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Economic analysis of vertical ground source heat pump systems in Melbourne

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ABSTRACT

This study assesses some economic indicators for residential vertical Ground Source Heat Pump (GSHP) systems in Melbourne, Australia. Publicly available data on the performance and costs associated with such systems is rare. To redress this issue, detailed cost breakdowns are reported herein based on actual installation costs. The average upper bound capital cost is found to be around AUD 31,000, with lower costs possible depending on many factors, particularly when considering the early stage of development of the GSHP industry in Australia. Using the gathered cost data as well as other performance data such as recorded average coefficients of performance of 3.8 and 3.6 for heating and cooling respectively, several economic indicators are used to evaluate alternative heating/cooling systems. The analyses found that for a design life of 20 years, an Air Source Heat Pump (ASHP) system is marginally more financially attractive than a GSHP system; however, for a design life of 40 years, GSHP system provide considerably more savings than other alternatives including ASHP systems. The relatively low rate of return for GSHP systems over the first 20 years is due to current high capital costs as well as the mild weather conditions in Melbourne. Climate change was also factored into the economic analyses, with only minor effects observed. Finally, a scenario with government incentives was found to make GSHP systems much more financially attractive, a tax credit on capital cost of as low as 8% was found as such threshold for a design life of 20 years.

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1. Introduction

Climate change and the need to protect the environment have given rise to renewable energy targets which drive the development of renewable energy technologies worldwide. Future fossil fuel shortages and the need for energy independence are also important factors. For Australia, with a target to reduce greenhouse gas emissions by at least 26% below the 2005 level by 2030 [1], it would be beneficial not only to produce 'greener' energy, but also to reduce energy consumption through the use of energy efficient technologies such as Ground Source Heat Pump (GSHP) technology. Considering that heating and cooling systems make up the majority of the energy consumed by commercial and residential buildings [2], a more efficient technology than currently exists would be highly desirable. A GSHP system represents one such technology.

GSHP systems, also known as ground coupled heat pump systems or shallow geothermal energy systems, have attracted considerable attention and have quickly expanded across the world, mostly in Northern Europe, the United States and China [3,4]. Advantages of using GSHP systems, when compared to other conventional heating/cooling systems, include a) a higher level of comfort, b) a lower running cost and c) less impact on the environment. However in Australia, the residential GSHP market is still quite new and the heating, cooling and ventilation (HVAC) market is still dominated by conventional methods, such as reversible air-source heat pumps, natural gas heating and electric heating. Most of GSHP systems installed are for commercial buildings or for primary or tourism industries, for instance fishing farms and hot spring resorts.

Due to the lack of publicly available *measured* system performance and costs data around the world, and in particular in Australia, it is difficult to assess with confidence the suitability of utilising shallow geothermal energy technology in the country. As a result, in early 2012, a shallow geothermal energy research and demonstration project under The Sustainable Energy Pilot Demonstration (SEPD) program, funded by the state government of

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Victoria, was initiated by The University of Melbourne. The main objectives of this project are a) to encourage the installation of GSHP systems, b) to study the feasibility of GSHP systems under Melbourne and Victorian ground and weather conditions and c) to stimulate the establishment of the shallow geothermal industry in Victoria. The installation work was outsourced to local contractors while the university is responsible for managing the project, monitoring, collecting and analysing the data from the installation phase through to the operation phase. Many of the properties in the project are typical residential properties of 130–160 m^2 with 2–3 bedrooms, which were selected for installation of vertical GSHP systems as less expensive horizontal systems were not an option due to land space limitations. These properties are estimated to have an average annual peak heating/cooling demand of 8–10 kW. The project started in 2012 and is still ongoing [5,6]. The data generated under this project provides a rich basis for further technical, economic and environmental analyses and system optimisation studies.

There exist a limited number of publications about the economic feasibility of GSHP systems, and even though these publications arise from countries where the GSHP industry is active; they show some limitations such as outdated and/or assumed costs, lack of representativeness, and limited actual recording of capital and running costs and operational efficiencies (see Section 3 for further details).

This paper presents an analysis of the performance of several GSHP systems within the SEPD program and compares the cost of these GSHP systems against other conventional heating/cooling methods using several economic indicators. The article aims to identify the most economical way for satisfying residential heating and cooling needs as well as to quantify the cost associated with a typical residential GSHP system in the Australian context. In addition to this, since a residential HVAC system is considered as a long-term investment, the effect of climate change as well as possible government incentives are briefly discussed to better inform decision makers. Unless otherwise specified, costs are shown in Australian Dollars throughout the article.

2. Description of GSHP systems

A schematic view of a vertical GSHP system is shown in Fig. 1. A vertical GSHP system mainly consists of three components: a) a heat pump, b) a ground heat exchanger (typically less than 100 m deep) and c) a building distribution system. The detailed functionality of these three components has been covered in detail in various past publications [7,8]. The thermal energy of the ground is passed to the circulating liquid within the ground heat exchanger; this energy is then extracted and raised by the heat pump to be delivered to the building via a distribution system, such as fan coil units. The system is reversed in summer, rejecting heat to the ground to cool the building down.

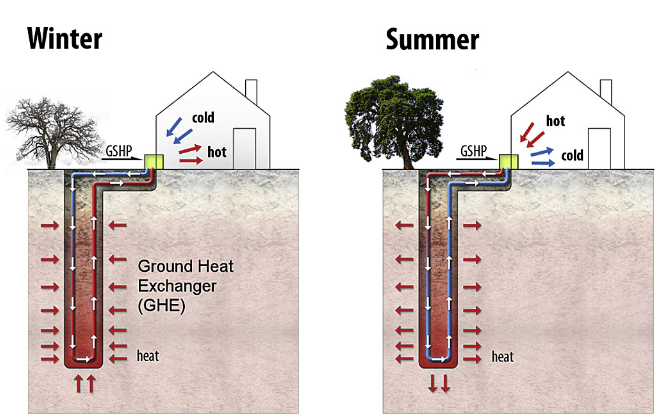

Fig. 1. Schematic diagram of a GSHP system [5].

The performance of a heating/cooling system is typically evaluated in terms of the coefficient of performance (COP). This is the ratio of energy output to energy input (i.e. electricity). As the heat pump is able to transfer more thermal energy than the input electrical energy, the COP for a heat pump should be greater than one. The COP of a GSHP system depends on a number of factors including flow rate, ground thermal properties, local climate [9], but is typically in the range of 3–5 [4,8,10].

The GSHP systems installed within the SEPD program cover a range of different conditions, such as geology and climate, encountered in the state of Victoria. The typical residential heating and cooling requirement in Melbourne is 1270 degree days of heating and 530 degree days of cooling [5,6].

3. Previous studies addressing costs

Over the past twenty or so years, there has been an increasing number of articles published which report on the costs of GSHP systems and which compare this with other renewable and conventional systems. In this section, we review the literature and discuss the economic feasibility of GSHP systems.

In 1995, Kavanaugh et al. [11] reported the detailed cost breakdown for over 250 GSHP systems which had been collected using a mailed survey. The study found that the average capital cost of a vertical GSHP system in the US is US$8,997. This finding provided a basis for several cost comparisons by other researchers; for example, the German economic feasibility study by Badescu in 2006 [12] and the cost comparison between GSHP and other heating options in Canada by Self et al., in 2012 [9]. In these articles, COP values of 3.5 and 4, respectively, were *assumed* to compute the ongoing cost and the present worth (PW) method was chosen to analyse the economic feasibility of GSHP systems. Both studies found that the GSHP configuration was the best economic solution under a design life of 25 and 20 years respectively.

One study in South Africa found that vertical GSHP systems are marginally cheaper than their air-source counterparts [13]. This analysis was based on an *assumed* capital cost of a GSHP system and used a constant COP to compute the ongoing electricity cost. Inflation in electricity prices was not considered. The economic method used included internal rate of return (IRR), PW and simple payback period (SPP).

Several studies in Turkey obtained similar findings [7,14,15]. For example, Esen et al. [15] used the data from a test room (with thermal loadings of 30.6 kWh for heating and 37.2 kWh for cooling) within Firat University in Turkey, to conduct the feasibility analysis. The economic method used is the SPP with 4% annual increase in fuel price. It was reported that the GSHP system is more financially attractive than an Air Source Heat Pump (ASHP) system.

More recent literature by Shi et al. [16] for China and by Nguyen et al. [17] for the Canadian city of Toronto has also indicated similar conclusions. Both articles use SPP as the economic method with *assumed* capital cost and COP values.

These publications about the economic feasibility of GSHP systems cover most countries where the GSHP industry is active. However they all include one or more of the following limitations:

- Most articles use an *assumed* capital cost which may differ significantly from the actual cost. Some literature refers to the cost break down of GSHP systems conducted around two decades ago, which may be outdated. Other articles gather real, current cost data but only focus on one particular GSHP

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