An investigation on the environmental impact of GSHP systems

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Rationale and Summary

Geothermal energy, a renewable energy source, is categorized into shallow and deep applications. Shallow geothermal energy, through the use of Ground Source Heat Pumps (GSHPs) is used for space heating and cooling, where the Ground Heat Exchangers (GHEs), are used to extract or reject heat to the ground. GHE is eventually a network of pipes, with various configurations, placed either vertically or horizontally in a medium. Due to the high initial cost and long payback periods of the GSHP systems, solutions have been introduced by the scientific community. Such systems include the Thermo-Active Structures (TAS) or Energy Geo-Structures (EGS), with applications such as energy piles, diaphragm walls, shallow foundations, retaining walls, and tunnel linings.
Compared to Air Source Heat Pumps (ASHPs), GSHPs achieve a better coefficient of performance (COP) resulting in savings on the consumer electricity bill. This reduction in consumed energy can be translated to less primary energy used, hence a reduction in fossil fuels used and specific environmental "harmful" gas emissions. However, it is not all black and white, and the environmental impact does not lie only on one aspect. Based on literature, such effects are presented in this study. Furthermore, a discussion on the comparison among different types of ASHPs and of GSHPs is performed.

Introduction

❖ The GSHPs, compared to ASHPs, exhibit significantly higher performance, but with greater initial cost.

❖ The design and configuration of the GHEs depends mainly on the available space, the building's heating and cooling loads, and the geomorphological characteristics of the location.

❖ GHEs are characterized by their type, namely horizontal and vertical types. Horizontal GHEs consist of single tube, overlapping slinky loops and vertical spiral loops. Vertical GHEs consist of single or double U-tube, W U-tube, spiral tube and coaxial [1].

❖ Boreholes can consist of the following materials [1]: concrete, bentonite and sand addictive, High Density Polyethylene (HDPE) for the pipes, with steel and copper pipes being used in some cases.

Life Cycle Assessment (LCA)

LCA investigates the potential environmental impact by evaluating input and output materials and processes for a single or multiple products, processes and services. LCA is achieved by covering the extraction and processing of the raw materials, the manufacturing process, transportation and distribution, product usage, and finally recycling and disposal, though the life time of a product. The General LCA flow can be seen in Figure1. The environmental LCA principles and frameworks, and, requirements and guidelines, are described by ISO 14040 (2006) and ISO 14044 (2006) respectively.

Figure 1. LCA General Flow [from the web]

LCA design requires knowledge of the raw materials quantity and processes used in order to accurately estimate the LCA of a specific product. This information can be either extracted from a manufacturing plant or from literature.

GHP Economic Note

Several studies indicate that GSHPs are not an obvious profitable economic alternative compared to other solutions. However, other studies suggest that a small payback period results for GSHP systems, giving them an economic advantage. The discrepancies in such estimations is based on the parameters and factors present for each specific case.

GSHP LCA investigation

The difference on the use of PE and steel pipes has been investigated by Chen et al [3]. The authors have noted a 44.9% reduction of CO_2 for the life cycle of the steel pipes and a CO_2 reduction ration of 0.45 against the PE pipes. The CO_2 payback time in a borehole with bentonite and PE pies has been reported by Genchi et al. [4] to be at 1.7 years, with a 54% CO_2 emissions reduction. Comparisons between ASHPs, GSHPs, Water Source Heat Pumps (WSHPs) and gas boilers has been performed by Greening and Azapagic [5]. Results are shown in Figure 2, where by comparing only the heat pumps, the worst impact is provided by the ASHP, with the GSHP and the WSHP performing better on all categories. Additionally, the WSHP performs slightly better, with a negligibly effect, due to the minimum required excavation requirements, as compared to the other GSHPs. Horizontal GHEs, on the other hand, require longer pipes and higher quantities of antifreeze, hence providing a slightly higher impact compared to vertical. CO_2 savings of GSHPs during operation for a region have been investigated by Blum et al. [6]. The authors have demonstrated that the use of a GSHP system, with a German electricity mix, have a CO2 saving ranging from 1800 to 4000 kg per year and 65 gCO2/kWh. Different results have been demonstrated by Koroneos and Nanaki [7], where the highest emissions were observed in the raw materials production. The reviewed results indicate that the raw material production cover the 79%, 81% and 45% for CO_2, SO_2 and NO_x emissions respectively. One can observe on the reviewed results, indicated in table 1 [6], that the acidification effect has the largest contribution to the total environmental impact score.

Table 1. Quantitative effect of emissions released to the environment during the GSHP system life span

Impact category	Normalization factors	Valuation factors	Total emissions	Total assessment (%)
Greenhouse effect	0.5039	2.5	1.26	14.54
Ozone depletion	0.0020	100	0.207	2.39
Acidification	0.6368	10	6.368	73.49
Eutrophication	0.1556	5	0.778	8.98
Carcinogenity	0.00011	10	0.001	0.011
Heavy metals	0	5	0	0
Winter smog	0.01016	5	0.051	0.59

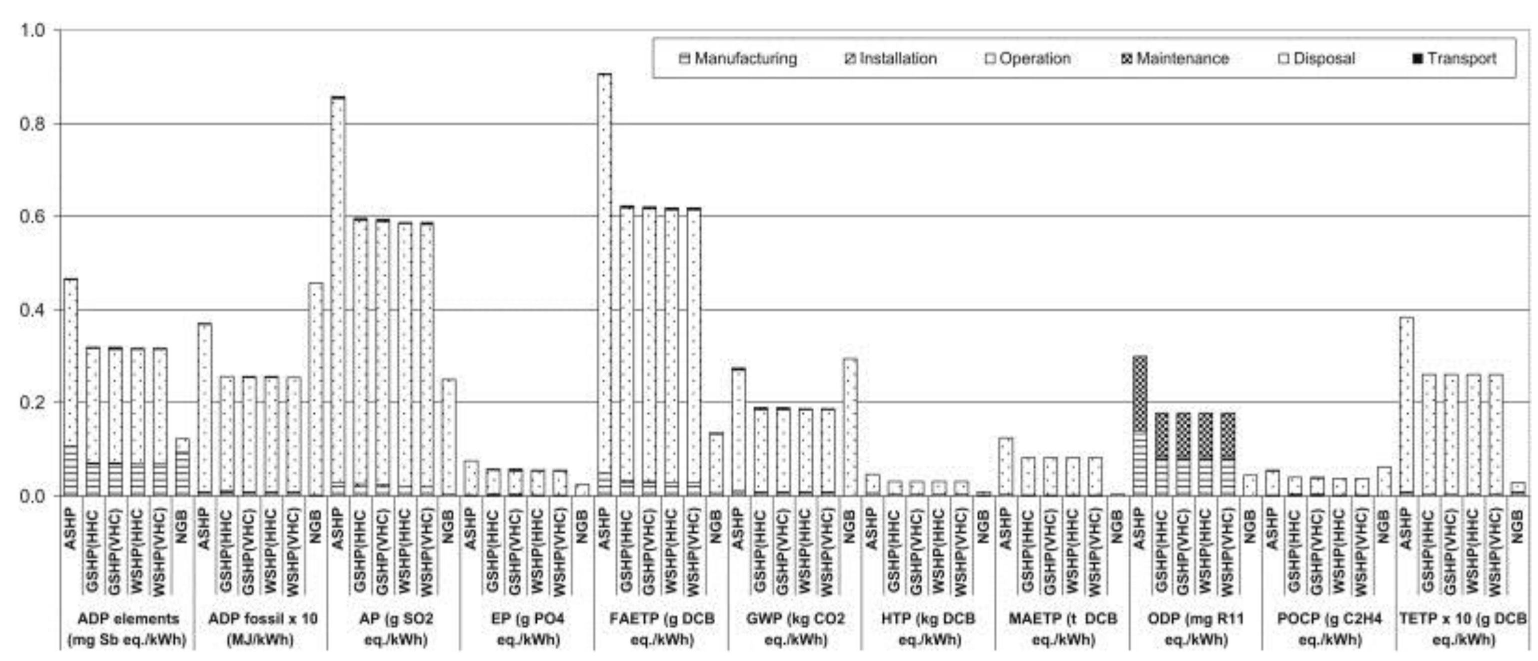

Figure 2 . Life cycle environmental impacts of heat pumps and gas boiler [5]

Conclusions

❖ Several authors in the literature have used Life Cycle Analysis to evaluate the environmental impact of GHSP systems.

❖ Comparison between the GSHPs and the ASHPs based on the review of existing studies show that the GSHP system is a more environmentally friendly solution than an ASHP system.

❖ Also, depending on the electricity production processes, the GSHP environmental impact could be higher on the operation level and/or on raw materials.

❖ Finally, one should also consider the cost benefits and drawbacks of GSHPs with accordance to the environmental benefits.

Selected References

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