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REHVA 14th HVAC World Congress
22nd – 25th May, Rotterdam, The Netherlands

Implementation of a shallow geothermal energy system in a multi-source green building

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Abstract.
The building stock is responsible for a large share of greenhouse gas emissions (GHG in the European Union. Major emission reductions can be achieved through changes in this sector and the building sector is crucial to achieving the EU's reduction targets. From 2021 all buildings must respect the nZEB standard and must use a certain amount of renewable energy sources. While condensing gas boilers have lower costs these cannot provide cooling and do not use renewable energy. The best alternative is the use of geothermal heat pumps that have high efficiencies and can avoid large amounts of GHG. Currently, geothermal energy sources provide more than 15 GWth for heating and cooling in the European Union, equivalent to more than 4 Mtoe per year, whereby geothermal heat pump systems contribute to the largest part. Shallow geothermal systems are more complex to realize than conventional solutions. Critical aspects include correct design, adequate performance in operation and costs for the installation. The combination with other Renewable Energy Sources (RES like solar energy could improve the return on investment. The main goal of this paper will be to tackle all the above-mentioned areas by developing and demonstrating the potential of shallow geothermal system to be connected in a precise and efficient way to other renewable sources systems, in particular solar thermal energy. This approach is realized by adapting hybrid solutions to reach nZEB standards through a holistic engineering, construction and controls approach. The demo-site was carried out on an energy-efficient house EFdeN House, an active single-family dwelling that was planned and built in Bucharest for academic and research purposes and it is the first Excellence Research Centre in Romania.

Keywords. Renewable Energy Sources, Geothermal Heat Pumps, nZEB energy-efficient house, EFdeN, green building, Geothermal Energy
DOI: https://doi.org/10.34641/clima.2022.108

1. Introduction

The scientific community needs multiple experimental demonstration stands that could be used as a reference in the validation of numerical models for the implementation of ground-to-water heat pumps. Adapting ground-to-water heat pumps to provide the necessary indoor temperature for existing heating and cooling systems that cannot be easily replaced represents a huge challenge. It is also necessary to optimize the energy management of the installations in order to reduce the number of operating hours of the system and to provide support tools to overcome technical challenges in the operation of geothermal systems.

According to the GEO4CIVHIC and CHEAP-GSHP projects [1,2], many research centres in Europe benefit from such experimental stands for testing and coupling geothermal systems with energy-efficient buildings (figure 1).

Our study addresses the main barriers identified in the implementation of geothermal heat pumps by developing and demonstrating the potential of geothermal systems to be connected in a precise and efficient way to other systems using renewable energy sources and especially to solar thermal and photovoltaic systems. This approach is achieved by adapting hybrid solutions in order to achieve nZEB construction standards in a holistic manner.

Fig. 1 - Similar experimental stands in Padua (Italy), Bilbao (Spain), Valencia (Spain), Pikermi (Greece), Mechelen (Belgium) or Dublin (Ireland). This study aims to put Romania on the map of European research centres where the coupling of geothermal systems with heat pumps together with energy efficient buildings are analysed and studied intensively in order to promote and raise awareness of the benefits of implementing this system, to reduce energy consumption and reduce CO_2 emissions, part of the European Union's strategy until 2050 [3].

2. House and system description

The building on which the studies are conducted is carried out on two levels - ground floor and first floor (figure 2 and 3), level hight 2.5m, intended for residential building and exhibition pavilion, with the following geometric characteristics: footprint 96m^2, net area (heated) 133m^2, gross area 170m^2 and total air volume 400m^3.

Fig. 2 – Ground floor plan.

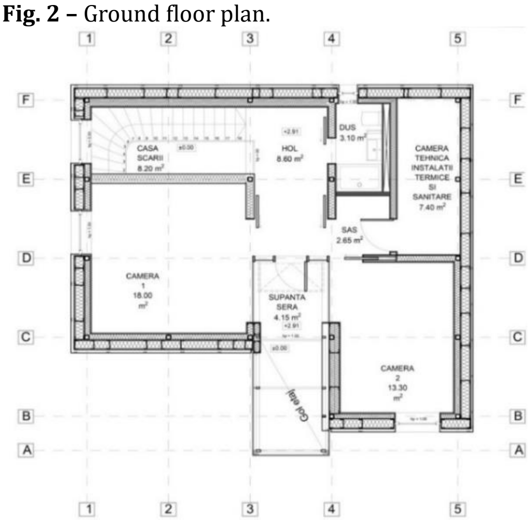

Fig. 3 – Floor plan.

The construction is modular, made of metal structure and is particularly well thermal insulated by approaching the design requirements of passive houses. Table 1 shows the values of the heat transfer coefficients of the construction elements that define the building envelope. The value obtained for the terrace is due to an additional layer of rockwool with variable thickness (thus determining the terrace slope), and the value obtained for the exterior walls is due to an additional layer of rockwool (5cm) present behind the radiant system. heating/cooling, as well as an intermediate layer of air. Plasterboard boards with micro-encapsulated phase change materials are placed in the walls of the house, which have the role of giving thermal mass to the building and of decreasing the energy consumption for cooling during the summer.

Tab. 1 - Heat transfer coefficients of tire elements.

Construction element	U [W/m^{2}K]
Exterior wall	0.129
Flooring	0.124
Terrace	0.121
Interior walls	0.39
Triple glazing windows	0.8

The heating and cooling systems within the studied building were designed to ensure an indoor temperature during the summer of 26ºC, respectively an indoor temperature during the winter of 20ºC, taking into account that the outdoor design temperature for winter (related to climate zone II -Bucharest) is -15ºC, respectively 35.3ºC for summer [4-6].

The existing installation of the EFdeN solar house has as a source an air-to-water heat pump that supplies a buffer used for cooling, a buffer used for heating and a DHW tank used for domestic hot water preparation. The DHW tank and the heating buffer are also connected to a system with two solar panels with vacuum tubes. The indoor installation of the building has a heating / cooling system with radiant panels, positioned within the ceiling and walls of the house. Also, the water flow circulates through the heating/cooling coil after the heat recovery unit used for the fresh air supply. To complete the existing installation, two 3-way valves with servomotor will be provided, and the proposed geothermal installation will represent an independent heating system for the indoor installation. The equipment's that have been implemented to complete the geothermal installation are: Ecoforest ground-to-water heat pump, Ecoforest air-to-water heat pump, plate heat exchanger for passive cooling, pipes for horizontal route geothermal probes, elastomer insulation for installation pipes, buffer 200 litters, 300 litters trivalent boiler for domestic hot water preparation, expansion vessels, temperature sensors, 3-way valves with modulating servomotor and other accessories (figure 4).

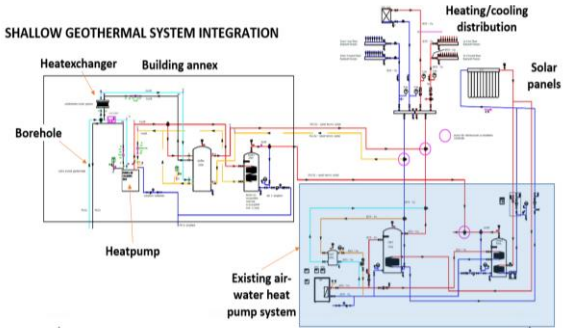

Fig. 4 – System hydraulic schematics

The proposed ground-to-water heat pump will operate in a hybrid system, being complemented by an air-to-water heat pump. The heat pump conducts the water flow to a buffer useful for heating storage and efficient operation of the heat pump and a trivalent DHW tank for domestic hot water preparation connected to the heat pump, thermal solar panels or even an electric heater as back-up. Furthermore, the role of the plate heat exchanger is to ensure the operation of the heat pump in passive cooling mode.

The system proposed within the GEOPILOT project is completely independent of the original building system analysed and it connects to the existing indoor installation through two 3-way valves located before the general distributor-collector that transmits the water flow to the radiant heating / cooling system located in the ceiling and walls of the building (figure 5).

Fig. 5 – Heat pump used within the proposed system

An experimental Ecoforest ecoGEO + 1-6PRO & AU hybrid heat pump will be used in the experimental stand, which can operate in both ground-to-water and air-water mode, in bivalent mode, thus ensuring maximum efficiency of the entire system. The heat pump can provide the functions of heating, cooling and domestic hot water preparation and uses R290 as refrigerant, with a very low GWP value (GWP = 0), with a low impact on the environment. The heat pump has a heating capacity ranging from 1kW to 6kW, COP (B0 / W35) up to 4.9, EER (B35 / W7) up to 5.2 and can supply a water flow with a temperature of up to 70ºC on the installation flow.

3. Preliminary numerical results

The energy modelling of the analysed building was performed with the numerical simulation software Design Builder in order to determine the energy consumption related to the building and the values of thermal loads, for the optimization of the proposed geothermal system (figure 6).

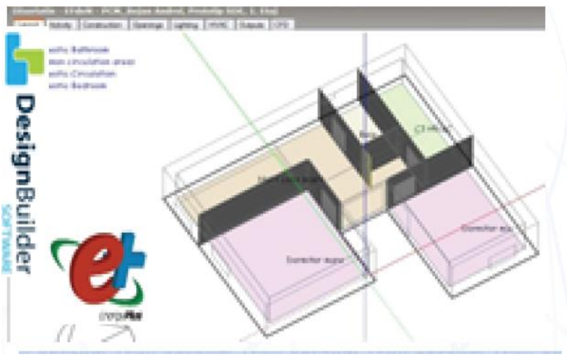

Fig. 6 – Energy modelling of the building in the numerical simulation software Design Builder

In the graphs within figure 7 it can be observed the evolution of winter outdoor temperatures for the climatic zone in which the analysed building is located (-20°C- + 35°C), the evolution of wind speed (0-17m/s), wind direction, position of the sun, atmospheric pressure and intensity of solar radiation (direct and diffuse) for Bucharest.

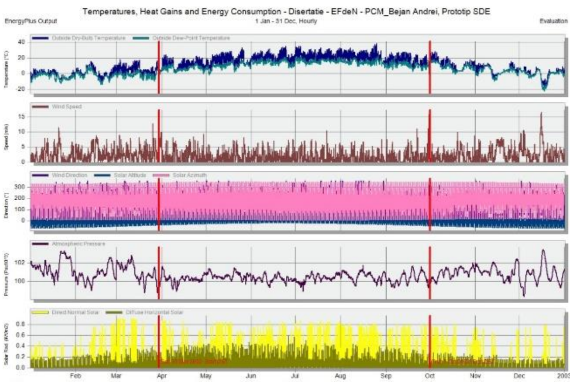

Fig. 7 – Exterior conditions for energy modelling of the building

In table 2 we can observe the values of summer thermal loads for the rooms within the prototype house analysed.

Tab. 2 – Summer thermal loads

Zone	Design capacity [kW]	Sensible [kW]	Latent [kW]
Living	1.66	0.92	0.41

Large bedroom	0.65	0.49	0.04
Small bedroom	0.58	0.44	0.02
Hall	0	0	0
Total	2.89	1.85	0.47

Table 3 shows the values of winter thermal loads for the rooms within the analysed house prototype.

Tab. 3 – Summer thermal loads

Zone	Steady-State Heat Loss [kW]	Design Capacity [kW]
Living	1.49	1.86
Large bedroom	0.55	0.69
Small bedroom	0.49	0.61
Hall	0.52	0.62
Bathroom 1	0.13	0.16
Bathroom 2	0.16	0.19
Total	3.34	4.16

The heating load of the house is 4.16 kW, while the cooling load is 2.89 kW, with the possibility to cover the entire cooling load using passive cooling with radiant panels.

The variation of the thermal loads during a year is highlighted in figure 8:

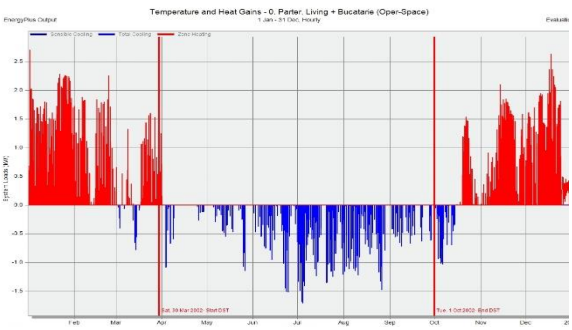

Fig. 8 – The evolution of thermal loads over a period of one year

As can be seen in Figure 9, the total energy consumption for cooling the analysed house is 590 kWh / year, according to the numerical simulations performed. By implementing a cooling system with a ground-to-water heat pump equipped with a passive cooling function, this energy consumption can be reduced by up to 85%; while covering the energy consumption for heating using the energy from the heat pump equipped with the active cooling function, the energy consumption for cooling can be reduced by up to 40%.

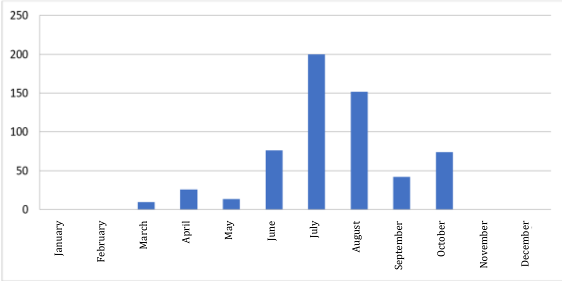

Fig. 9 – Monthly building energy consumption for cooling

As can be seen in Figure 10, the total energy consumption for heating the analysed house is 1878 kWh/year according to the numerical simulations performed. By implementing a ground-to-water heat pump heating system, this energy consumption can be reduced by up to 33%. The evolution of energy consumption during the year is also highlighted in figure 11.

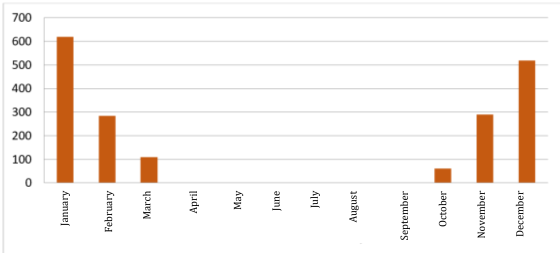

Fig. 10 – Monthly energy consumption of the building, for heating

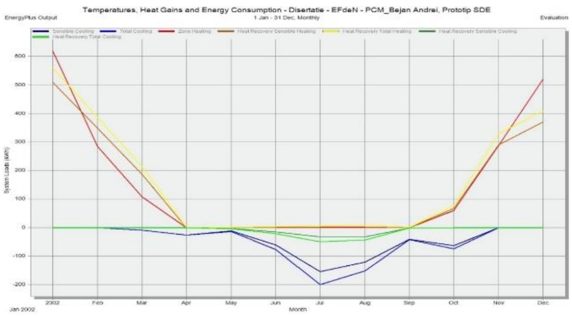

Fig. 11 – Energy consumption during a year

4. Preliminary experimental results

In parallel with the preliminary numerical studies conducted, experimental studies have been performed in order to analyse the energy consumptions for heating and ventilation, where the existing heat pump has a considerable input. These were corroborated with the values of the essential interior comfort parameters according to national and international standards (SR EN 15251: 2007, SR EN 16798-1: 2019) - indoor temperature and CO_2 concentration level [4-6].

The data presented in Figures 12 and 13 were collected during the experimental campaign conducted during the winter and shows the evolution of the values recorded during a reference week, for the main rooms of the building. During the analysed week, the system consumed 38kWh for heating, even if the outdoor temperatures dropped below 5ºC. The indoor air temperature recorded values above those proposed by the standard SR EN 15251 (21ºC for the IDA1 room category and 20ºC for the IDA2 room category) for residential buildings. Moreover, the CO_2 concentration values were within the limits proposed by SR EN 15251 in over 85% of the time for the IDA1 comfort category (below the 800-ppm concentration) and 100% of the time for the IDA3 category (below the 1200 ppm concentration). In order to maintain a low level of indoor CO_2, 10kWh were consumed throughout the week.

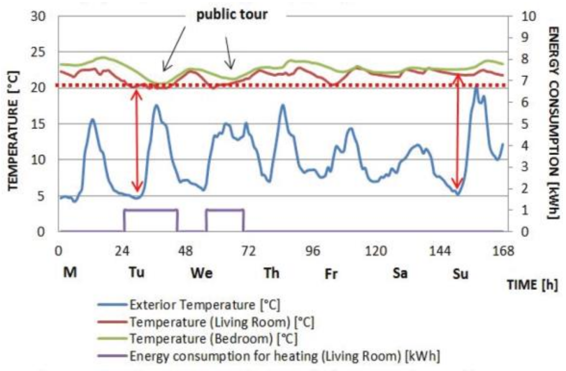

Fig. 12 – Variation of measured temperatures and energy consumption for heating (for a reference week)

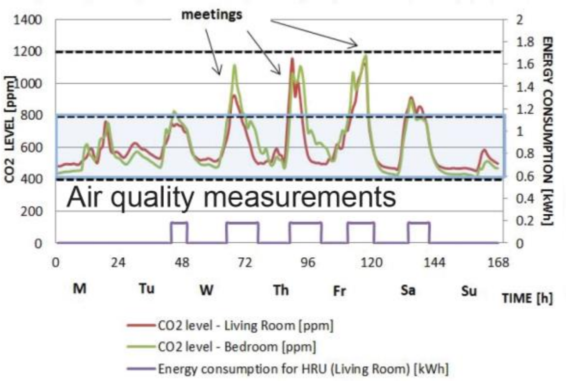

Fig. 13 – Variation of measured CO_2 concentration and energy consumption for ventilation (for one reference week)

Due to the implemented photovoltaic system, the building is not only a passive house, but an active house that produces more energy than it consumes, analysing the annual energy balance. The annual energy production is approximately 6844 kWh / year, while the annual energy consumption is 4330 kWh / year, the surplus energy being injected into the network. (figure 14).

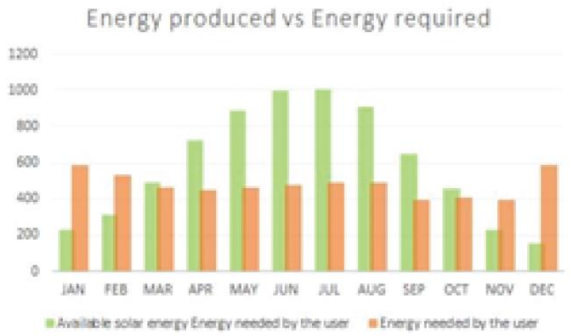

Fig. 14 – Photovoltaic system production and energy consumption of the building

5. Conclusions

The implementation of energy efficient solutions and ground-to-water heat pumps on an nZEB building has a great impact on achieving indoor environmental quality with minimum energy consumptions. By implementing high quality materials, the heating load of the nZEB building studied is only 4.16kW, while the cooling load is only 2.89kW thus being covered only with passive cooling system. Total energy consumption for heating is 1878kWh/year while the total energy consumption for cooling is only 590kWh/year.

6. Acknowledgement

This study was supported by Romanian National Authority for Scientific Research, project GEOPILOT – "Demo geothermal pilot for application in residential buildings nZEB" PN-III-P2-2.1-PED-2019-2881.

7. References

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evaluarea performanței energetice a clădirilor, privind calitatea aerului interior, confortul termic, iluminatul și acustica. Modul M1-6

[6] SR EN 16798-1:2019/NA:2019 - Performanța energetică a clădirilor. Ventilarea clădirilor. Partea1: Parametrii ambientali pentru proiectare și evaluarea performanței energetice a clădirilor, privind calitatea aerului interior, confortul termic, iluminatul și acustica. Modul M1-6. Anexă națională