Investigation of HGHE near building basement – a case study

A M Bulmez¹*, V Ciofoaia¹ and I Boian¹

¹ Department of Building Services, Faculty of Civil Engineering, Transilvania University of Brasov, Romania

* alexandru.bulmez@unitbv.ro

Abstract. Ground heat exchangers represent the barrier between installing a ground source heat pump (GSHP) or a heat pump that use another source as water or air. While the vertical ground heat exchangers (VGHE) yield better results than horizontal ground heat exchangers (HGHE), the installation cost is higher than HGHE. Although, HGHE installation cost is a lot more affordable for residential use, it has the disadvantage of requiring a large installation area and lower efficiency than VGHE due to the temperature variation at the surface of the ground throughout the year. This study focuses on investigating possible use of the energy that is lost through the ground from basements in general, to help the heat pump when the HGHE is installed in the proximity of the basement. In order to achieve concluding results, an experiment was conducted at the University of Transilvania from Brașov, at the Faculty of Civil Engineering. In the experiment the HGHE was installed next to the basement exterior wall. In addition, a CFD numerical study was conducted. Firstly, to verify the experimental measurements and secondly, to obtain results with different working parameters. The results indicate that the thermal insulation degree of the basement wall and floor is an important parameter when considering heat loss into the ground. Likewise, the thermal state of the basement, heated or unheated, contributes considerably to the final results. Consequently, positioning the HGHE in the proximity of basements can represent an energetic optimization, especially when the basement is heated and it isn’t thermal insulated, as can be the case for an existing building.

1. Introduction

Ground source heat pump (GSHP) systems are becoming more and more attractive as time goes by. As of today, approximate 60% energy consumption in buildings is used for heating, cooling and domestic hot water production [1]. In Romania, almost half of the electrical energy is produced from renewable sources [2]. From that half, around 70% is hydropower and the rest consists mainly in wind, solar and bio renewable energy [3]. Although energy efficient indoor systems [4, 5] contribute a lot for the total energy consumption, the heat source represents the major factor in renewable energy systems. For tapping into geothermal energy stored into the earth, GSHP systems use geothermal heat exchangers (GHE). These are split into two main groups, open loop and closed loop GHEs. The closed loop GHEs also split into two main branches of vertical and horizontal GHEs. While vertical boreholes are the most efficient solution, the drilling cost represents a barrier even today. Horizontal GHEs are cheaper, but have the disadvantage of lower efficiency due to temperature variation at the surface of the earth.

In order to research possible optimizations for HGHEs, a small experiment was conducted at the Faculty of Civil Engineering at University of Transilvania from Brașov. The HGHE was positioned
next to the basement wall in order to take full advantage of the heat loss from the heated basement. Few studies have been made to this point considering building foundations and basements as heat sources such as [6-9], but this field still needs more research.

This study focuses on the heat loss from building basements and how HGHEs can take advantage of that. Many existing buildings today have basements that are not thermally insulated. In the future most of these buildings will be required to have renewable energy systems for heating, cooling and domestic hot water production. This in fact means that if the basement residual heat has an impact in the overall heat pump system efficiency it must be taken into account when designing such systems.

2. Materials and procedures
The experiment conducted is represented by a low capacity heat pump that uses as main renewable energy source the ground. For the source a horizontal GHE with the surface of 25 $m^2$ was proposed. The HGHE is positioned next to the basement wall. The pipe used is a polyethylene $\Phi20$mm pipe buried at the depth of 1,2 m. At that depth 18 temperature sensors were placed, as seen in figure 1.

![Figure 1. HGHE experiment schematic](image)

Ground temperature at 1,2 m depth, exterior air temperature, interior air temperature, and the heat pump inlet and outlet temperatures were measured for the duration of the experiment. The position of the HGHE was chosen to be next to the heated basement wall in order to use as much energy as possible which is lost from the basement to the ground. The experiment was conducted for the heating season between 15 October 2019 and 15 April 2020, for a duration of a total of 181 days. This experiment was made at a small scale, the heat extracted from the ground was used to heat and maintain the interior comfort temperature for one room. Although solar auxiliary source was also embedded into the experiment, this study focuses on how much energy the basement is losing during the heating season. Similarly, the interest focused on how the heated basement affects the temperature inside the HGHE. In Figure 2 the temperature measurements are represented, along with the reference temperature sensor. It shows that the temperature near the basement wall is higher with around 2-3°C for the duration of the heating season and it lowers as you move away from the basement wall.
3. Heat loss from the basement

The heated basement can be considered a heat source for HGHEs. The basement room next to the HGHE is the room of the thermal power plant, which operates intermittently during the heating season. To calculate the energy from the heated basement, the standard SR EN ISO 13370/2017 “Thermal performance of buildings. Thermal transfer through the ground. Calculation methods” was used.

![Figure 3. Thermal energy lost from the basement to the surroundings](image-url)
After that, multiple wall and floor thermal resistances were used, as well as different interior temperatures to obtain the results. The calculation was made for three interior temperatures during the heating season: 10°C, 20°C and 35°C as was the case of the experiment.

Firstly, as seen in Figure 3, the insulation degree of the basement walls and floor represents the most important parameter when considering heat loss. Even if the interior temperature is high, the basements will not lose much heat when properly insulated.

Secondly, the interior temperature has a less important role, as a heated basement has more thermal energy than an unheated one. In the case of the experiment, the average temperature inside the room next to the HGHE is 30-35°C. The calculation results show that 122,75 kWh/heating season are transferred into the ground near that room. The basement wall and floor are not thermal insulated, this being the main reason when the HGHE position was chosen.

4. Numerical simulation results

In the experiment the temperature inside the ground where the HGHE is placed was registered. All the measurements made from all 18 sensors were averaged intro a mean daily temperature for the whole HGHE. To verify the measurements, a virtual model was created in COMSOL Multiphysics in which HGHE temperature was simulated based on experimental system. The conditions used were the same as in the experiment, respectively same outside air temperature, basement room temperature, inlet and outlet temperature as well as pipe geometry, pipe diameter, pipe step and bury depth. Similarly, the numerical simulation was made for the same 181 days period.

In Figure 4, seen with green, is the HGHE average temperature for the heated basement, and the results from the numerical simulation confirm the experimental measurements. Afterwards, a case with the basement being unheated was simulated, showing that the ground cools more during the peak of the heating season. It is interesting to notice that the temperature difference between the two cases increases as time goes by. This reflects the thermal processes that occurs inside and at the surface of the earth. When the exterior temperature drops, more heat is needed for the building but also the ground surface loses more heat in the environment. The heat pump extracts more heat from the HGHE. While the basement provides a good heat buffer for high temperature variations, the heated or unheated state of it has an important role.
5. Discussion

Based on the results that validated the experimental measurements, more cases were simulated, in order to better understand the temperature variation with the use of auxiliary and residual heat sources.

Firstly, a case was simulated that treated the basement as unheated with an average temperature of 10°C inside. This case showed a gradual increase in the temperature difference as time went by and can be seen in both Figure 4 and 5. The temperature difference at the season peak between the experimental case and this simulated one was of approximate 2°C.

Secondly, a case was simulated that eliminated the thermal energy supplied to HGHE from the solar source, but had the temperature input from the heated basement, as the experimental case. This simulation showed further decrease in temperature in the season peak with the difference between it and the experimental case being of approximate 3.5°C.

Thirdly, a case was simulated that eliminated all heat sources, solar and heated basement. The trend of gradual temperature difference increase was confirmed for this case as well. This case showed how the temperature inside the HGHE would be if the system was a regular one, with no additional heat source. The peak temperature difference reached almost 5-6°C.

From analyzing the results, it can be seen that the heated basement has an important role in reducing the ground freeze period from approximate 4 weeks to 3 weeks during the season peak. Similarly, the solar source reduced this period to 2 weeks and both additional heat sources eliminated the freeze period completely. This aspect is important because the ground freeze represents a well-known issue for horizontal ground heat exchangers that can impact other systems nearby such as water or sewerage.

![Figure 5. Average HGHE temperature for experimental case and three simulated cases](image)

Figure 5. Average HGHE temperature for experimental case and three simulated cases

Another interesting fact that the numerical simulation showed that the temperature inside the HGHE at the end of the season is not the same for the different simulated cases. According to this results, the additional heat sources can maintain a lower temperature variation inside the HGHE. Also, it means that if the thermal energy supplied to the HGHE during the cooling season is not enough, in time the ground will be colder and colder at the start of the heating season, thus reducing the heat pump system performance.
6. Conclusions
The optimization of HGHEs is necessary today for the spread of GSHP systems in order to reduce the greenhouse gas emissions. After analyzing the results several conclusions were established:

- overall conclusion is that the heated basements can be a reliable heat source for the HGHEs, even if it is a residual source;
- the most important parameters for the basement to be a reliable source are a high inside temperature and a low thermal resistance;
- the experimental measurements show that the heated basement rivals the solar panels as auxiliary heat source for the HGHE and the GSHP system overall;
- the solar panels contributed with an approximate 3°C average temperature difference during season peak and reduced the freezing period with approximative 2 weeks;
- the heated basement accounted for approximate 2°C average temperature difference during the season peak and reduced the freezing period from approximate 4 weeks to approximate 3 weeks;
- using both heat sources completely eliminated the ground freezing period during the season peak.

This implies that for existing buildings where space is an issue and the existing basements are not thermal insulated, positioning HGHEs next to them need to be considered. Therefore, as temperature variation is a well-known issue when designing HGHEs, basements provide a reliable heat source towards increased efficiency and thermal equilibrium.

Since HGHE design still base today on empirical results from previously installed heat pump systems, there is untapped potential from using additional heat sources. This can be successfully applied to either prevent the heat pump performance drop or reduce the temperature variation inside the HGHE during the heating season.

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