SIMPLIFIED METHOD OF DESIGNING AN AIR-GROUND HEAT EXCHANGER


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Summary

The paper presents description of simplified method used for calculation of required length of air-ground heat exchanger. The comparison between obtained results and results of calculation done with PH-Luft and GAEA programs is included. The paper gives also some information about the economical aspects of construction and of AGHE, taking into account cost of electric energy used by the fans.

Keywords: Air-ground heat exchanger, ventilation system, passive and low-energy building

1 Introduction

One of the method of increasing energy efficiency of ventilation system is either recovering heat form exhaust air or preheating external air with energy gained form e.g. ground. It can be done with help of air-ground heat exchanger. This system gains growing popularity among individual investors also in Poland. Therefore the paper presents a simplified method of designing an air-ground heat exchanger. It compares also the calculations results, obtained on a base of simplified method, with results obtained from programs available on the market used for design of such exchangers.

2 A simplified method of designing an air-ground heat exchanger

2.1 The air-ground heat exchanger

Simple air-ground heat exchangers are constructed from pipes buried in ground 1.5-2 m deep. The exchanger is using an almost constant temperature of the ground at this depth. During winter cold air flows through the exchanger and warms up. The system works as a preheater. In summer situation is reversed. Warm air gives back heat to the ground so the exchanger works as precooler. AGHE can thus increase the efficiency of ventilation or heating system.

Air-ground heat exchangers are very often made of plastic pipes and have total length form 30 to 50 meters. External air is collected by inlet with built-in coarse grid protector (against insects and rodents) and filter. Exchanger has to be lied with slope to enable outlet of the water that can condensate on pipe walls during summer. Leaving the condensate in pipes can cause moulds, mushrooms and other microorganisms growth. As a result quality of fresh air can decrease. Therefore it is very important to make an appropriate design of the exchanger and solve the condensate problem. The way of ensuring high quality of the fresh air can be the use of pipes with addition of silver. It limits the risk of microorganisms growth.

There are many possibilities of arraying exchanger pipes. It can be built in: straight, winding, ring and Tichelman type.

2.2 Method description

The simplified method of designing an air-ground heat exchanger was created on basis of IGSPA (The International Ground Source Heat Pump Association Method). The IGSPA method is being used to calculate required length of ground exchangers cooperating with heat pumps and was published in [1]. The method assumes that heat exchange between air flowing in AGHE and ground surrounding the exchanger has steady character. The required length of the AGHE is therefore function of required heating load Q_w, W, thermal resistance of exchanger pipe wall R_p, m·K/W, thermal resistance of ground R_G , m·K/W, an average logarithm temperature difference between air flowing in the exchanger and ground surrounding it ΔT_{ln}, K, work cycle coefficient F_h and can be described with following formula:

$$L = \frac{Q_W \left(R_P + R_G \cdot F_H \right)}{\Delta T_{\ln}}, \quad \text{m} \tag{1}$$

Work cycle coefficient depends on total work time of the exchanger during heating or cooling season t, h as well as number of work days during heating or cooling season n and is described with following formula:

$$F_H = \frac{t}{24 \cdot n} \tag{2}$$

The average logarithm temperature difference between air flowing in the exchanger and ground surrounding it is calculated on a basis of formula (3). It depends on temperature of the ground surrounding beginning of the exchanger t_{g1}, °C, temperature of the ground surrounding end of the exchanger t_{g2}, °C, temperature of external air, t_e, °C as well as temperature of air leaving the exchanger t_1, °C:

$$\Delta T_{\ln} = \frac{\left(t_{g1} - t_e\right) - \left(t_{g2} - t_1\right)}{\ln\left(\dfrac{t_{g1} - t_e}{t_{g2} - t_1}\right)}, \quad \text{K} \tag{3}$$

Required heating or cooling load depends on designed air flow rate V_n, m^3/h, density of air ρ, kg/m^3, specific heat of air c_p, kJ/kg·K as well as temperature of air leaving the exchanger

t_1, °C and is described with formula (4). Air density and specific heat should be taken for average air temperature in the exchanger.

$$Q_w = \frac{V_n \cdot \rho \cdot c_p \cdot (t_1 - t_e)}{3,6}, \quad \mathrm{W} \tag{4}$$

Air temperature leaving air-ground heat exchanger should be higher than 0 °C. This condition protects surfaces of air to air heat exchanger (which usually cooperates with AGHE) before freezing. Intensity of energy exchange between air flowing in AGHE and ground depends mainly on type air movement – laminar or turbulent. Movement type depends whereas on internal dimension of the pipeline and velocity of air flowing in it. Therefore the exchanger has to be designed to assure a turbulent movement of air in it but at the same time the velocity of air should not be too high. Over boost of velocity can cause increase of total pressure losses in the exchanger, need of increase of fan load and finally additional costs.

Thermal resistance of exchanger pipe wall is described with formula (5) and it is a sum of convection resistance at the internal side of exchanger wall R_α, m·K/W and conduction resistance of the exchanger wall R_{sc}, m·K/W:

$$R_P = R_\alpha + R_{sc}, \; \mathrm{m \cdot K / W} \tag{5}$$

Convection resistance at the internal side of exchanger wall is calculated on basis of formula (6). The resistance depends on internal dimension of exchanger pipe d_w, m as well as from convection coefficient at internal side of exchanger wall α_i, W/m^2·K. The convection coefficient is obtained on basis of formulas describing heat exchange in pipes with forced flow. The value of convection coefficient depends mainly on internal dimension of exchanger pipe and velocity of air flowing in it.

$$R_\alpha = \frac{1}{\pi \cdot d_w \cdot \alpha_i}, \; \mathrm{m \cdot K / W} \tag{6}$$

Conduction resistance of the exchanger wall is described with formula (7) and depends on thermal conductivity of exchanger pipe wall λ_{sc}, W/m·K, internal d_w, m and external d_z, m dimension of exchanger pipe:

$$R_{sc} = \frac{1}{2 \cdot \Pi \cdot \lambda_{sc}} \cdot \ln\left(\frac{d_z}{d_w}\right), \; \mathrm{m \cdot K / W} \tag{7}$$

Thermal resistance of the ground is obtained on basis of formula (8) and depends on thermal conductivity of the ground λ_{gr}, W/m·K, value of function $I(X_{dz})$ for $X = d_z$ as well as value of the function $I(X_{2H})$ for $X = 2H$ where H, m is average depth on which the exchanger was buried.

$$R_G = \frac{I(X_{d_z}) - I(X_{2 \cdot H})}{2 \cdot \Pi \cdot \lambda_{gr}}, \; \mathrm{m \cdot K / W} \tag{8}$$

Value of function *I(X)* is obtained on basis of formula (9), (10) in depends on *X* value:

- $0 < X \leq 1$:

$$I(X) = \frac{1}{2} \cdot \begin{pmatrix} -\ln X^2 - 0{,}57721566 + 0{,}99999193 \cdot X^2 - 0{,}24991055 \cdot X^4 \\ + 0{,}05519968 \cdot X^6 - 0{,}00976004 \cdot X^8 + 0{,}00107857 \cdot X^{10} \end{pmatrix}, \tag{9}$$

- $1 \le X < \infty$:

$$I(X) = \left[1/\left(2 \cdot X^2 \cdot e^{X^2}\right)\right](A/B). \tag{10}$$

Coefficients *A* and *B* are described with following formulas:

$$A = X^8 + 8{,}5733287 \cdot X^6 + 18{,}059017 \cdot X^4 + 8{,}637609 \cdot X^2 + 0{,}2677737 \tag{11}$$

$$B = X^8 + 9{,}5733223 \cdot X^6 + 25{,}6329561 \cdot X^4 + 21{,}0996531 \cdot X^2 + 3{,}9684969 \tag{12}$$

Total pressure loss in the exchanger was calculated as a sum of linear and punctual losses.

3 Comparison calculations

Use o air-ground heat exchanger in ventilation system enables not only preheating of the air during winter but also precooling of air in summer. The exchanger gives then effect similar to air-conditioning system.

Tab. 1 presents comparison of required length of pipe AGHE obtained on basis of: simplified calculation method, PHLuft program and GAEA program. The calculation was made for city of Warsaw. **Tab. 2** shows comparison of total pressure losses in the exchanger obtained on basis of simplified method and two programs.

Programs PHLuft and GAEA were written by German specialists. Program PHLuft enables calculation of required length of the exchanger for all climatic zones in Poland. Whereas climatic data of GAEA include only Warsaw. The program assumes that design winter temperature for Warsaw is – 18,7 ºC, meanwhile it should be – 20,0 ºC. Calculation method of GAEA is also different from simplified method and PHLuft program. As a result we receive potential energy savings and not the length of the exchanger. That is why GAEA program requires for calculation precise data about length, dimension and localization of the exchanger.

Tab. 1 Required length of air-ground heat exchanger, m

Climate data / Air flow rate (m^3/h)	t_{des} = -20 °C SM	t_{des}=-20 °C PHLuft	t_{des} =-18,7 °C GAEA
100 (Ø200 mm)	31	30	26
150 (Ø200 mm)	38	41	34
200 (Ø200 mm)	45	51	40
250 (Ø250 mm)	53	62	46
300 (Ø250 mm)	59	72	55

Calculations made with simplified method and programs PHLuft and GAEA give similar result in regard to required length of air-ground heat exchanger. Differences in results are caused by calculation methodology used and climate data. Simplified method can be then used by designers, investors and contractors to estimate required length of pipe air-ground heat exchangers.

Tab. 2 Total pressure loss in air-ground heat exchanger, Pa

Climate data / Air flow rate (m^3/h)	t_{des} = -20 °C SM	t_{des}= -20 °C PHLuft	t_{des} = -18,7 °C GAEA
100 (Ø200 mm)	23,6	23,2	23,2
150 (Ø200 mm)	28,7	28,9	28,0
200 (Ø200 mm)	36,9	38,9	35,4
250 (Ø250 mm)	30,4	31,6	29,4
300 (Ø250 mm)	36,0	38,6	35,2

4 Efficiency calculations

Simplified method was used to estimate the energy efficiency of air-ground heat exchanger. **Tab. 3** shows amount of heat that can be gained from ground during heating season in other Polish climate zones and **Fig. 1** total pressure losses in exchangers.

Tab. 3 Yearly amount of heat, kWh/a

Design temperature / Air flow rate (m^3/h)	t_{des} = -16 °C	t_{des} = -18 °C	t_{des} = -20 °C	t_{des} = -22 °C	t_{des} = -24 °C
100 (Ø200 mm)	498,4	569,2	640,1	765,6	781,8
150 (Ø200 mm)	750,2	854,8	959,3	1149,3	1174,4
200 (Ø200 mm)	1000,5	1141,0	1281,6	1533,7	1565,8
250 (Ø250 mm)	1251,9	1426,4	1600,8	1916,8	1958,4
300 (Ø250 mm)	1503,5	1712,5	1922,0	2300,7	2350,2

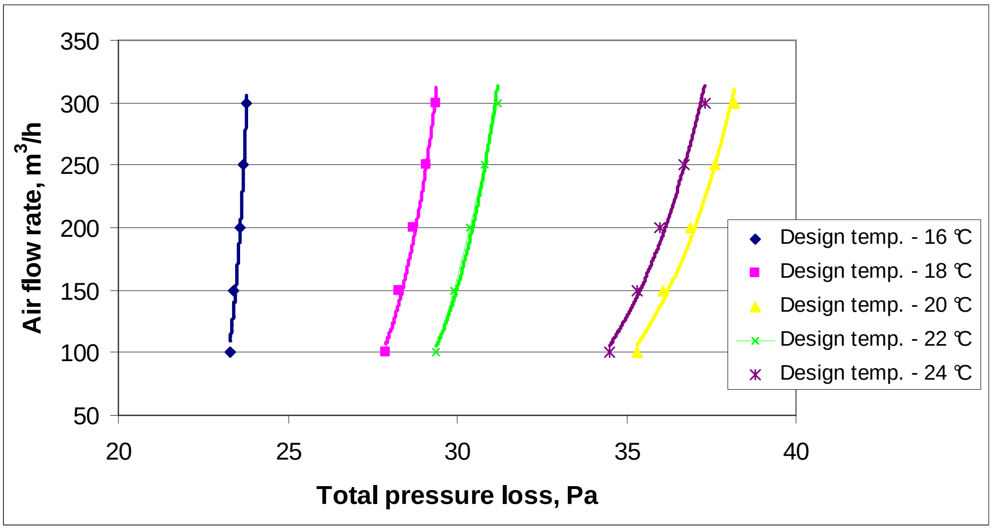

Fig. 1 Total pressure losses in air-ground heat exchanger – built as straight pipeline

Data from **Tab. 3** and **Fig. 1** were used to estimate reduction of annual heating cost. Obtained savings include additional cost of electric energy used by vents to cover pressure losses in the exchanger. Results of estimation are shown in **Tab. 4**. The calculation was made for Warsaw and air flow rate of 200 m^3/h (pipe dimension ∅ 200 mm). Energy prices represent Polish market in year 2006.

Tab. 4 Annual cost savings

Source of energy	Fuel cost	Annual cost savings EUR/year
Coal	101,4 EUR/t	4,17
Coal eko-pea	119,65 EUR/t	7,60
Electric energy (heat pump)	0,10 EUR /kWh	17,39
Natural gas (condensing boiler)	0,35 EUR /m^3	19,22
Natural gas	0,35 EUR /m^3	25,79
Pellet	0,15 EUR /kg	31,45
Fuel oil	0,72 EUR /l	65,51
Liquid gas	0,53 EUR /l	85,96
Electric energy (electric heaters)	0,10 EUR /kWh	106,41

Use of air-ground heat exchanger is not always cost efficient. Therefore decision about building it should be supported with economic analysis.

Presented work has been performed with support of the PL0077 project entitled Thermomodernisation of public buildings conducted in accordance with the conditions of sustainable development – STEP, financed by EOG Financial Mechanism, within WP1.8 Aquis Communautaire in a scope of new energy requirements.

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