Environmental Impact of a Ground Source Heat Pump system of in a Mediterranean residential building – a Preliminary Assessment

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Renewable Energy Systems (RES) have gained high attention in recent years due to the constant "fight" against the use of fossil fuels. Ground Source Heat Pump (GSHP) systems (consisting of ground heat exchangers (GHEs) and HPs) exploit Geothermal Energy (a RES) and are used for space heating and cooling, exhibiting a superior performance than the conventional Air Source Heat Pump (ASHP) systems. This research focuses on the ecological aspect of GSHP systems, examining a case study in the Mediterranean island of Cyprus to determine the environmental impact of such systems when installed in high- and low-insulated residential buildings. At first, the GLD software is used to estimate the required GHEs' parameters for the high and low building's load. The Ecoinvent database in combination with the openLCA software is then used to perform the Life Cycle Analysis (LCA) of the system and calculate the environmental impact of both cases. The yearly heating and cooling loads of the building are used as a functional unit, with the system boundaries containing only the GHEs manufacturing and the operation of the system. An ASHP system is set as the baseline for both high and low insulations of a residential building. The GSHP system is compared to the baseline in percentage deviation. The LCA comparative results indicate that the GSHP system being a renewable energy solution, is also the most environmental-friendly solution.

Keywords: Environmental Impact, GSHP system, GHE, LCA

INTRODUCTION

Geothermal energy, being a renewable energy source, finds application with either electricity production or space heating and cooling, with the latter owing a high capacity in Europe [1]. A Ground Source Heap Pump (GSHP) system, which is also a Renewable Energy System (RES), exchanges heat with the ground, and either extracts or rejects heat with the use Ground Heat Exchangers (GHEs). GHEs are a network of tubes connected with the GSHP and buried in the ground, and come in different types. The systems are classified as open- and closed-loop or of vertical (U-tube, coaxial, spiral, etc.) and horizontal type. The design and configuration of the GHEs for each system depends mainly on the building's heating and cooling load, the available space and the ground thermal characteristics. A discussion on the different design aspects and modelling approaches of GHEs can be found extensively in the literature [2-3].

The use of geothermal energy and GSHP systems has been evaluated to be an environmentally friendly alternative in cases where high heating and cooling loads are observed [4]. In this paper a case study is examined, where high and low insulated residential building cases are introduced. For the insulated cases, the loads are estimated and an environmental assessment is presented and compared to conventional Air Sour HP (ASHP) systems.

METHODOLOGY

In order to examine the environmental impact of a GSHP system, a case study of a residential building in the Mediterranean island of Cyprus is considered. The selected building has a flat roof and an area of 220 m^2, loess that the average single detached house area of 260 m^2 observed in Cyprus [5]. The technical characteristics of the investigated building are varied to study high- and low-insulated cases. For the high insulated case, the characteristics determined by the nearly zero energy building (nZEB) EU derivative [5-6] are met.

The estimation of the required length / depth of GHE types is performed based on the building's heating and cooling loads and peak loads. The yearly heating and cooling loads for the low-insulated case were estimated at 2150 and 21630 kWh respectively, and for the high-insulated case at 530 and 5400 kWh respectively. The heating and cooling peaks were estimated at 8.97 and 11.10 kW for the low-insulated case, and 2.99 and 7.22 kW for the high-insulated case respectively.

For residential applications and in an urban dense area, the vertical type GHEs are more approprtiate due to the less land area required. Although the vertical types are a more appropriate selection, they come at a higher cost due to the required specific machinery for the installation and extra materials required for the grout.

The environmental impact of products / processes is assessed with the use of Life Cycle Analysis (LCA). OpenLCA is selected as the tool to perform the LCA; it is a free software but requires external database and methods to be imported. The Ecoinvent 3.6 database and its methods was selected to be used.

The main objective of this study is to evaluate whether the use of the GSHP system has an environmental benefit over the use of an ASHP system. To simplify the study, only the parts where the two systems, namely the GSHP and ASHP, differ were taken into account for the included system boundaries. The HPs were assumed to have the same materials and processes used and were neglected from the examined system. The functional unit (FU) was therefore set as “a unit to satisfy the residential building’s yearly heating and cooling demand”. The Life Cycle Inventory (LCI) was set with the same materials and processes as proposed in [4], but with amounts to satisfy the examined case. The widely used CML2001 method was considered for the LCI Assessment (LCIA) and the Climate Change or Global Warming potential (GWP) (in kg CO2-Eq) was selected as the impact category to estimate.

RESULTS AND DISCUSSION

The building’s characteristics and loads were incorporated in the GLD software and the pipe length of the different GHEs was estimated (see Table 1). The coaxial configuration required the shallowest borehole (shortest pipe) and the double U-tube the longest pipe for any insulation. The COP for all GSHP types was estimated at 5.1 and 4.4 for heating and cooling respectively, while the ASHP manufacturer’s COPs were 3.0 and 3.3 respectively.

Table 1 GHEs characteristics as obtained by GLD software

GHE type	**Borehole length (pipe length), m**	
	High insulation	**Low insulation**
Single U-tube	152.4	203.9
Double U-tube	132.5 (265)	174.8 (349.6)
Coaxial	131.9	172.8

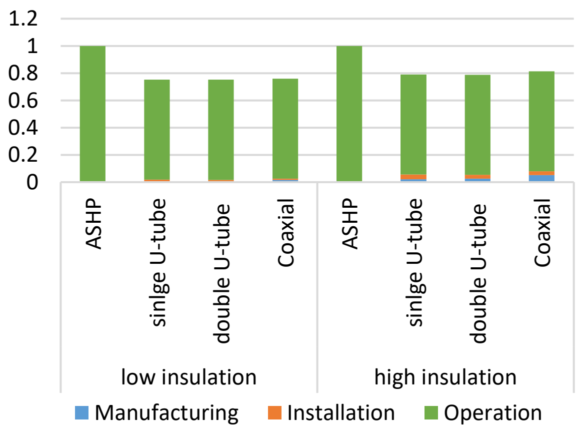

Figure 1 LCIA estimations per FU using the CML2001 method for the GWP 20a category.

The results obtained in the GLD software, were incorporated into the openLCA software to estimate the LCIA of the GSHP systems compared to the ASHP system. The LCIA results are presented in Figure 1 as percentages, where ASHP system is used as baseline (100% = 1). It is evident that in both cases, with the use of high and low insulation, all GSHP systems outperform the ASHP systems.

CONCLUSIONS

In this study, a preliminary environmental assessment of GSHP systems in a residential building with either high or low insulation, compared to a conventional ASHP system was performed. The GWP impact category was investigated with three vertical types of GHE, which outperform the ASHP system in both cases. Although these results are favourable for the GSHP systems, a cost comparison and a more detailed environmental assessment should be performed in the future to estimate the overall performance of both systems in every aspect.

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