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Ground-source energy systems for building heating and cooling — A case study

Victor P. Sanmamed[a], Nídia S. Caetano[a,b], Carlos Felgueiras[a,*]

[a] *CIETI, School of Engineering (ISEP), Polytechnic of Porto (P. Porto), R. Dr. António Bernardino de Almeida 431, 4249-015 Porto, Portugal*
[b] *LEPABE - Laboratory for Process Engineering, Environment, Biotechnology and Energy, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal*

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Abstract

The growing concern about decarbonization of the energy production system led to the use of Renewable Energy Sources (RES). However, RES has the drawback of being inherently intermittent and lack controllability, placing limitations on their use. To avoid such limitations, the exploitation of a wide range of energy storage strategies that allow the balancing of energy production and demand is needed. One possibility is to use (BTES). This paper explores the use of BTES in a warehouse in Norway. The system presented in this Borehole Thermal Energy Storage study consists in hybridization of several technologies: PV-T solar panels, air, heat pumps and 8 geothermal wells.

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Keywords: Borehole thermal energy storage; District heating; Energy storage; Geothermal energy; Ground source energy system; NZEB; PV-T; ZEB

1. Introduction

Energy consumption related to heating and cooling assumes special importance in a global scenario, making it worthwhile to analyze how non-conventional strategies, such as geothermal air conditioning systems, especially high-powered ones, could be used to improve their overall usage. The total energy consumption for heating and cooling corresponds to 30% within households [1], and of this total, 68% of energy consumption is used in cooling and heating systems [2] involving water production processes.

These data show the need for development of energy systems that meet these demands, heat and cold, in a more efficient way while sustainable for the environment. One promising solution is the hybridization between various technologies, namely geothermal heat pumps, PV-T solar panels and the air system to perform free-cooling. Along with the above considerations, in the last decade, the Energy Performance of Buildings Directive (EPBD)

* Corresponding author.
E-mail address: mcf@isep.ipp.pt (C. Felgueiras).

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has introduced several concepts such as low energy consumption through passive construction and buildings with net positive energy balance. Some authors [3] use ZEB as net zero energy buildings and NZEB as near zero energy building. Net refers to a balance between the energy taken and supplied to the energy networks over a period of time. Therefore, net ZEB refers to buildings with a zero balance, as well as buildings that the NZEB applies to are buildings with a negative balance.

The need to implement energy efficiency in heat and power generation systems, together with the shift from oil to coal or biomass in the energy sector, would lead to the possibility of generating Combined Heat and Power (CHP), requiring the use of District Heating (DH), due to the attractiveness of its temperature ranges, due to global efficiency, focused on optimizing the cogeneration process. One of the advantages of using very low temperatures is the possibility of implementing systems with heat storage. The introduction of DH systems contributes significantly to the reduction of air pollution, is conceived as a response to the reduction of CO2 emissions. It shows the general trend of governments to reduce the emissions from the generation of heat and electricity. The great advantage of the capacity of DH systems, together with the hybridization of several technologies with renewable energy sources and thermal storage, is to make DH an efficient, cost-effective and alternative option for solving the problem of intermittent supply of energy to the electricity grid, a clear example being Denmark [4]. The implementation of DH systems demonstrates a reduction of losses in the network and takes advantage of synergies, increasing efficiency in the units of systems that work at low temperatures. The consideration of this alternative for heating is shown as the concentration of demand, thus minimizing distribution costs and consequent heat losses [5]. The Fourth Generation District Heating system (4GDH) is defined as a technological strategy of institutional interest, since the use of intelligent thermal technology helps the proper development of sustainable energy supply networks. 4GDH systems provide the heat supply of low-energy buildings with low grid losses, so that the use of low-temperature heat sources is integrated with the operation of intelligent energy systems [6].

The interconnection of the underground geothermal exchangers with the technology of the Heat Pump, unlike the traditional systems of heat production based on the combustion of fossil fuels, allows the use of the Earth's energy for its formation, being transferred to air conditioning in a cleaner and more efficient way. It should be noted that one of the strong points of this technology is the reduction of electricity consumption, since, compared to the boiler system, it allows for savings of between 40% and 75% of the primary energy used [7]. Although the price of electricity is not one of the biggest problems in Norway [8], the contribution of electricity can be satisfied by the current infrastructure, using PV-T panels and an energy storage system, making the proposed system much more interesting for implementation in southern European areas [9].

2. Methodology

The present paper is based on studies included on the Rockstore Project [10], which includes different researches and functional facilities in the range of operating temperatures from 50 to 90 ºC. Among all these systems, several stand out with solutions in temperature ranges from 70 to 90 ºC, one of them being thermal energy storage in the soil, starting from the use of earth energy. Several stand out in Denmark, Sweden and a school in Norway, where there are problems with the thermal balances of the soil, leading to ice crystals forming in the boreholes.

The system under study is called the 2020park [11] and has a temperature range of less than 50 °C, typically operating at 45 °C. This operating situation is particularly interesting since it is the production range of DH, because it is in this range that the pumps selected heaters have the best performance. A negative factor to point out is the risk of Legionella proliferation, since these conditions are prone to its development. The system consists of the hybridization of several technologies: PV-T solar panels, air, heat pumps and 8 geothermal wells, as represented in Fig. 1.

The two heat pumps that are connected as master–slave in the design, each providing 60 kW of power. The PV-T solar panels provide a power of 8 kW for heat and the air system provides cold (always operating above 5 ºC, to avoid freezing points). In the forecast phase of the project, the potential of being able to produce thermal energy storage in the soil with the help of boreholes has been highlighted. In a first approach to understand how the system works, a very simplified scheme has been provided. As a following step, some diagrams have been made based on the heat pump supplier in order to know how the series association of heat pumps and their interconnection between geothermal wells, the PV-T solar panel system, the air system and its interaction to cover the demands of heat, cooling and the possibility of generating electricity. Note that no sanitary hot water will be produced. The system operates at a temperature of 50 ºC, but considering the losses, it is considered to work at 45 ºC. The system

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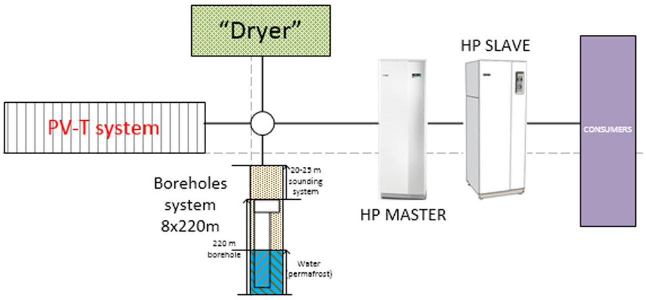

Fig. 1. Installation diagram.

with heat pumps provides up to 120 kW of power, together with the possibility of PV-T solar panels to provide an extra 8 kW, highlight the air system to produce free-cooling. The system is therefore able to meet demands of 130 kW of power. The global design is depicted in Fig. 2.

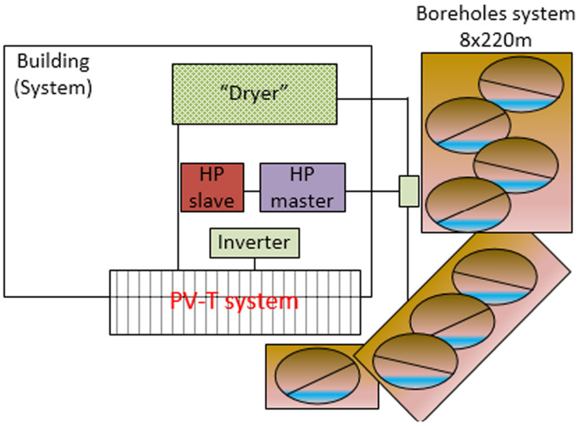

Fig. 2. Interconnexion system to deliverer 130 kW.

3. Results

An impossibility of thermal storage in the ground was observed, caused by the generation of ice in times of great demands of heating, reaching temperatures of −20 °C and in demands of refrigeration of temperatures that surpass 45 °C, that make impossible the correct operation of the system of geothermal wells. When the probes were included, it was observed that there was no correct thermal balance, since much heat was removed from the ground and the boreholes in contact with the groundwater reached the freezing point [12,13]. The results of the analysis of the energy demand and supply by the system are shown in Fig. 3.

The system is not currently operating with the power of demands foreseen for the future, so thermal storage is ruled out at this stage. Together with the fact that the boreholes are disposed at an inclination and there is an overlap of their influence, due to the fact that there are no adequate safety distances between them, this leads to more problems and makes it impossible to store energy on the ground.

The objectives will be achieved through the study of increased use of control systems, geothermal wells, hybrid solar cells and efficiency improvements [14]. It must also be adapted to new products, such as hydrogen and the use of PCM for thermal storage. In total, the annual reduction of purchased electricity [14,15] is estimated at 1,440,000 kWh while the reduction of district heating purchases is estimated at 2,100,000 kWh. The calculations are based on 3000 m2 of PV-T and 5000 m2 of traditional PV, which is still in the implementation phase [16]. These results show several future avenues of study [17–19]; thermal storage in the ground by boreholes walls, cascade configuration of heat pumps, thermal storage tanks + PCMs, use of residual heat from the engine room >20 °C. This only represents a small approximation of the work done, leaving out much of the data that was used for the analysis of this technology and for its implementation decision and study, in comparison with many other

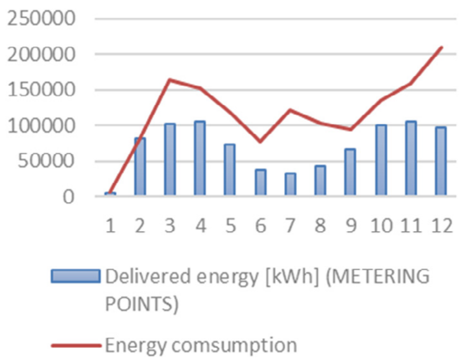

Fig. 3. Comparison between the energy supplied and consumed.

technologies available. With this project and its possible modifications neeeded due to the setbacks shown, it is expected to supply energy to consumers in a residential area of nZEB [6]. This will represent an improvement in the technology that was available until now, with more profitability, better interior comfort, higher energy efficiency and lower environmental impact [20,21]. This applies to each building as well as to the entire area.

4. Conclusions

This paper explores the use of BTES in a warehouse in Norway. With this system, the main objective is to promote and implement new technologies of renewable energy and storage systems, and this is positioned ahead of development. In the long term, this will contribute to the introduction of new, more energy-efficient and climate-friendly products and solutions onto the market, and their reuse in other projects. This will also contribute to raising the level of ambition in terms of energy efficiency, energy flexibility and the use of renewable energies in general.

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