% to 29% lower pressure losses than exchangers with the angle 90°,
- total pressure losses for 2x45° structures are slightly higher than for 45° structures (from 2 to 10%).

The results show that the angle of connection between main and parallel pipes of multi-pipe earth-to-air heat exchangers significantly affects the total pressure losses and consequently – the energy efficiency of mechanical ventilation system. Using 45° structures instead of 90° structures one can save 24% to 30% energy for driving the EAHE fan. The angle of connection 2x45° results in the total pressure losses similar to 45°structures and it also seems to be the most convenient type from the installation point of view, because the less space is needed to place that kind of exchangers in the ground than for 45° exchangers.

References

[1] Amanowicz Ł. and J. Wojtkowiak J.,. Experimental flow characteristics of multi-pipe earth-to-air heat exchangers. Foundations of Civil and Environmental Engineering. Poznan University of Technology Publishing House. 2012, No. 15, 5-18

[2] Amanowicz Ł. and Wojtkowiak J., Experimental investigation of main pipes diameter influence on earth-to-air multi pipe heat exchangers flow characteristics, 11th REHVA world Congress CLIMA 2013, Prague, 16-19.06.2013

[3] Coleman H.W. and Steele W.G. Experimentation and Uncertainty Analysis for Engineers 2nd Ed. John Wiley and Sons. New York. 1999

[4] Florides G and Kalogirou S.. Ground heat exchangers – A review of systems, models and applications. Renewable Energy 32 (2007) 2461-2478

[5] Górka A. and Szymański M. and Mróz T., Measurements and modeling of an earth-to-air heat exchanger for retail building ventilation, Proceedings of the 34th AIVC Conference "Energy conservation technologies for mitigation and adaptation in the built environment: the role of ventilation strategies and smart materials", Athens (2013)
[6] Nayak S., G.N. Tiwari, Theoretical performance assessment of an integrated photovoltaic and earth air heat exchanger greenhouse using energy and exergy analysis methods, Energy and Buildings 41 (2009), 888-896
[7] Ozenger O. and Ozenger L., An experimental study of the exergetic performance of an underground air tunnel system for greenhouse cooling, Renewable Energy 35 (2010), 2804-2811
[8] Von Zabeltitz C., Solar energy: alternative energy sources for greenhouse heating, Energy Conservation and Renewable Energies for Greenhouse Heating, FAO (1988), 122-128
[9] Zierep J., Ahnlichkeitsgesetze und Modellregeln der Stromungslehre, G. Braun, Karlsruhe, 1972 (Polish edition PWN, Warszawa 1978).