MULTI-PIPE EARTH-TO-AIR HEAT EXCHANGER (EAHE) GEOMETRY INFLUENCE ON THE SPECIFIC FAN POWER (SFP) AND FAN ENERGY DEMAND IN MECHANICAL VENTILATION SYSTEMS

Łukasz Amanowicz[1], Janusz Wojtkowiak[2]

1 Poznan University of Technology
Pl. M. Skłodowskiej-Curie 5
60-965 Poznań
**Corresponding author:*
lukasz.amanowicz@put.poznan.pl

2 Poznan University of Technology
Pl. M. Skłodowskiej-Curie 5
60-965 Poznań

ABSTRACT

The energy efficiency and energy consumption of mechanical ventilation systems depend mainly on the heat and cool recovery efficiency and the operational costs of electric energy for air handling unit fans.
For free pre-heating of fresh air in winter and pre-cooling in summer and to protect the heat exchanger in the air handling unit against freezing earth-to-air heat exchangers (EAHEs) are used. For large demand of fresh air multi-pipe systems are used to diminish total pressure losses and provide required amount of thermal energy.
Total pressure losses in EAHEs and consequently the specific fan power (SFP) depends on their geometrical parameters such as: the length, diameter and number of parallel pipes, angle of connection parallel pipes to the main pipes and main pipes diameter. In this paper an influence of the angle of connection between main and parallel pipes (45 and 90 degrees) on the SFP factor and energy demand for ventilation system operation was investigated using experimentally obtained total pressure losses of EAHEs models. Results are shown in graphical form. Quite significant influence of the investigated angle of connection on the fan power, and on the SFP value is presented.

KEYWORDS

earth-to-air heat exchangers, pressure losses, specific fan power SFP, energy demand

1 INTRODUCTION

Increasing energy costs contributed to the great development of energy efficient HVAC systems (heating, ventilation and air conditioning) for buildings. For well insulated and tight buildings the mechanical ventilation system with heat recovery are often used to diminish the energy demand for the building. In cold and moderate climate in order to avoid freezing of plate-type heat exchangers in air handling units earth-to-air pipe-type heat exchangers (EAHEs) are used (Jacovides C.P., Mihalakakou, 1995 and Lee, Strand, 2008 and Bansal, Misra, 2009 and 2010).
EAHEs enable to obtain additional heat or cool gains because of the relatively stable soil temperature at a depth of about 2 m during the whole year. Unfortunately the operation of EAHEs is always connected with additional pressure losses and additional electric energy consumed by air handling unit supply fans. Total pressure losses depends on the heat exchanger structure and airflow. For higher airflow the multi-pipe EAHE structures are used (De Paepe, Janssens, 2003). The experimental investigations (Amanowicz, Wojtkowiak, 2010) show that one of the structure parameter influencing the total pressure losses in multi-pipe EAHEs is the angle of connection between main pipes and parallel pipes. In this paper results of experimental investigations into the influence of the angle of main and parallel

pipes connection (45 or 90 degrees, see Fig 1) on the total pressure losses of earth-to-air multi-pipe heat exchangers and specific fan power (SFP) are presented. Fig. 1 shows the investigated multi-pipe Z-type 45^0 EAHE structure.

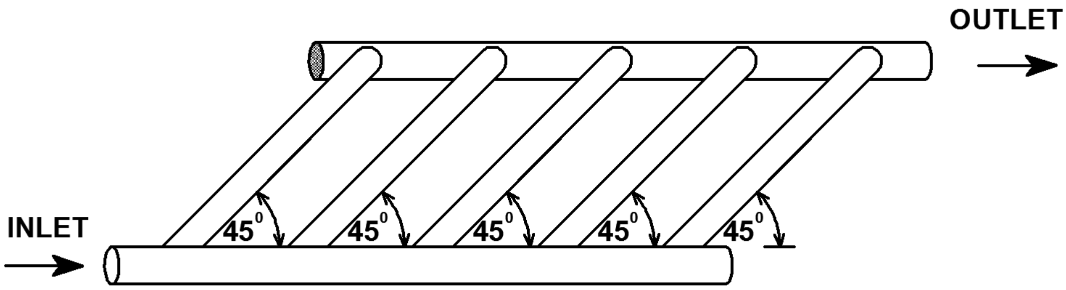

Figure 1: Multi-pipe earth-to-air heat exchanger, Z-type structure, $\alpha = 45^0$ structure

2 EXPERIMENTAL INVESTIGATIONS

Total pressure losses and total airflow were measured using multi-pipe earth-to-air heat exchanger models made in a scale 1:4 from PCV pipes of a diameter DN50 (d = 0,0461m) and length L/d = 76 for exchangers with 3, 5 and 7 parallel pipes connected to the main pipes with the angle of 45 or 90 degrees. The internal diameters of the main and parallel pipes were the same. Fig. 2 shows the schema of experimental set-up, Fig. 3 shows the view of the experimental set-up.

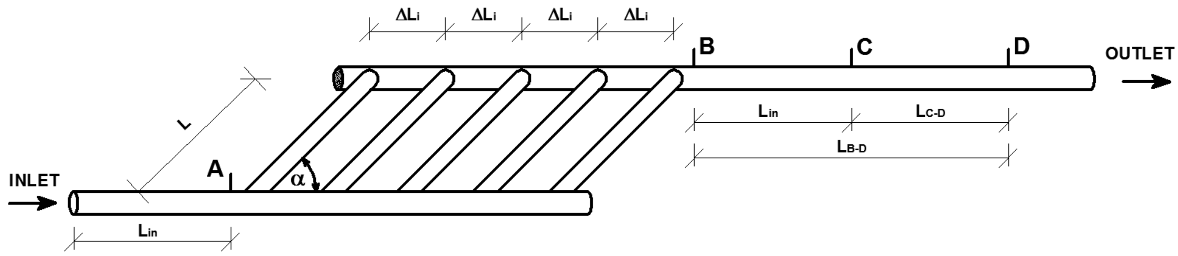

Figure 2: The schema of experimental set-up

Figure 3: View of the experimental set-up: Z-type, 7 pipes 90^0 EAHE model in a scale 1:4

Measured values:

Δp_{A-D} – pressure losses at the measuring sector between points A and D [Pa] (Fig. 2)
Δp_{C-D} – pressure losses at the measuring sector between points C and D [Pa] (Fig.2)
L_{C-D} – length of measuring sector between C-D points [m]
L_{B-D} – length of the sector between B-D points [m]
L_{in} – the developing flow region of about 20-30d, [m]
ΔL_i – distance between parallel pipes, [m]

Calculated values:

V_{tot} – total airflow as a function of friction pressure losses at the C-D sector (fully developed flow), calculated from equation (1) based on Blasius formula and Darcy-Weisbach equation,
$\Delta p_{A-B} = \Delta p_{EAHE}$ – total pressure losses on EAHE, calculated from equation (2),
$k_{EAHE,Vi}$ – total pressure loss coefficient for the EAHE for V_i = maximum or minimum value, calculated from the equation (3),
k_{EAHE} – mean value of EAHE total pressure loss coefficient calculated as an average of $k_{EAHE,Vi}$ for minimum and maximum airflows (equation (4)).

$$\dot{V}_{tot} = 3600 \cdot \left(\frac{2\Delta p_{C-D} \cdot d^{1,25}}{0,3164 \cdot \rho \cdot L_{C-D} \cdot \upsilon^{0,25}} \right)^{\frac{1}{1,75}} \cdot \frac{\pi \cdot d^2}{4} \ [(m^3/h)] \quad (1)$$

$$\Delta p_{EAHE} = \Delta p_{A-D} - \frac{L_{B-D}}{L_{C-D}} \cdot \Delta p_{C-D} \ [Pa] \quad (2)$$

$$k_{EAHE,Vi} = \frac{\Delta p_{EAHE,Vi}}{\frac{\rho \cdot w_{tot,Vi}^2}{2}} \quad (3)$$

$$k_{EAHE} = \frac{k_{EAHE,Vmin} + k_{EAHE,Vmax}}{2} \quad (4)$$

w_{tot} – average air velocity in main pipes, [m/s]
d – internal diameter of main pipes and parallel pipes, [m]

Minimum and maximum airflows were specified for the range of Reynolds number from 20 000 – 80 000 (typically values of Re for such systems). The mean value of the total pressure loss coefficient valid for the above mentioned range of Re number results in only 5-10% uncertainty, because of quite stable value of $k_{EAHE,Vi}$ (turbulent flow) what is shown in Fig. 4. Re_{tot} was calculated from equation (5).

$$Re_{tot} = \frac{w_{tot} \cdot d}{\nu}, \quad w_{tot} = \frac{\dot{V}_{tot}}{\frac{\pi \cdot d^2}{4}} \text{ [m/s]} \tag{5}$$

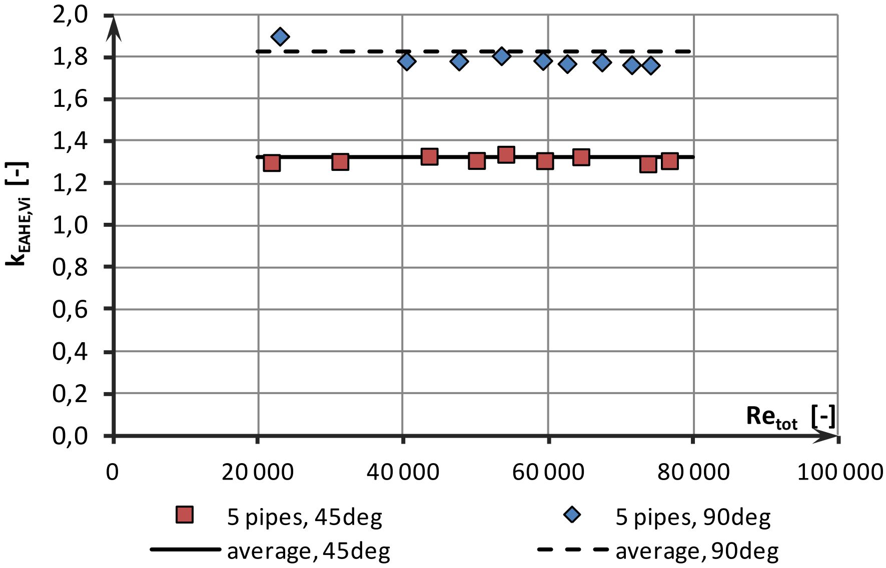

Figure 4: Total pressure losses coefficient $k_{EAHE,Vi}$ as a function of Reynolds number for exchanger with 5 parallel pipes

The mean values of total pressure loss coefficients for considered exchanger structures are listed in table 1.

Table 1: Experimental average k_{EAHE} coefficients for heat exchangers of L/d = 76, ΔL_i = 6d

Number of pipes	k_{EAHE}, 45^0 [-]	k_{EAHE}, 90^0 [-]
3	1,26	1,77
5	1,32	1,83
7	1,42	1,87

3 RESULTS

The specific fan power (SFP) was calculated from the equation (6) both for supply and exhaust parts of the system with the assumption of total pressure losses of whole ventilation system $\Delta p_{system,Vtot,max}$ = 200 Pa for the maximum (nominal) flow rate $V_{tot,max}$ = 600 m^3/h (ducts, air handling unit, supply and exhaust parts). For the system with EAHE the total pressure losses were calculated using equation (7). The results are shown in Fig. 5

$$SFP = \frac{N}{\dot{V}_{tot,max}} = \frac{\Delta p_{tot,Vmax} \cdot \dot{V}_{tot,max}}{\eta \cdot \dot{V}_{tot,max}} = \frac{\Delta p_{tot,Vmax}}{\eta} \text{ [W/(m}^3\text{/s)]} \tag{6}$$

$$\Delta p_{tot,Vi} = k_{EAHE} \cdot \frac{\rho \cdot w_{tot,Vi}^2}{2} + \Delta p_{system,Vi} \tag{7}$$

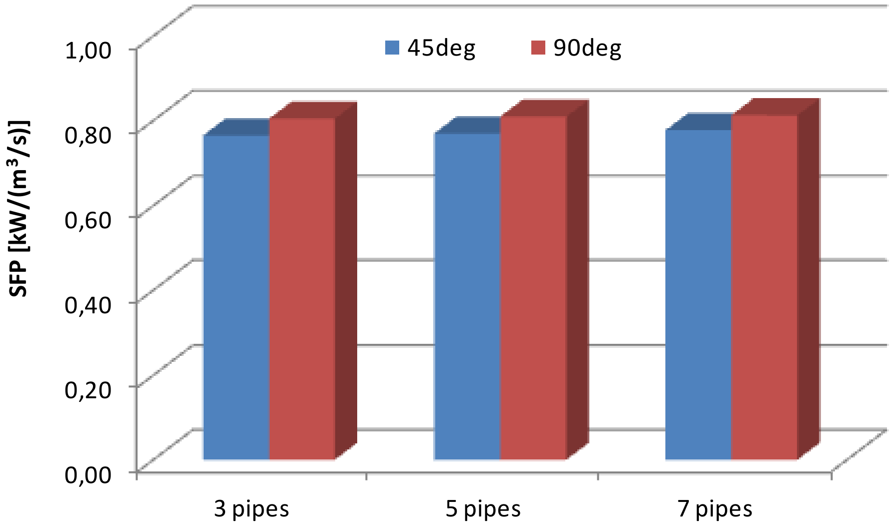

Figure 5: SFP factors for supply fan in mechanical ventilation system
with heat recovery and multi-pipe earth-to-air heat exchanger, $V_{tot,max}$ = 600 m^3/h, d = 0,184 m, L/d = 76

Calculation of a whole year energy demand for 5-pipes EAHE were done for 3 cases:

- whole system (supply and exhaust fan),
- supply only (only supply fan),
- EAHE only (only EAHE fan).

Main assumptions:

- EAHE operates during a day with various flow rates, in hours 1-6: 50%, 7-16: 100%, 17-24: 30% of maximum flow rate $V_{tot,max}$ = 600 m^3/h,
- EAHE operates 365 days per year,
- d = 0,184 m, L/d = 76,
- the total efficiency coefficient of the engine-fan-system was assumed to be constant: 0,30.

Total pressure losses of the ventilation systems for different airflows were calculated using a simplified method based on an assumption of quadratic relationship between pressure losses and air velocity (equation (8)).

$$\Delta p_{system,Vi} \approx \Delta p_{system,Vtot,max} \left(\frac{V_{tot,Vi}}{V_{tot,max}}\right)^2 \qquad (8)$$

Calculation results are shown in Fig. 6. The percentage differences between SFP factors and whole year energy demand for ventilation system operation are given in table 2. The percentage differences were calculated using formulas (10) and (11).

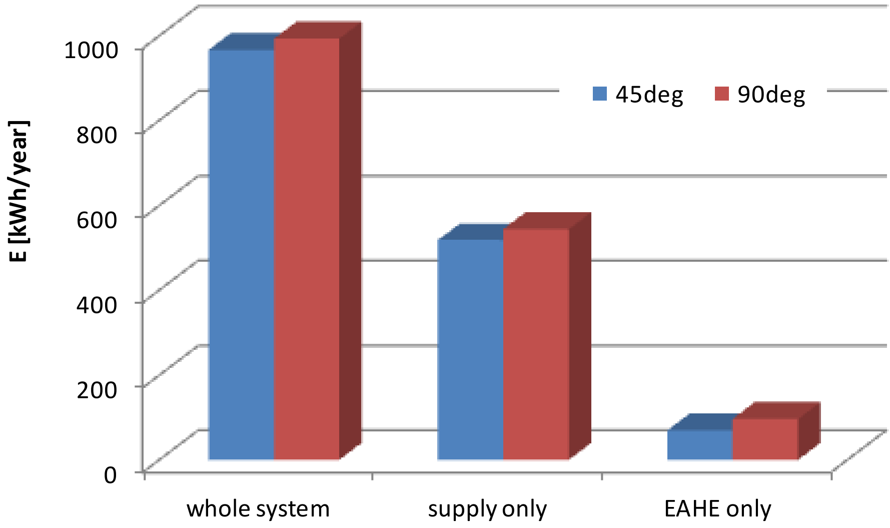

Figure 6: The whole year energy demand for mechanical ventilation system with heat recovery and 5-pipe earth-to-air heat exchanger

Table 2: Percentrage differences between SFP factors and whole year energy demand for operation of ventilaton system

Number of pipes	ΔSFP [%]		ΔE [%]
3	4,9	-	-
5	4,9	whole system	2,7
		supply only	4,9
		EAHE only	28,0
7	4,3	-	-

$$\Delta \mathrm{SFP} = \frac{\mathrm{SFP}_{90} - \mathrm{SFP}_{45}}{\mathrm{SFP}_{90}} \cdot 100\% \qquad (10)$$

$$\Delta \mathrm{E} = \frac{\mathrm{E}_{90} - \mathrm{E}_{45}}{\mathrm{E}_{90}} \cdot 100\% \qquad (11)$$

For mechanical ventilation system with EAHE additional stand-alone fan only for EAHE operation is used to overcome additional EAHE pressure losses. The required power of fans for considered systems is presented in the Fig. 7. Required fan power for 45 degrees structures for exchangers with 3, 5 and 7 parallel pipes is respectively: 29%, 28% and 24% lower than for 90 degrees structures. It means that there is an opportunity to apply 25-30% smaller (and cheaper) fan for 45 degrees structures of EAHE in comparison with 90 degrees structure.

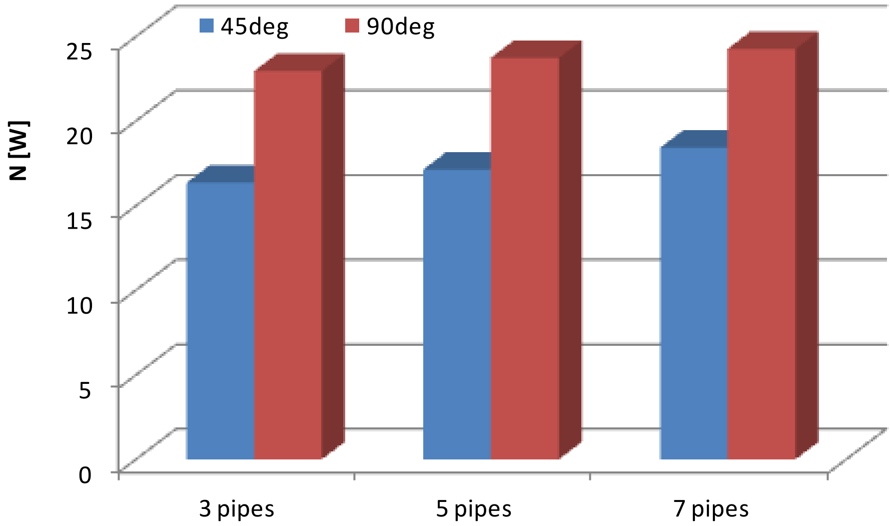

Figure 7: Required fan power for EAHEs with different angles of parallel and main pipes connections

4 CONCLUSIONS

The main conclusions are listed below:

- for the same total airflow the relative differences between SFP factor for 45 and 90 degrees EAHE are almost the same for 3, 5 and 7 pipes exchangers and equal to 4-5%,
- EAHE branches connection of 45 degrees can reduce the energy demand for the whole ventilation system operation of about 3% in comparison to 90 degrees,
- the difference in energy demand for EAHE fan for 45 and 90 degrees EAHE is 28%,
- in a case of using additional stand-alone fan for EAHE operation there is possible to use smaller (25%-30) and cheaper one for 45 degrees structures,
- EAHE structure and consequently the EAHE's total pressure losses has quite significant influence both on the SFP and the whole energy consumption of ventilation system.

5 REFERENCES

Jacovides C.P., Mihalakakou G., An underground pipe system as an energy source for cooling/heating purposes, *Renewable Energy Vol. 6, No. 9, 1995*, 893-900

Lee K. H., Strand R.K., The cooling and heating potential of an earth tube system in buildings, *Energy and Buildings 40 (2008)*, 486-494

Bansal V., Misra R., Ghansyan A.D., Mathur J., Performance analysis of earth-pipe-air heat exchanger for winter heating, *Energy and Buildings 41 (2009)*, 1151-1154

Bansal V., Misra R., Ghansyan A.D., Mathur J., Performance analysis of earth-pipe-air heat exchanger for summer cooling, *Energy and Buildings 42 (2010)*, 645-648

De Paepe M., Janssens A., Thermo-hydraulic design of earth-air heat exchangers, *Energy and Buildings 35 (2003)*, 389-397

Amanowicz, Ł., Wojtkowiak, J., Experimental investigations concerning influence of supply system of ground earth-to-air pipe-type heat exchanger on its flow characteristics. Part 1. Flow characteristics, *Ciepłownictwo Ogrzewnictwo Wentylacja 6/2010*, 263-266, 282, (in Polish)

Amanowicz, Ł., Wojtkowiak, J., Pressure losses in ground earth-to-air multi-pipe heat exchangers with connection angle of 45 degrees, *Ciepłownictwo Ogrzewnictwo Wentylacja 12/2010*, 451-454, (in Polish)