Measured and Calculated Energy Saving on Ventilation of a Residential Building equipped with Ground-Air Heat Exchanger

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Abstract. The significant share of energy consumption of the building sector in the total energy consumption makes it responsible for 36% of CO2 emission in the European Union. In the last decade a key objective of the EU is to improve the energy efficiency and increase the use of renewables in buildings. Ground-to-air heat exchangers can be a solution for reducing primary energy consumption from non-renewable sources in buildings and contribute to the share of energy from renewable sources. The research in this paper deals with investigations on a ground to air heat exchanger of a pilot energy efficient building, constructed in west side of Romania. The study presents the assessment of the heating and cooling energy potential of the ground-to-air heat exchanger serving the energy efficient building. Three full years of measurements of the air temperature entering the ground-air heat exchanger and the outlet air temperature are available and were used in the study. A comparison is made between the energy potential determined based on temperature measurements and the energy potential based on calculated outlet temperatures using a computational model and conventional climate data for the building location.

1 Introduction

1.1 Energy consumption in buildings

Energy consumption in the European Union (EU) building sector represents approximately 40% of the total energy consumption, above the consumption in the transport and industry sectors. The significant share of energy consumption of the building sector in the total energy consumption makes it responsible for 36% of CO₂ emission in the European Union. Thus, a key objective of the EU is to improve the energy efficiency and increase the use of renewables in buildings. This is reflected in the EU concerns of the last few years to promote and implement the nearly zero energy building (nZEB) concept as a future requirement for the energy efficiency of buildings. In Romania 86% of the built area is represented by residential buildings [1]. A study made on the existing residential building stock in Romania, shows that almost 61% are single family houses. The heating energy consumption in these building represents approximately 80% from the total energy consumption [2]. In order to reduce the energy consumption of buildings, several design techniques and technologies are available nowadays. Probably the best known worldwide energy efficient building concept is the passive house. Passive houses have as main objective, besides energy efficiency, to ensure a quality, healthy and comfortable indoor environment to its occupants. This objective can only be achieved if the indoor air is regularly exchanged with outdoor fresh air. In order to minimize the heat losses through ventilation, passive houses have

mechanical ventilation systems with heat recovery. In addition to the heat recover, ground to air heat exchangers are used to preheat the outdoor fresh air. In general, during winter, the ground has a higher temperature than the outdoor air and during summer a lower temperature. Therefore, it is effective to preheat or precool the fresh air by using ducts buried in the ground. At present, both in Romania and in other developing countries, pilot projects of energy efficient buildings that are monitored in real, represent an effective path to investigate the real performance of such building and their systems. The research in this paper deals with investigations on a ground to air heat exchanger of a pilot energy efficient building (passive house standard), constructed in west side of Romania.

1.2 Literature review

The ground-to-air heat exchangers, hereafter referred to as GAHE, is used to preheating / precooling the air needed to ventilate the building, thus reducing energy consumption from non-renewable sources. In the literature review made by Peretti et al the authors stated that GAHE combined with passive cooling strategies such as night cooling and a good thermal insulation, the need of an air conditioning system can be reduced or completely eliminated in many cases [3]. The results of the simulations presented in [4] show that a GAHE system can preheat or precool the air in a satisfactory way during the whole operating period. Thus, the authors concluded that a bypass is necessary in order to optimize

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the heating and cooling potential of GAHE. Estimation of the energy input of GAHE in the energy consumption of the building can be achieved by specialized mathematical models. A simplified GAHE calculation model, but using the hourly method, is presented in the EN 15241 [5] and large discussed in [6]. In previous theoretical studies, the authors applied the daily model and the hourly model [7, 8, 9]. A research made by Chiesa introduces a simplified method to assess the energy potential of GAHE in accordance to local climate data and soil characteristics. Through the performed research, the author of [10] concluded that the applicability of GAHE is influenced by a series of factors such as building insulation level, solar and internal gains. Ramirez-Davila et al [11] conducted a study on the thermal behaviour of a GAHE for three different locations and climate. The conclusions of this study show that in climates with very high summer temperatures, the thermal performance of a GAHE is better in summer than in winter [11]. Moreover, the authors stated that the use of GAHE is suitable for heating and cooling energy gains in climates with extreme and moderate temperatures [11]. Another study investigated the achievable energy performance of GAHE for an air conditioned building [12]. The authors performed a parametric study and concluded the following: the tube material has a very small influence on the energy performance of a GAHE; tube lengths lower and equal to 10 m are not satisfactory; cost effective depth GAHE can be achieved at depths of about 3 m.

In this paper, a comparative study of the net energy potential of a GAHE, determined using standard outdoor air temperatures and measured temperatures (heat exchanger input and output), is carried out for the early mentioned residential building from Timisoara, Romania. Timisoara is characterized by a climate with extreme temperatures in both summer and winter. Thus, the use of a GAHE in the case study building contributes to both heating and cooling, being in operation all year long.

2 Method

2.1 Description of the evaluated ground to air heat exchanger (GAHE)

The investigated GAHE is part of a mechanical ventilation system of an existing passive house constructed near the city of Timisoara, Romania. The mechanical ventilation system with heat recovery is a key element alongside the performance and airtight thermal envelope as it has two main roles: to ensure indoor air quality through an appropriately controlled air exchange; to recover heat from the vicious air to reduce the energy demand for heating. An additional method of energy savings through the ventilation system consists in the use of GAHE for preheating/precooling the air before it is introduced into the heat recovery unit by passing it through pipelines located in the soil (Figure 1).



Fig. 1. GAHE pipes execution.

The pipe system is buried at an approximately 2 m distance from the house, following the house perimeter. Thus, before being introduced into the heat recovery ventilation unit, the air is passed through pipes installed in the ground at a varying depth of 1.5 to 3 m. The passive house GAHE consists of a single PVC pipe having the thermal and geometric characteristics presented in Table 1.

Table 1 - Characteristics of the ground-air heat exchanger

Parameter	Value
Pipe thermal conductivity [W/(mK)]	0.35
Exterior diameter [m]	0.200
Interior diameter [m]	0.185
Length [m]	35

2.2. Temperature measurements

The building under investigation is equipped with a which performs complex monitoring system environment and energy measurements. The design and implementation of the monitoring system were performed by the research team at the Politehnica University of Timisoara. The process is accurately presented in other scientific papers [13]. The monitoring system is composed of the central unit and ambient energy flow meters. For the research performed in this paper, the measurements related to the air temperature entering the GAHE (Tair grdn) and the outlet air temperature are used (Tair_intk). Each of the sensors has a unique identification name as presented in Figure 2.



Fig. 2. Schematic representation of GAHE.

For this research three full years of monitoring were used (2012, 2013 and 2014) for the two parameters. These two parameters are measured for several years now through temperature sensors. Air temperature monitoring, at both inlet and outlet, was done every minute with sensors ranging from -55 ° C to 125 ° C. Each monthly file contains approximately 44000 lines of values for each measuring component. The hourly averages of the monitored values were used in the calculations. The processing of the monitoring data was performed using Microsoft Excel tool.

2.3. Computational model

As stated in the paper summary, a comparison of the GAHE energy potential was made between the results obtained by applying the calculation model in EN 15241 using conventional climate data for the building location, hereafter referred to as CCD case, respectively by using monitored temperatures from three years of monitoring 2012, 2013 and 2014. The ground temperature and outlet air temperature calculations for CCD were performed using the hourly calculation model presented in EN 15241 [5]. The total heat transferred to the air when flowing through GAHE was calculated following the formula in the following equation for all the considered cases [14]:

$$\dot{Q}_{GAHE} = \dot{m}_{air} \cdot c_{air} \cdot \left(T_{air,out} - T_{air,in} \right)$$
(1)

In Equation 1, the following parameters are used: \dot{Q}_{GAHE} – heat in W, \dot{m}_{air} – air mass flow rate in kg/s, c_{air} – specific heat capacity in J/(kgK).

The air mass flow rate was calculated following the formula in Equation 2:

$$\dot{m}_{air} = \dot{v}_{air} \cdot n_d \cdot \rho_{air} \tag{2}$$

In Equation 2, the following parameters are used: \dot{m}_{air} – air mass flow rate in kg/s, \dot{v}_{air} – air volume flow in m³/s, ρ_{air} – air density in kg/m³, n_d – number of buried ducts. The values of these parameters that were used in the calculations are presented in Table 2.

Parameter	Value
Air density ρ_{air}	1.23 kg/m ³
Number of ducts n_d	1
Air volume flow \dot{v}_{air}	0.04 m ³ /s
Specific heat capacity <i>c</i> _{air}	1011 J/(kgK)

 Table 2 – Values of the parameters used in the calculations

3 Results

3.1 Temperature analysis

The full year temperature behaviour of the GAHE is plotted in Figures 3 to 6, where the hourly temperature variation throughout the considered years are presented. Figures 3 to 5 show the measured outdoor air temperature (Tair in) and the air temperature after passing GAHE (Tair out) for the three considered years of monitoring. Figure 6 shows the outdoor temperatures case of CCD for Timisoara provided by in METEONORM [15] and the GAHE outlet temperature calculated following EN 15241 [5]. We can observe in all situations that the outlet temperature is higher than inlet temperature for the majority of time during winter and lower during the summer period. Also, the outlet air temperature line has the same trend for all the considered years.



Fig. 3. Outdoor air and outlet air temperature - in 2012.







Fig. 5. Outdoor air and outlet air temperature – in 2014.



Fig. 6. Outdoor air and outlet air temperature – based on CCD for Timisoara.

3.2 Monthly energy gain

Figures 7 to 10 show the monthly energy gain related to GAHE correlated with the monthly average outdoor air temperature. We can see that depending on the inlet air temperature and ground temperature, there are situations when cooling energy gain occurs in the winter months and heating energy gain during the winter months. The highest energy gain for heating occurred in February 2012 and December 2012, when the average outdoor temperature was below 0°C and slightly higher than 0°C. When it comes to energy gain for cooling, it is noticeable that in case of the CCD, the gains are significantly higher than for the other years based on temperature measurements. The highest cooling energy gain is visible in the summer months in the situation of CCD (Figure 10).







Fig. 8. Monthly thermal energy provided by GAHE - in 2013.



Fig. 9. Monthly thermal energy provided by GAHE - in 2014.



Fig. 10. Monthly thermal energy provided by GAHE - CCD for Timisoara.

3.3 Seasonal energy potential

Considering the calculated monthly values and their distribution over the months of the year, the yearly energy potential of the heat exchanger was determined in continuous operation without a running algorithm. The results are shown in Tables 3 and 4.

As we can see from the results presented in Table 3 and 4, the energy gains are dependent on climate and the operation time of the GAHE. In this case study, the GAHE was available all year long without being served by a bypass. Because of the continuous operation of the GAHE, we can see that the net heating and cooling potential are reduced due to the occurrence of cooling energy gains when heating is needed and vice versa. In case of the energy potential calculated based on monitoring data, we can observe that the heating net energy potential is almost 50% higher than the cooling energy potential. In the situation of CCD, the heating and cooling net energy potential of GAHE have similar values. During the heating season, the GAHE net heating energy potential has close values for the considered years, except for 2012 when considerable higher heating energy was obtained due to the lower outdoor air temperatures. Differences are remarkable for net cooling energy potential between the values based on temperature measurements and the ones based on the calculation model using CCD for Timisoara. The net cooling energy potential resulted from the calculation model using CCD is higher with an average of 33% compared to the evaluations based on temperature measurements.

Year	Seasonal energy potential [kWh]		Seasonal net energy
	Heating	Cooling	potential [kWh]
2012	1770	270	1500
2013	1537	286	1251
2014	1265	259	1006
CCD	1557	420	1137

 Table 3. Energy potential of GAHE in kWh – heating season 7 months (October to April)

 Table 4. Energy potential of GAHE in kWh– cooling season 5 months (May to September)

Vaar	Seasonal energy potential [kWh]		Seasonal net energy
rear	Heating	Cooling	potential [kWh]
2012	236	932	696
2013	224	866	642
2014	148	806	659
CCD	119	1277	1159

3.4 GAHE contribution to the ventilation heating energy need

In order to determine the contribution of GAHE to the ventilation heating energy need, the total energy needed to supply fresh air at the interior air temperature was calculated using Equation 1. For this calculation, hourly measured interior air temperature was used from the monitoring campaigns in 2012, 2013 and 2014 to determine the real contribution to ventilation heating of GAHE. The average measured interior air temperature for the three years is approximately 22.7°C. In Table 5 is presented the contribution of the GAHE to the total ventilation energy need. In average, the GAHE covered approximately 31% of the ventilation energy need during the heating months. Table 5 also presents the GAHE contribution ventilation thermal energy in case of the CCD, for which a conventional interior air temperature of 20°C was used. Of course, the GAHE percentage contribution to the heating energy need by ventilation is higher if a lower interior energy temperature is preferred.

Year	Total ventilation heating energy need [kWh]	GAHE contribution [kWh]	Percentage contribution [%]
2012	4411	1500	34 %
2013	3769	1251	33%
2014	3595	1006	28%
CCD	2801	1196	43%

 Table 5. GAHE contribution for the heating moths to the total ventilation energy need (October to April)

3.5 Increasing the GAHE energy potential through bypass system

The investigated GAHE does not have an automated control in order to bypass the system when it happens to be counterproductive. This led to some cooling gains when heating was needed and heating when cooling was needed. Thus, the energy potential of GAHE can be increased with the implementation of a bypass system. During the GAHE operation, the fresh air passes though the underground pipes. In the situation in which a bypass is installed, the GAHE is disconnected and the fresh air is taken directly from outside (Figure 10). The control can be made through a temperature sensor. During the heating months, when the GAHE outlet air temperature is lower than the outdoor air temperature, the GAHE is bypassed. Also, during summer, when the GAHE outlet air temperature is higher than the outdoor air temperature, the system is bypassed.



Fig. 10. Schematic representation of GAHE with bypass.

The heating and cooling energy potential of GAHE with and without bypass is presented comparatively in Figure 11 and Figure 12. We can observe that both cooling and heating energy potential of the GAHE is increased if a bypass systems is used. The heating energy potential increases with an average of 26% while the cooling energy potential increases with an average of 25%.



Fig. 11. Comparative heating energy potential (October to April) – continuous operation and bypass.



Fig. 12. Comparative cooling energy potential (May to September) – continuous operation and bypass.

4 Conclusion

This paper investigated the energy potential of a ground to air heat exchanger implemented in a residential building. For the study, three full years of temperature measurements were available, including outdoor air temperature and outlet air temperature after passing though the GAHE. A comparison was made between the measured outlet air temperatures and theoretical outlet air temperature calculated by applying a calculation model provided in EN 15241 [5] and using conventional climate data for Timisoara. In all situations, the outlet temperature is higher than inlet temperature for the majority of time during winter and lower during the summer period. Also, the outlet air temperature line has the same trend for all the considered years. During the heating season, the GAHE net heating energy potential has close values for the considered years, except for 2012 when considerable higher heating energy was obtained due to the lower outdoor air temperatures. Differences are remarkable for net cooling energy potential between the values based on temperature measurements and the ones based on the calculation model using CCD for Timisoara. In average, the GAHE covered approximately 31% of the ventilation energy need during the heating months. The GAHE percentage contribution to the heating energy need by ventilation is higher if a lower interior air temperature is preferred. Continuous GAHE operation, without control, reduces energy savings due to cooling of the air in the heating season or heating during the cooling season.

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