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GROUND SOURCE HEAT PUMPS COST ANALYSIS IN MODERATE CLIMATE

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ABSTRACT
A debate is taken up on whether it is economically preferential to install Ground Source Heat Pumps (GSHPs), Renewable Energy Systems, instead of Air Source Heat Pumps (ASHPs). To this end, a typical house heating/cooling load for moderate climates is chosen and the thermal response of Ground Heat Exchangers (GHEs) of GSHPs and their characteristics – based on experimental data and CFD-model simulations in FlexPDE – are discussed. The results indicate that with greater difference between the inlet GSHP temperature water and the ground, a higher heat rejection is observed. The GSHP capacity over the input power operating temperature is affected by the fluid temperature entering the Heat Pump, affecting the system cost as more GHE boreholes may be needed for reducing the temperature. A cost analysis is thus presented for different-length GSHP systems and a comparison of the total energy savings is obtained versus highly competitive inverter technology ducted series ASHP systems.

Keywords: Ground Source Heat Pump Systems, GHE cost analysis in moderate climate conditions, Air Source Heat Pumps

1. INTRODUCTION
Geothermal Energy, a form of Renewable energy, has attracted attention in recent years due to the energy shortage. While the transfer of heat from a high temperature source to a low temperature one is natural, the opposite is done through HPs that are commonly used for the air-conditioning of buildings. A HP operates with electricity, using as an exchange source either the surrounding air (ASHPs) or water in the pipes of a GHE (GSHPs) that uses the Earth's energy to gain or reject heat.

The GHEs, compared to air-to-air heat exchanger systems, exhibit significantly higher performance (Yu et al. 2013), but their installation cost is high, and they require larger spaces. Recent research has focused on the reduction of the cost (Aresti, Christodoulides and Florides 2018) and, consequently, GSHP installations that may be economically beneficial over convectional heating and cooling systems have increased over the last decade (Yang, Cui and Fang 2010). Naturally, there have been studies in the literature concerned whether it is cost beneficial to use GSHP instead of ASHPs.

Healy and Ugursal reported that between four different residential heating/cooling systems in a residential building in Nova Scotia, Canada, namely GSHP, electric resistance heat, oil-fired furnace and ASHP systems, the GSHP system was the least expensive to install-operate (Healy and Ugursal, 1997).

For similar studies conducted in Turkey, the results showed that the GSHP system is a cost-effective solution compared to electric resistance, fuel oil, liquid petrol gas, coal and diesel oil, with payback periods between 8 and 21 years (Esen, Inalli and Esen 2006), (Camdali and Tuncel 2013). Other studies include Chang et al. in China with a payback period of 7.1 years for a GSHP system versus a water-cooling machine and matching gas furnace system (Chang et al. 2017), and Badescu with a payback period of 3–10 years for a GSHP system versus convectional systems and GHEs with convectional systems (Badescu 2007).

On the other hand, Lu et al., using different economic methods from previous studies, concluded GSHP systems would provide an economic advantage compared to the ASHP systems only in the long term (40 years) (Lu et al., 2017).

In general, based on the literature, GSHP may or may not be an economic solution for heating/cooling a house, depending on many factors, such as ASHP efficiency, location of the house and climate conditions and installation cost of the GSHP (Christodoulides, Aresti and Florides 2019). The work presented below mainly aims at contributing in the study of the effectiveness and usefulness of GSHP in moderate climate conditions.

2. TYPICAL HOUSE LOAD AND MODERATE CLIMATE DESIGN
To evaluate and compare the cost effectiveness of a GSHP system, a typical house in moderate climate in Cyprus is considered. The characteristics of the

residential buildings in Cyprus were presented by Panayiotou et al. (2010), where using a sample of 500 residential buildings, the authors found that most of the houses are between 51–200m^2 and a primary energy between 51–150 kWh/m^2. For the design of a GSHP system, typical house loads are required. Usually plots are built as two houses semi-detached (Figure 1(a)), or as linked-detached houses with a short distance between them (Figure 1(b)). In both cases, the only available space for drilling boreholes and use a GSHP is a 3–4 m region at the edge of the plot. Rarely, houses are detached (Figure 1(c)) having enough land space free for drilling as many boreholes as needed.

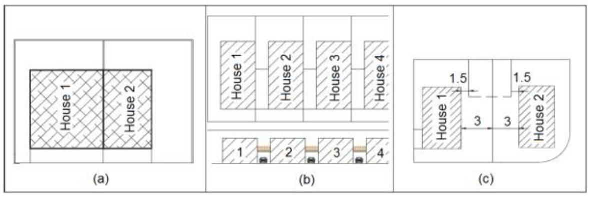

Figure 1: Typical positioning of houses in plots; (a) semi-detached, (b) linked detached, (c) detached

The selected typical house here is a 3-bedroom 2-storey house, with a total floor area of 190m², attached to another house, and with available land space of at least 4m on the other three sides. The house is made of reinforced concrete pillars and beams while the walls are made of red and sandy clay bricks. All parts of the house are thermally insulated with extruded polystyrene while double glazed aluminium framed windows are used. In a moderate climate (in the study case located at Lakatamia, Cyprus) the estimated heating/cooling loads of the typical house are shown in Table 1 (Pouloupatis et al., 2017). Peak cooling load is observed in July at 11.56kW, and peak heating load in February at 20.78kW.

Table 1: Heating/cooling loads of the typical house

Month	Cooling load (kWh)	Heating load (kWh)
January	0	2300
February	0	2450
March	0	600
April	150	0
May	500	0
June	1050	0
July	1600	0
August	1500	0
September	1000	0
October	300	0
November	0	600
December	0	1450
Total	6100	7400

3. GHE SUMMER AND WINTER MODELING

The thermal response of the GHE is examined for the maximum and the minimum load months of the year in Cyprus i.e. July and February. The equation governing the problem on convective and conductive heat transfer, under consideration here, is the following.

$$\rho c_p \frac{\partial T}{\partial t} + \rho_f c_{pf} u_{in} \cdot \nabla T + \rho_w c_{pw} u_w \cdot \nabla T + \nabla \cdot (-\lambda \nabla \mathrm{T}) = Q \quad (1)$$

where ρ is the density [kg m^{-3}], c_p the specific heat capacity [J kg^{-1} K^{-1}], t the time [s], T the temperature [K], u the velocity [m s^{-1}], λ the thermal conductivity [W m^{-1} K^{-1}], Q the power density of the heat source [W m^{-3}], while subscript f denotes fluid, w water, in inside tube and p porous media.

At the boundary between the fluid and the tubes the convective heat flux is $h\Delta T$, where h is the convective heat transfer coefficient of the process [W m^{-2} K^{-1}] and ΔT the temperature difference at the boundary. The convection heat transfer coefficient h is a function the hydraulic diameter and the Nusselt number (Stylianou et al. 2019).

A Computational Fluid Dynamics model, following the geometry of an experimental set up was developed and validated in the FlexPDE software for various input temperatures of the GHE circulating water, the reproduced model being validated. The Lakatamia GHE domain is illustrated in Figure 2.

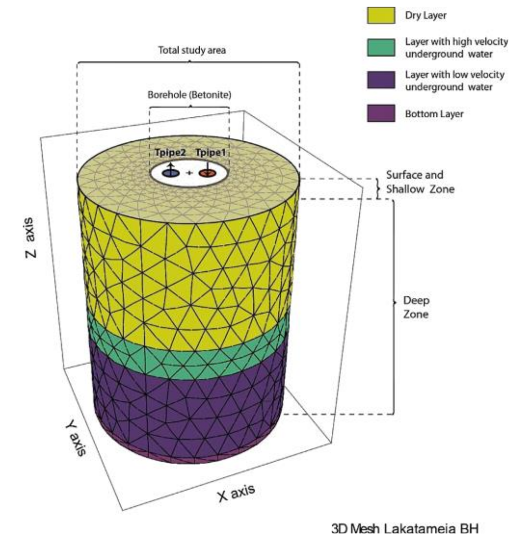

Figure 2: The FlexPDE computational model for the Lakatamia GHE. The dry well area is shown in yellow (80 m), high water velocity area is shown in green (25 m), low water velocity area is shown in blue (55 m), base area is shown in purple (5 m) (sketch not to scale) (Stylianou et al. 2019).

Calculated steady state values for summer for input temperature of 28°C, 35°C and 45°C showed that the greater the difference between the input water temperature and the ground temperature, the greater the rejected heat to the ground (Figure 3). Similarly, for winter operation with input temperature of 0°C, 9°C and 18°C showed that the greater the difference between the input water temperature and the ground temperature, the greater the absorbed heat from the ground.

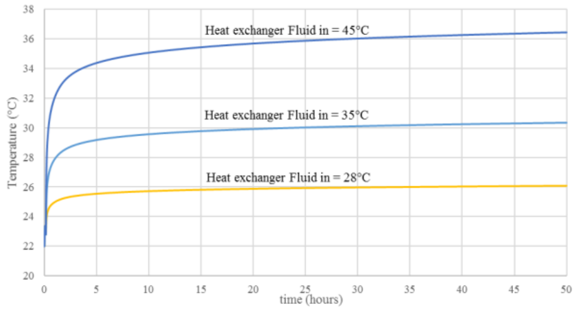

Figure 3: GHE exiting fluid temperature plotted against time for three cases of steady temperature fluid entering the GHE of 45, 35 and 28 °C (Stylianou et al. 2019).

The characteristics of such GHE/GSHP are given in Pouloupatis et al. (2017). The HP capacity over the input power is nearly doubled from a HP entering fluid temperature of 44°C to 20°C (cooling) (similarly for heating). This means that to achieve lower temperatures a bigger number of boreholes are needed and consequently the greater the initial cost will be. Therefore, the designer should consider the benefits of a greater HP efficiency against the disadvantage of greater initial cost.

4. GHE COST ANALYSIS

Robert and Gosselin demonstrated a good case of a techno-economic analysis of a GSHP system (Robert and Gosselin 2014). The total cost of any GSHP system consists of the initial capital invested and the operating costs, namely the sum of costs of the HP, mechanical room installation, drilling, piping, ground loop installation, fittings, etc., electricity consumption by the HP, the heat transfer fluid circulation pump and the backup heating/cooling system.

Hence, the difference in the cost between an ASHP and a GSHP system lays in the GHE and the associated equipment, such as the borehole extraction, U-tube GHE, grout material, ground loop installation, header-flowmeter valves, horizontal pipe circuits, and some general expenses (Christodoulides, Aresti and Florides 2019). Typical extra costs for the installation of a GHE of 400m, 600m and 800m are calculated at €12600, €18200 and €23800 respectively, based on information taken from companies based in Cyprus in 2018.

Note that, as stated by Rawlings and Sykulski, direct comparison between different countries or even regions cannot be done owing to economies of scale (Rawlings and Sykulski 1999).

Now, a specifically designed inverter technology ducted series ASHP of similar capacity, can have a ratio of Pump Capacity/Power Input of around 3.0 (cooling) and 3.7 (heating). An estimation for the electrical power needed to cover the total heating/cooling load per year is shown in Table 2.

Lu et al. discussed different methods used in the literature to examine the economic benefits of installing a GSHP system (Lu et al. 2017). It is though beyond the scope of the current study to go in detail into such methods, as the goal of comparing a single GSHP (of a vertical GHE) and a simple ASHP can be achieved through a simple methodology explained below with adequate precision.

The power savings per year for (a) the 800m GHE are 961 kWh, (b) the 600m GHE are 862 kWh and (c) the 400m GHE are 673 kWh. Considering the current price for house holdings of 0.19€/kWh would result to the following corresponding savings per year: (a) €183, (b) €164, and (c) €128. It turns out that, for all cases, the payback period would be well over 20 years.

The results show that the new specifically designed, inverter type ASHPs, have reached such a high stage of technology that can antagonize strongly GSHPs for residential use.

Table 2: Energy savings per year for the typical house

Season /GHE length /Ratio	Cooling/ Heating load (kWh)	Input electrical energy (kWh)	Savings vs ASHP (kWh)
ASHP summer /3.0	6100	2033	
ASHP winter /3.7	7400	2000	
GSHP summer /800m /4.9	6100	1245	788
GSHP summer /600m /4.7	6100	1298	735
GSHP summer /400m /4.4	6100	1386	647
GSHP winter /800m /4.05	7400	1827	173
GSHP winter /600m /3.95	7400	1873	127
GSHP winter /400m /3.75	7400	1973	27

5. CONCLUSION

The work presented here has pointed to novelty with its study of a typical house in Cyprus (moderate climate) with a GSHP system, through the analysis of its thermal response numerically. A typical residential building in Cyprus has been presented with heating/cooling loads in moderate Mediterranean climate conditions. The 3-bedroom house of 190m^2 has peak cooling/heating loads of 11.56 kW and 20.78 kW.

Moreover, the paper has offered a cost analysis of a GSHP system with different lengths as well as a cost comparison of GSHP systems with an ASHP system based on experimental data. It turned out that the payback period of using GSHP systems over ASHPs would be well over 20 years, making it not an economical solution in the specific case. This is due to comparable Pump Capacity/Power Input ratios between specifically designed inverted technology ducted series ASHPs and GSHPs.

Even using methods such as Present Worth, Annual Worth, Internal Rate of Return, External Rate of Return, Simple Payback Period, Discounted Payback Period would not alter dramatically the result (Lu et al., 2017), (Christodoulides, Aresti and Florides 2019).

Concluding, one could argue that GSHPs would be an economic and viable solution as alternatives to ASHPs if sufficiently subsidized as Renewable energy source by the State.

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