EXPLOITATION OF AN AIR-GROUND HEAT EXCHANGER IN A LOW-ENERGY FAMILY HOUSE

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Summary

Air-ground heat exchangers (AGHE) are used for preheating of ventilation air in winter, and for precooling in summer. Currently, AGHEs are often proposed as a complement to the warm-air heating system. In such case, winter preheating also serves as an anti-frost protection of a heat recovery unit.

The paper deals with annual energy simulation of AGHE and its cooperation with warm-air heating system in a new-built low-energy family house in a North Moravia region. Simplified model created in TRNSYS code was used. Four variants were solved: exploitation of AGHE with and without heat recovery, and the same cases without AGHE as comparative variants. Consequent energy savings are compared with investment costs.

Keywords: air-ground heat exchanger, warm-air heating, heat recovery, energy savings

1 Introduction

Contemporary low-energy dwellings often use a warm-air heating system with ventilating air heat recovery, which reduces heat demands. As an optional equipment, an air-ground heat exchanger for further reducing of energy requirements is offered. Both preheating of ventilating air in winter and its precooling in summer (theoretically) bring energy savings.

The assessment of winter energy savings of AGHE, which is combined with heat recovery unit, is however problematic, because both equipments compete with each other – the exploitation of AGHE lowers the contribution of heat recovery, and vice versa. The benefit of AGHE for cooling in summer season depends on the building construction [1].

2 Simulation model of the air-ground heat exchanger and its operation

The energy simulation of the considered air-ground heat exchanger (**Fig. 1**) was carried out using modular simulation program TRNSYS 16.1 (Transient System Simulation), which is intended for dynamic analysis of building energy systems.

The heating/cooling of passed air is considered in a straight section of the AGHE only; an influence of the inlet and outlet parts has been neglected. A fundamental simplification of the simulation was made, that the exchanger does not affect the temperature distribution in a soil. Its temperature in a given depth, z [m], below the earth surface, in time t [d] from the beginning of a year, was determined using “Simple Ground Temperature Model“, implemented in the TRNSYS code, i.e. according to the equation

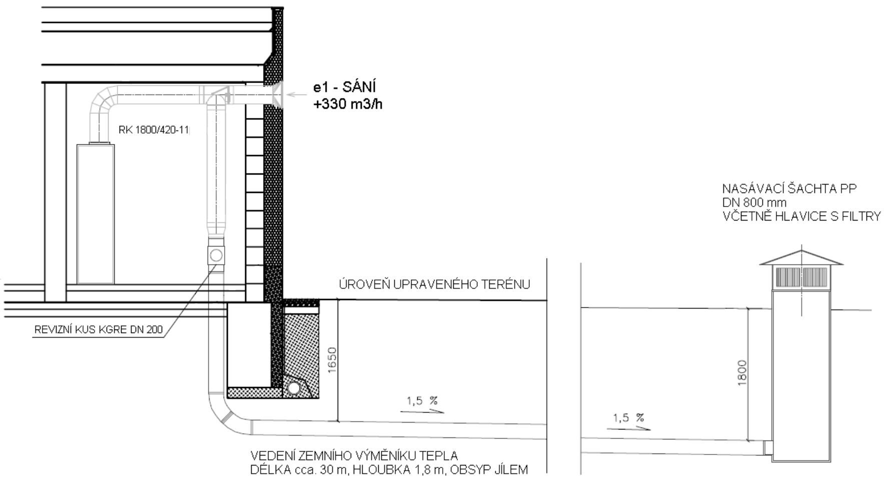

Fig. 1 Scheme of simulated air-ground heat exchanger

$$T_g(z,t) = T_M - T_A \cdot \exp\left(-\frac{z}{d_p}\right) \cdot \cos\left[\frac{2\pi}{365} \cdot (t-\tau) - \frac{z}{d_p}\right] \quad (1)$$

where the values of T_M = 9.3 °C, T_A = 11.2 °C, τ = 30 days, are based on a simplified sinusoidal yearly course of average daily air temperatures in the nearest weather station Mošnov. A constant depth of deposit, equal to the arithmetic average of the value at the beginning and the end of the pipe, was considered. The penetration depth, $d_p = (a \cdot 365 \cdot \cdot 86{,}400 / \pi)^{½}$, depends on the temperature conductivity of the soil, $a = \lambda / (\rho \cdot c_p)$. The AGHE is located in heavy clay soil; its physical properties are given in **Tab. 1**.

Tab. 1 Parameters of simulated AGHE

Air-ground heat exchanger		Soil			
Dimensions	0.2 × 30 m (DN 200)	Thermal conductivity	λ	1.28	W/(m·K)
Wall thickness	6.2 mm	Density	ρ	1500	kg/m^3
Material	KG 2000 Polypropylen®	Specific heat capacity	c_p	880	J/(kg·K)
Thermal conductivity	0.22 W/(m·K)	Volume heat capacity	C	1320	kJ/(m^3·K)
Average depth	1.825 m	Temperature conductivity	a	9.70	m^2/s

The outlet air temperature, $T_{a,out}$, is then given by the equation of heat transfer for the internal flow in pipes with constant surface temperature, T_S, which equals – in this case – to the ambient soil temperature (Eq. 1):

$$T_{a,out} = T_S + \left(T_{a,in} - T_S\right) \cdot \exp\left(-\frac{\overline{h} \cdot A_p}{\dot{m}_a \cdot c_{p,a}}\right) \quad (2)$$

Inlet air temperatures, $T_{a,in}$, were taken from the METEONORM climate database for the nearest available location (Ostrava-Poruba), and were changed at one-hour intervals. Average heat transfer coefficient, $\overline{h}$, was evaluated according to the Colburn equation [2]:

$$\overline{\mathrm{Nu}_D} = 0{,}023 \cdot \overline{\mathrm{Re}_D}^{0,8} \cdot \mathrm{Pr}^{0,33} \quad (3)$$

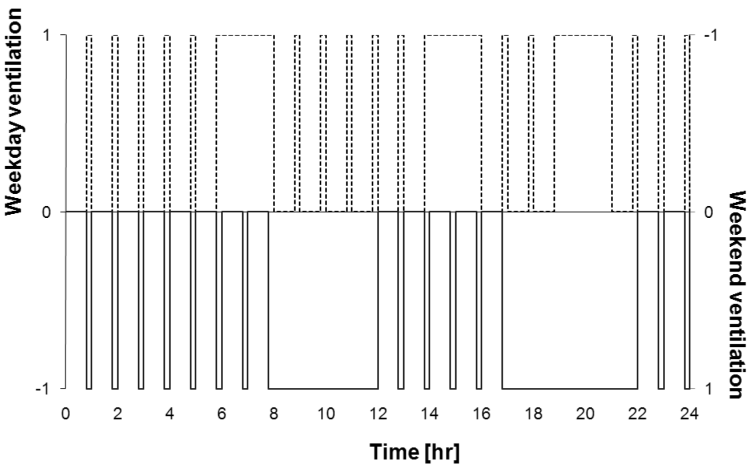

Fig. 2 Simulated ventilation regime

As an important question of the simulation, the supposed ventilating regime appears. Here, a different working-days and weekend profiles were considered throughout the year (**Fig. 2**). Continual ventilation with volume flow rate of 330 m^3/h is considered in time, when high ventilation loading is expected, and intermittent ventilation for 12 minutes/hour otherwise. The total average ventilation intensity 0.4 h^{-1} in working days, and 0.5 h^{-1} during weekends, respectively, is somewhat higher than the projected one, 0.3 h^{-1}. However, it should represent the maximum possible value that can be expected (in contrast to really observed conditions in many dwellings, see e.g. [1]).

Another important factor is the choice of the interval of outdoor temperatures, in which the AGHE is operated. The main asset of AGHE is supposed to lie in its function as an anti-frost protection of subsequent recuperation heat exchanger. Therefore, the ventilating air is sucked through the AGHE, only when the freezing threats, and directly from the facade otherwise (in this case, it would be unwise to exhaust the heat capacity of the soil). However, the threshold temperature can be chosen variously [3], although it is usually set above or, at least, to the freezing point. On the contrary, the upper limit is due to the cooling of the intake air during summer operation. Here, the recommended range for direct entry of ventilating air (0 to 25) °C [4] was adopted.

3 Results and discussion

Four variants of winter operation and one for summer conditions were solved. The basic variant V0 represents mechanical ventilation without heat recovery, where the inlet air is heated electrically (this is analogous to the window ventilation, where the air is heated by heating system). Heat recovery is used in all other winter variants, assuming a constant effectiveness of 78 % (exploitation of latent heat of waste air moisture condensation is not considered). In the V1 variant, no preheating of ventilation air is applied (i.e., freezing of heat exchanger may occur). In the remaining winter cases, V2 and V3_w, the inlet air is preheated before it enters the heat recovery unit: using supplementary electric heater in the V2 variant (to the temperature of 0 °C), and using its passing through the AGHE in V3_w, respectively. Variant V3_s deals with summer operation of ventilation.

The results of simulation are summarized in **Tab. 2**. Total amount of heat supplied to the fresh air is the same in all variants (at the given quantity of air), but their percentage proportion is different. Comparison of variants V0 and V1 shows the importance of waste

Tab. 2 Results of energy simulation

Variant	Preheating/ Precooling	Recuperation	Heating	Electricity consumption	Loss/ Gain		
	[kW·h/a]				[kW·h/a]	[CZK/a]	[EUR/a]
V0	0.0	0.0	5,689.8	5,689.8	– 4,620.1	– 9,914.1	–388.5
V1	0.0	4,444.2	1,245.6	1,245.6	– 175.9	– 377.5	–14.8
V2	360.3	4,177.6	1,152.0	1,512.3	– 442.5	– 949.6	–37.2
V3_w	663.5	3,956.6	1,069.7	1,069.7	0.0	0.0	0.0
V3_s	116.8	0.0	0.0	46.7	+116.8	+144.2	+5.8

heat recovery (reducing ventilation heat losses to 22 %). Energy benefit of the AGHE is obtained by comparison of two variants of anti-frost protection: from an economical point of view, the reduction of “paid” energy (i.e., the total electric energy for heating) is crucial, although the recovery heat is slightly lower in V3_w variant. The summer operation of AGHE brings additional savings in electricity needed for air conditioning (variant V3_s); however, they are lowered by an average COP factor.

4 Conclusions

Total annual economical savings (based on electricity prices in low tariff for heating, and in high tariff for cooling) are relatively small, namely in comparison with investment costs for the AGHE (about CZK 60,000.–, i.e. EUR 2,347). The resulting payback time is approx. 55 years (or slightly shorter, if rising energy prices are taken into account). Moreover, the results represent an upper limit of potential savings corresponding to high intensity of ventilation considered. Real savings will therefore be probably smaller.

However, the exploitation of AGHE should not be definitively reprobated. It can be beneficial for simple anti-frost protection of a heat recovery exchanger in winter and natural cooling of ventilating air in summer.

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