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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.



## 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 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

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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.

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].

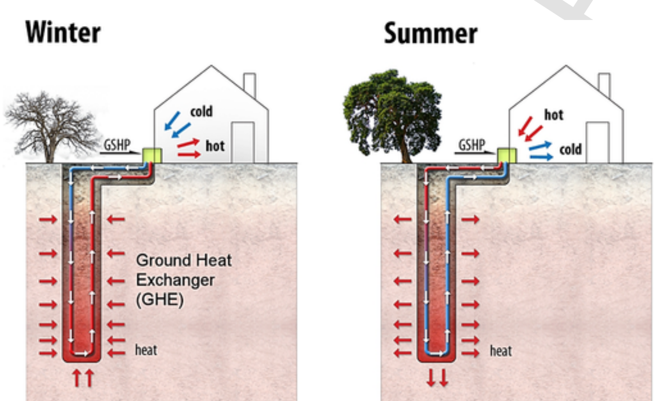



**Fig. 1.** Schematic diagram of a GSHP system [5].

## 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 installation and cannot therefore be said to be representative. To the best of the authors' knowledge the only recent literature which provides a comprehensive cost breakdown of GSHP systems was conducted by Blum et al., in 2010 [18]. These researchers gathered costs from over 1,100 individual GSHP systems installed in Germany. However, there is no further cost analysis provided by the research. For Australia no such cost data was available.
- Most studies use *assumed* or simulated annual thermal loading to compute the ongoing cost. As many studies have already pointed out, including this work (section 4.2), these design values could deviate quite significantly from the true thermal loading [19–21]. Therefore, ongoing costs based on estimated design load need to be treated carefully. Other studies use the experimental thermal loading data from either a single house/building or from a test facility, which may not represent general residential heating and cooling re-

quirements as thermal loading may differ from building to building depending on the users' behaviours and as well as the building insulation. Obviously a broader set of observations from several properties/buildings would be desirable but this is not available in the literature, especially for Australia.
- Most of the literature uses an *assumed* value of COP, typically between 3 and 4, to compute the electricity consumption and thus to calculate the ongoing electricity cost. The drawbacks of this approach include the following. First, the heating COP is typically different from the cooling COP and therefore should not be assigned the same value. As the COP affects the ongoing energy cost, which will significantly influence the life cycle cost [22], therefore a representative COP should be used for economic analyses. Such COP values should reflect both the user pattern and local climate conditions. Second, a COP value over 3 is not easily achieved and maintained [23]. Common design mistakes, such as improper ground loop design or under- or over-estimated thermal loading, can lead to sub-optimal system performance and thus reduce the COP during the lifespan of the GSHP system [23].
- Most economic feasibility studies conducted for GSHP systems use one of a small number of simple economic methods such as IRR, PW or SPP. More advanced methods such as external rate of return (ERR), annual worth (AW) and discounted payback period (DPP) are rarely used. The advantage of using more advanced economic methods will be discussed later in the methodology section.
- Inflation of the fuel/electricity is either ignored or simply *assumed* based on Consumer Price Index (CPI), which may mislead final conclusions. It should be noted that, in Australia, the compound price inflation from 2000 to 2015 is 6.20% for electricity and 6.14% for gas, while the general CPI value is merely 2.58% over the same period [24].
- To comprehensively examine the feasibility of investing in a long term heating/cooling system, the effect of climate change should be considered. The effects of climate change are location specific. For example, simulations for UK and New Zealand have indicated a mean air temperature rise would lead to energy saving and emission reduction [25,26] mainly due to the reduction of the heating demand. For Melbourne, where winter is cold while summer is moderate with a few peak hot days, it is expected that under the medium greenhouse gas emission scenario for an existing 5 star house, there will be a reduction of heating demand by 36% and an increase of cooling demand by 90% by 2050 [27]. These figures translate into an overall reduction in combined heating and cooling energy demand of the order of 16%, given the heating dominant situation that prevails for residential properties in Melbourne and surroundings. This reduction would be beneficial; however property owners in Melbourne may need to invest extra on cooling systems, given that cooling demand will double in 35 years (by 2050).

This article aims to redress some of these shortcomings as well as to provide some information for Australia, recognizing that the GSHP market in the country is still in the emerging stage.

## 4. Economic analysis: methodology and measured input data

As in other countries where GSHP industry is not mature, the biggest obstacle facing Australia's GSHP industry is customers' uncertainty concerning the economic benefits and the technology itself. In financial terms, the lack of imminent financial benefits and the relatively high capital cost are the key factors that make many homeowners wary of installing a GSHP system. As Sullivan et al. [28] pointed out, "the alternative that requires the minimum investment of capital and produces satisfactory functional results will be chosen unless the incremental capital associated with an alternative having a larger investment can be justified with respect to its incremental benefits". The aim of this section is to use a number of economic methods to assess the benefits of installing a GSHP system and thus whether the incremental capital cost of a GSHP system when compared to other options can be justified.

A number of economic methods including IRR, PW, and SPP have been used extensively in the literature [9,12–15]. In this paper these, as well as ERR, DPP and AW are also to be used to examine the economic performance of GSHP systems. Brief descriptions of all of the methods used herein are summarised in Table 1.

As discussed earlier, most of the limitations on the current economic analyses of GSHP systems result from the lack of up-to-date and representative data. Fortunately, the GSHP systems project under the SEPD program provides such information in the context of Australia, which will be presented in the following sub sections.

For data presentation and subsequent calculations, a deterministic cost analysis is used instead of a probabilistic approach such as a Monte Carlo simulation. The primary reason for this is that the cost database collected is still not large enough to create an objective probability distribution curve, while the creation of a subjective probability distribution curve typically involves a number of assumptions. In one related study, Zhu et al. examined the uncertainties associated with different cost components of a GSHP system using a Monte Carlo simulation program called "@Risk" [22]. In their research both objective and subjective probability distribution curve were created based on available historical data. It was concluded that probabilistic methods may produce the same conclusion to that derived by using a deterministic method and that, while the levels of sensitivities may change, the ranking does not. For the purpose of this study, the absolute level of sensitivity is not critical. Therefore, a conventional deterministic cost analysis was used throughout the study.

### *4.1. GSHP systems: documented capital cost*

Throughout the project carried out under the SEPD program, most of the documents relating to cost were retained and archived and this served as a basis for the studies in this paper. All of the cost data in this study include a Goods and Service Tax (GST) of 10%. Note that since most of the GSHP installations were coordinated by the university, and this is not its primary business, the normal economies of an established GSHP installer company are not realised, and thus leading to a higher cost that one would normally expect from a continuous commercial operation. Nevertheless, given the lack of publicly available data for the Australian market, the authors report these costs herein, perhaps as an upper bound capital cost.

The drilling and installation of the ground loop is the highest cost component of the system [11]. The average cost of drilling found in this study is $130.45 per metre (with standard deviation of only $4.45 per metre, considering nine properties[1]). Note that most of the drilling is to depths of 40 m–60 m, which contributes to a more consistent pricing (i.e. low standard deviation) among competing contractors. Out of the $130.45 per metre for drilling, an average of $60.50 was for drilling alone, $20.34 was for grouting, $17.72 was for ground loops and $31.89 was for labour (geothermal loop installation). Within the project funded by the SEPD program, the drilling works were carried out by different sub-contractors located both in Melbourne and Sydney.

[1] Of the 20 properties under the SEPD program, only 9 of which have detailed cost breakdown for drilling vertical boreholes are included.

**Table 1**
Economic methods used to evaluate engineering projects [28].

| | Brief Description | Key equation | Disadvantage |
|---|---|---|---|
| PW (Present Worth) | Calculates the equivalent worth of all cash flows relative to starting point. When PW > 0 the project is feasible. | $PW(i\%) = F_0(1+i)^0 + F_1(1+i)^{-1} + \ldots + F_N(1+i)^{-N} = \sum_{k=0}^{N} F_k(1+i)^{-k}$ | Future cash flow assumed to be reinvested at a rate of MARR.[a] |
| AW (Annual Worth) | Annual equivalent savings minus annual equivalent capital recovery amount. When AW > 0 the project is feasible. | $AW(i\%) = R - E - CR(i\%)CR(i\%) = I\,(A/P, i\%, N) - S\,(A/F, i\%, N)$ | Future cash flow assumed to be reinvested at a rate of MARR.[a] |
| IRR (Internal Rate of Return) | Most widely used. It is the interest rate when the equivalent worth of cash inflows equates to the equivalent worth of cash outflow. When IRR > MARR,[a] the project is feasible. | $IRR = i'\% \sum_{k=0}^{N} R_k\left(P/F, i'\%, k\right) = \sum_{k=0}^{N} E_k\left(P/F, i'\%, k\right)$ | Future cash flow assumed to be reinvested at a rate of IRR. |
| ERR (External Rate of Return) | Similar to IRR, but address the issue of reinvestment rate. When ERR > MARR[a] the project is feasible. | $ERR = i''\% \sum_{k=0}^{N} E_k\,(P/F, \varepsilon\%, k)\left(F/P, i''\%, N\right) = \sum_{k=0}^{N} R_k\,(F/P, \varepsilon\%, N-k)$ | |
| SPP (Simple Payback Period) | Calculate the number of years required for cash inflows to just equal cash outflows. | $Simple\ Payback\ Period = \theta$, such that $\sum_{k=1}^{\theta}\left(R_k - E_k\right) - I \geq 0$ | Does not consider the time value of money; does not indicate project desirability; results may be misleading. |
| DPP (Discounted Payback Period) | Similar to Simple Payback Period, except it considers the time value of money. | $Discounted\ Payback\ Period = \theta'$, such that $\sum_{k=1}^{\theta'}\left(R_k - E_k\right)(P/F, i\%, k) - I \geq 0$ | Does not indicate project desirability; results may be misleading. |

Variables: $i$ = effective interest rate or MARR per compounding period (e.g. monthly or yearly), $k$ = index for each study period, $F_k$ = future cash flow at the end of period $k$, $N$ = number of study periods, $R$ = annual equivalent saving of a project, $E$ = annual equivalent expense, $CR$ = annual equivalent capital recovery amount, $I$ = initial investment, $I\,(A/P, i\%, N)$ = annual $(A)$ initial investment given the present value $(P)$ at interest rate $i\%$ per study period for $N$ study periods, $S$ = salvage (market) value at the end of study period, $S\,(A/F, i\%, N)$ = annual $(A)$ salvage value given the future value $(F)$ at interest rate $i\%$ per study period for $N$ study periods, $R_k$ = net revenue or savings for the $k$ th year, $E_k$ = net expenditure for the $k$ th year, $i'\%$ = internal rate of return, $\varepsilon\%$ = external reinvestment rate (usually the MARR), $i''\%$ = external rate of return, $I$ = capital investment made at the present time $(k = 0)$.

[a] MARR refers to Minimum Attractive Rate of Return. For non-business purpose, MARR is typically treated as equal to the interest rate of a saving account. For business purpose, MARR is normally set by the top management to reflect the minimum rate of return required for the company's operation.

The second highest cost component is the heat pump with an average cost of $6,580.75 for a capacity of 8 kW. Most of the heat pumps installed were manufactured in the US and shipped to Australia. Because the Australian geothermal market is comparatively small in relation to those in the US or Europe, not many heat pump companies are interested at this point in time in developing an industry locally. As a result the price for the heat pumps is quite high and the choices are limited. In addition, getting a GSHP from the US typically requires 12–16 weeks lead time for manufacturing and shipping to Australia. This could potentially cause delays in project completion.

Other cost components are relatively small: the average cost of installing header pipes which includes digging trenches and connecting ground loops to the header pipes is $3,590.54 per site; the average cost of mechanical room installation, which includes the installation of the circulation pump, expansion tank and the connection of the header pipes to the heat pump unit, is $3,103.61; the average cost of fittings, which includes the installation of the connectors, is $2,112.16. The cost for fittings is quite significant; this is mainly due to the fact that all the fittings are electrofused to the pipes. Electrofused fittings are more expensive than the conventional method of using compression or push fit fitting. However, they are more robust and less likely to leak under pressurized conditions.

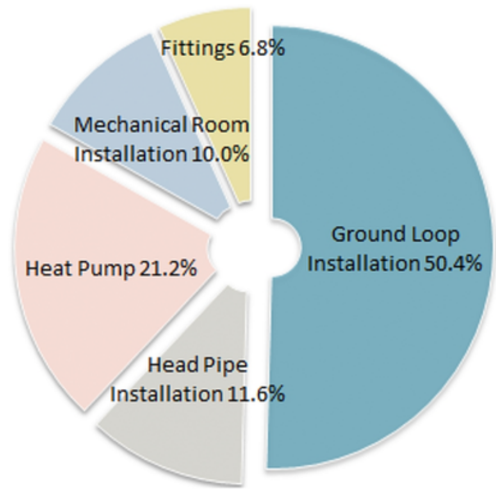
Based on the documented cost data, the average upper bound capital cost of installing a GSHP system (excluding distribution system) in a typical residential property in Melbourne is about $31,000. The cost breakdown for the GSHP system is summarised in Table 2, and the corresponding data is shown in Ref. [29].

### *4.2. GSHP systems: documented thermal loading*

Most of the 20 residential properties under the SEPD program have finished construction, so the capital cost data is quite compre-

**Table 2**
Cost breakdown of a GSHP system.

| | Cost ($) | Variation ($) |
|---|---|---|
| Ground loop installation | 15,654 | 534 |
| Head pipe installation | 3,591 | 100 |
| Heat pump | 6,581 | 407 |
| Mechanical room installation | 3,104 | 294 |
| Fittings | 2,112 | 171 |
| Total | 31,041 | 1,506 |




hensive and accurate. Of these 20 properties, three were selected to study the thermal loading conditions in Melbourne. This would allow a more realistic understanding of the anticipated or assumed household heating/cooling demand, and the result will be used during the economic analysis for computing the ongoing operational cost. The reasons for not using all of the properties in the analysis are: a) most properties have just got GSHP systems installed and the operation period is quite short (less than a year) at the time of writing this article b) some properties use the GSHP system for heating a swimming pool or for hot water supply and therefore are not representative for space heating/cooling and c) heating/cooling patterns are quite user dependent and some units were simply not operating that often and were therefore not suitable for analysis due to the limited usage data available.

During the design phase, the energy loading was determined using the Bin Method. The Bin Method is recommended by the IGSHPA (International Ground Source Heat Pump Association) for residential buildings. In order to use the Bin Method, a load profile needs to be established. This is determined by both the peak loading at the design temperature and the balance point temperature. For heating, a balancing temperature of 16.7 °C is used, which means no heating would be required if the ambient air temperature is above 16.7 °C. For cooling, a balancing temperature of 19.4 °C is used. The data collected from the properties confirms the validity of the balancing point temperatures. As shown in Fig. 2, over 98% of heating occurs when the ambient temperature falls below 16.7 °C. A similar observation was made during cooling, where over 97% of cooling occurs when the air temperature rises above 19.4 °C (see data in Ref. [29]).

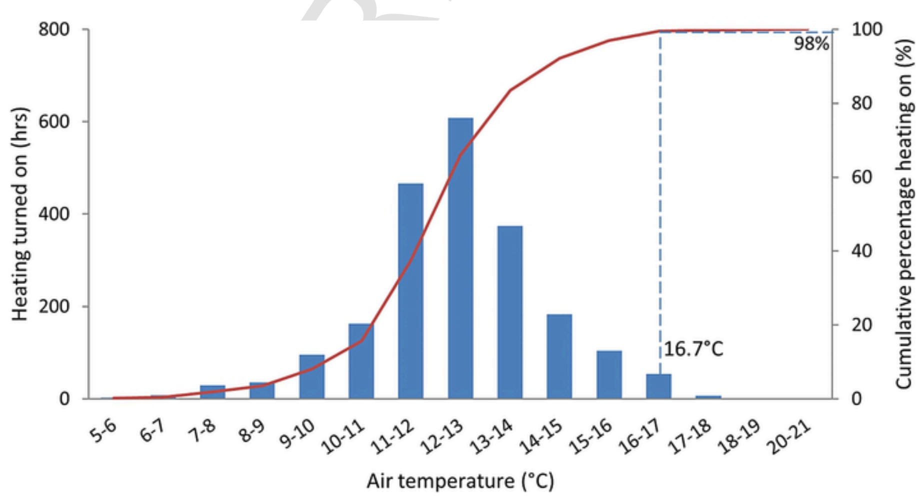



**Fig. 2.** Number of hours when heating is turned on among different temperature ranges and its cumulative percentage (Note: The low number of hours when heating is on during extremely cold weather, such as 5–6 °C, is because of the rare occurrence of such temperatures in Melbourne).

The recorded thermal loading data from the three selected properties are presented in Fig. 3, where data can be found in Ref. [29]. The peak design load is highly user dependent. As shown in the figure, similar properties can have quite different loading patterns. It should be noted that 2015 was a mild year and all the recorded temperatures for heating were above 5 °C and therefore the peak design heating load of 8 kW at an ambient temperature of 2.1 °C was not reached. However, extrapolation of the actual usage trend suggests that at 2.1 °C the load of 8 kW would be achieved and so the design value could be considered as valid. The peak design cooling load of 10 kW at a temperature of 35.7 °C was over-estimated. Especially for the second property presented in Fig. 3, the peak cooling load seems well over-designed (at least for the monitored period). Because of the diminishing marginal rate of return, oversizing the design load carries a high capital cost penalty for minor savings in operating costs.

The dashed line in Fig. 3 represents the estimated loading profile during the design stage. Overall the thermal loading observed via the collected data is fairly consistent with the design value. However the data suggests that the design cooling load is slightly over-estimated and that the peak cooling design temperature of 35.7 °C was not high enough. A more accurate value would be 40 °C and at this temperature the load would be around 8 kW and not the design value of 10 kW. Again, loading patterns were highly user dependent; interpretations offered here only apply for general residential properties in Melbourne.

Using the Bin Method, the estimated annual heating and cooling loads for a residential property resulted in 16,296 kWh and 3,696 kWh respectively. These results will be used to compute the ongoing operational cost during the economic analysis.



### 4.3. GSHP systems: documented coefficient of performance

The value of COP significantly impacts on the economic feasibility of a GSHP system, as a higher value of COP would reduce the electricity consumption and thus reduce the ongoing operational cost. As discussed in the literature review section, most of literature uses an assumed value of COP, which may impair the validity of the findings. In this research, collected data were used to compute the COP value to facilitate a more accurate economic analysis.

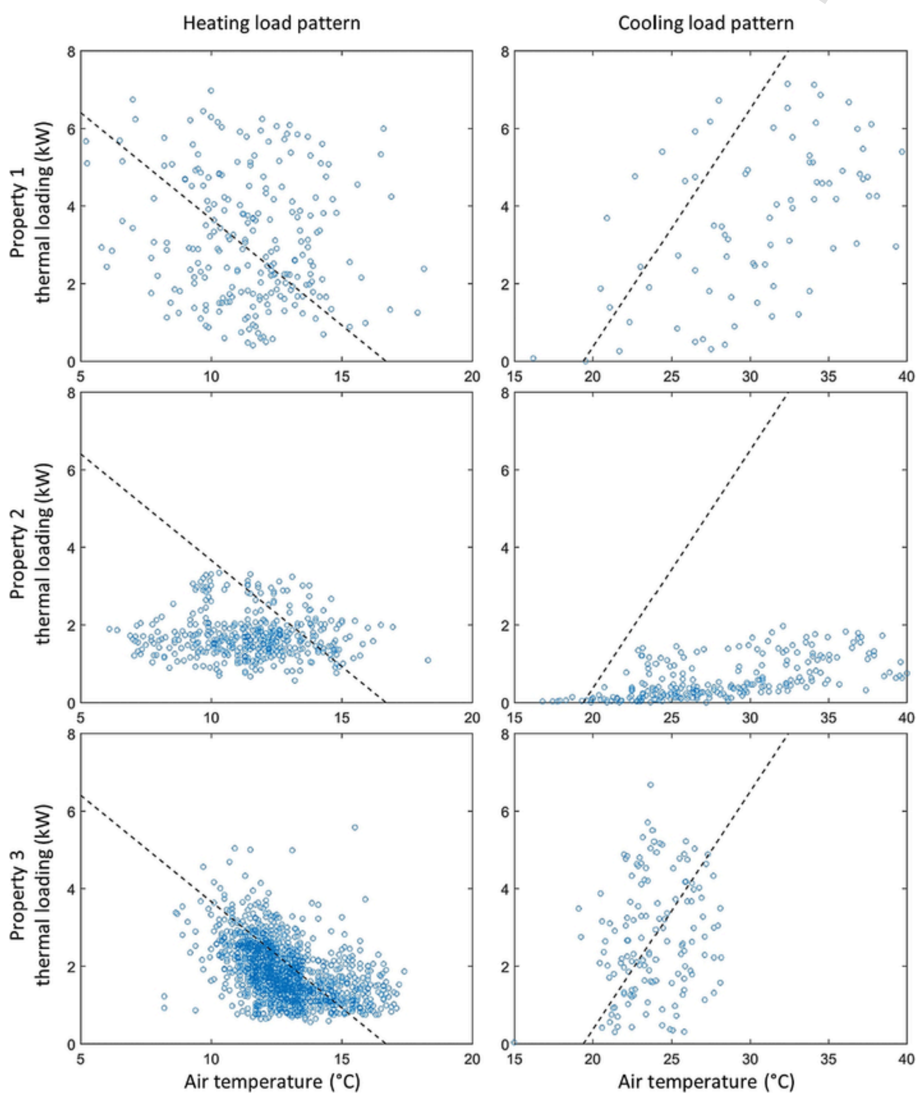



**Fig. 3.** Heating and cooling load pattern of selected properties (the small open circles on the graph represent the recorded data; the dashed black line is the design building load profile). Data from 2015.

The COPs observed under the project funded by the SEPD program differs significantly: with highly performing systems reaching an overall heating/cooling COP of 4.3 while some systems barely reached 1.5. Further investigations are currently underway to examine why certain systems are over performing while others are under-performed. Preliminary investigations suggest that different user pattern, inferior ground thermal properties, incorrect installation, and inappropriate flow rates are the major factors in those systems with low COP values. For the well-designed and well-executed GSHP systems the average COP observed for heating is 3.8 and for cooling is 3.6.

### 4.4. Other data used in the analysis

This paper focuses on comparing three heating/cooling systems: a GSHP system, a reversible ASHP system and combination of cooling only ASHP and gas furnace (Table 3). The reason for excluding other systems, for example electric heaters and wood furnace, is that they are neither energy-efficient nor financially competitive when compared to these three systems [7,9]. The advantage of an ASHP system is its relatively small capital cost as compared to installing a GSHP system and its relatively high efficiency as compared to other conventional systems. A gas furnace can be fuelled with either piped gas or the Liquefied Petroleum Gas (LPG). In rural regions, where no piped gas is available, LPG is the most common alternative used besides wood or electrical heating. The advantage of using a gas furnace is mainly the current low price of piped natural gas. So even though it is less efficient, it may be economically more attractive to install a gas furnace for heating [12], especially as in Melbourne where the heating demand is significantly higher than cooling demand (in a ratio of 3 to 1 for Melbourne). However, gas furnaces would only provide heating and therefore needs to be accompanied with an ASHP to provide cooling. Some key characteristics of the three systems studied are summarised in Table 3. As discussed earlier, the future inflation of electricity and gas assumed in this study are 6.20% and 6.14% respectively. These rates represent the actual compound inflation observed in Australia from 2000 to 2015. This and the other parameters used in the economic analysis are listed in Table 4.

The chosen design life for the economic analyses is 20 years and 40 years to accommodate the different life spans of the different systems. Unless a design life is the multiple of the system's life span, the salvage value of the heat pump would need to be taken into account. As there is still no widely agreed method for calculating the salvage value of a heat pump, this would introduce unnecessary uncertainty to the calculations.

**Table 3**
Characteristics of different heating/cooling systems.

| | System 1 (GSHP) | System 2 (ASHP) | System 3[c] (ASHP & Gas furnace) |
|---|---|---|---|
| Capital cost ($) | 31,041[a] | 8,481[b] | 8,481 + 4,203 = 12,684[b] |
| Life span (years) | 20 | 10 | 10 |
| Replacement cost ($) | 6,580 | 8,481 | 8,481 + 4,203 = 12,684 |
| Heating Efficiency | 3.8 | 3 | 0.92 |
| Cooling Efficiency | 3.6 | 2.5 | 2.5 |

[a] This capital cost is the average capital cost observed through the SEPD program.

[b] The capital costs for conventional HVAC were taken from the 2015 Rawlinsons construction cost guide [30].

[c] For the gas furnace in System 3, either piped gas or LPG would be used for the fuel.

**Table 4**
Parameters used for economic analysis.

| Item | Value | Unit |
|---|---|---|
| Annual heating requirement | 16,296 | kWh |
| Annual cooling requirement | 3,696 | kWh |
| Electricity price | 0.192 | $/kWh |
| Natural gas price | 1.36 | c/MJ |
| LPG gas price | 14 | c/kWh |
| Electricity inflation | 6.2 | % |
| Gas inflation | 6.14 | % |
| MARR[a] | 3.50 | % |

[a] This MARR value is the typical interest offered by banks for saving accounts in Australia.

## 5. Results and discussions

The economic feasibility of a GSHP system, for a typical residential property, will be compared with conventional heating/cooling systems using the different economic methods and the cost and performance data presented in the previous section. This section presents the result of economic feasibility of such GSHP system under three different scenarios: a) when current conditions are maintained b) when climate change is considered and c) when climate change and government incentives are considered.

The metrics provided under this section are purely economic measures. They do not take into account many other factors which influence the buying/selling price of an individual residence with a GSHP system. Factors such as desirability, marketability, environmental awareness are not considered.

### 5.1. Economic feasibility of GSHP systems under current conditions

In this sub-section, four scenarios will be presented by comparing different systems listed in Table 3 under a design life of 20 years and 40 years. These scenarios are: (1) comparing a GSHP system to a reversible ASHP system, (2) comparing a GSHP system to a cooling only ASHP & piped gas furnace, (3) comparing a GSHP system to a cooling only ASHP & LPG furnace, and (4) comparing a reversible ASHP system to a cooling only ASHP & piped gas furnace. These are alternative systems commonly encountered in the current Australian market. Table 5 summarises the results obtained using the different economic methods under current conditions, that is, without considering climate change and government incentives. For example, when comparing a GSHP system with an ASHP system, for a design life of 40 years, the GSHP system is more financially attractive. This

**Table 5**
Results for the different economic methods.

| | PW ($) | AW ($) | IRR (%) | ERR (%) | SPP (yrs) | DPP (yrs) |
|---|---|---|---|---|---|---|
| GSHP against ASHP (20yrs) | −545 | −38 | 3.31 | 3.37 | 20.0 | 29.6 |
| GSHP against ASHP (40yrs) | 12,643 | 592 | 5.65 | 4.69 | | |
| GSHP against ASHP & piped gas furnace (20yrs) | 1,757 | 124 | 4.20 | 3.99 | 19.2 | 29.2 |
| GSHP against ASHP & piped gas furnace (40yrs) | 10,255 | 480 | 5.81 | 4.69 | | |
| GSHP against ASHP & LPG furnace (20yrs) | 42,736 | 3,007 | 16.64 | 10.05 | 8.0 | 9.1 |
| GSHP against ASHP & LPG furnace (40yrs) | 119,049 | 5,575 | 17.82 | 8.92 | | |
| ASHP & piped gas furnace against ASHP (20yrs) | −2,302 | −162 | −1.93 | −0.74 | 25.9 | 35.3 |
| ASHP & piped gas furnace against ASHP (40yrs) | 2,388 | 112 | 5.13 | 4.70 | | |

conclusion can be observed via several indicators, for instance, a positive number of $12,643 in PW represents a net gain of $12,643 in present value when using a GSHP system instead of an ASHP system. This can also translate into an annual gain of $592, which is the AW value. The computed IRR value is 5.65% in this case; however, this is not the true rate of return for investing in a GSHP system. As discussed in Table 1, the mechanism of IRR method assumes that all the future cash inflows are reinvestigated at IRR. However this not probable as future cash inflows are more likely to be reinvested at a MARR of 3.5%. ERR takes account of this and yields a value of 4.69%, which represents the true rate of return. The computed SPP and DPP are 20.0 and 29.6 years respectively. These latter two methods do not consider project desirability, increased capital gain or improved marketability of the property with a GSHP system, and should therefore be considered carefully for decision making.

Table 5 suggests that in the short-to-medium term (20 years), it would be more economical to install an ASHP system rather than a GSHP system or an ASHP system with a gas furnace, mainly due to the high capital cost of the latter two systems. Note that in the first twenty years, installing an ASHP system is only marginally more economically beneficial than installing a GSHP system, as reflected by the annual equivalent gain of $38. In the long term (40 years), however, installing a GSHP system is the most financially favourable option. The completely different conclusion suggests that in the short term the capital cost of a system dominates its financial feasibility while in the long term the ongoing running cost is more important. A LPG furnace system is purposely selected to represent the conventional heating option in rural regions where no piped natural gas is available. As shown in Table 5, installing a GSHP system represents a significant economic benefit as compared to systems with LPG furnace, and a LPG fuelled furnace is always more expensive to run than a piped gas fuelled furnace.

An interesting observation is that when comparing a GSHP system against an ASHP system for a design life of 20 years, even though the SPP is 20 years, the GSHP system is still not as financially competitive as the ASHP system. Therefore, if only SPP is used as basis for decision making, this could result in a misleading conclusion. Therefore, SPP should be treated carefully as they do not reveal the project's overall attractiveness. The reason is that SPP assumes the money invested does not need any return while all other methods compare the rate of return with the MARR. This is also supported by studies in the field of economics [8,28,31].

### *5.2. Economic feasibility of GSHP systems considering climate change*

The changing local climate due to global climate change will impact the heating/cooling demand of residential properties. As Wang et al. [27] have pointed out, the heating demand in Melbourne will be reduced by 36% while the cooling demand will be increased by 90% by 2050, as shown in Fig. 4. This is an equivalent annual reduction of 1.27% in heating and annual increase of 1.85% in cooling for the next 35 years.

Table 6 shows the results of an economic analysis that takes into account these changes in thermal load. Perhaps counterintuitively, the difference is quite minor: in the short-to-medium term (20yrs), installing an ASHP system would still be marginally more financially attractive than a GSHP system, while in the long term (40yrs) installing a GSHP system is still more financially favourable. However, in the long term the difference between installing an ASHP system with a piped gas furnace and simply an ASHP system becomes negligible, reflecting no economic benefit of installing a piped gas furnace. This is mainly due to the scenario that heating demand will be reduced while cooling demand will be increased as a result of climate change. As a LPG fuelled furnace is always more expensive than piped gas furnace, LGP fuelled furnace is therefore excluded from study under the climate change condition.

Note that even though the cooling demand is forecast to double within the next 35 years, this does not necessarily mean that the capacity of the cooling system needs to be doubled; it simply means that house owners would need to run the cooling system more often in the summer. Indeed, an estimated increase of 2 °C in maximum daily temperature during summer by 2050 [32] would result in only a 0.8 kW increase in peak design cooling load based on the energy loading profile for Melbourne.

From the economic analysis, it may seem that climate change is not really relevant for determining the feasibility of a GSHP system while all other variables are kept constant. However this is not entirely true as the performance of GSHP systems would benefit from climate change due to the more balanced thermal loading under Melbourne condition. Typically, when thermal loading is unbalanced, the performance of a GSHP system deteriorates over time [33]. In Melbourne the thermal heating required (16,296 kWh) is much more significant than the thermal cooling required (3,696 kWh). This is not ideal for the operation of the GSHP systems. However, due to climate change, the heating demand will reduce while the cooling demand will increase. This net change would eventually result in a much better balanced ground thermal storage for extracting or rejecting heat. Indeed, it was estimated that in 2050, the thermal heating required (10,429 kWh) would be quite close to the cooling required (7,022 kWh), thus resulting in a better performance of the GSHP systems and lower running costs.

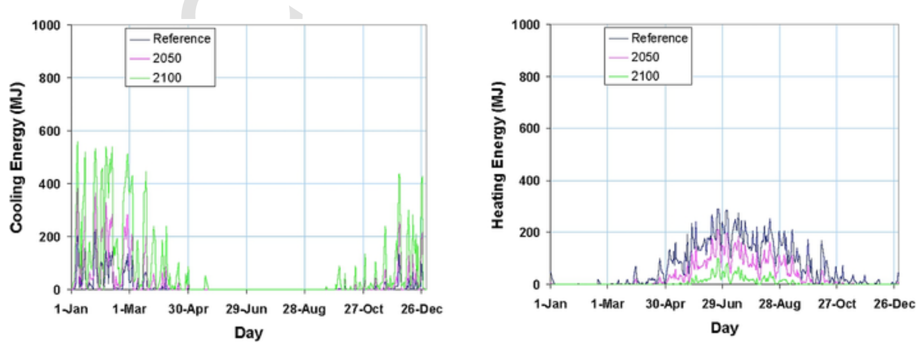



**Fig. 4.** Forecast changes in residential building heating and cooling demand in Melbourne [27].

**Table 6**
Results for different economic methods when taking into account climate change.

| | PW ($) | AW ($) | IRR (%) | ERR (%) |
|---|---|---|---|---|
| GSHP against ASHP (20yrs) | −760 | −53 | 3.24 | 3.32 |
| GSHP against ASHP (40yrs) | 12,268 | 574 | 5.59 | 4.66 |
| GSHP against ASHP & gas furnace (20yrs) | 2,161 | 152 | 4.35 | 4.10 |
| GSHP against ASHP & gas furnace (40yrs) | 13,185 | 617 | 6.25 | 4.95 |
| ASHP & gas furnace against ASHP (20yrs) | −2,921 | −206 | −4.11 | −2.87 |
| ASHP & gas furnace against ASHP (40yrs) | −917 | −43 | 2.69 | 2.84 |

### *5.3. Economic feasibility of GSHP systems considering government incentives/regulations*

Even though a GSHP system is considered in many cases to be both energy-efficient and financially attractive in the long term, there is still reluctance, not only in Australia but across the world to install these systems. However, the situation could be quite different with government intervention. In countries where the GSHP industries are active and prospering, for instance the United States and several countries in Europe, the governments have introduced various supportive tools to encourage the installation of GSHP systems. These tools include tax exemptions/reductions, loans at lower interest rates and direct or indirect subsidies [10].

In the United States, the Internal Revenue Service (IRS) provides a tax credit of 30% of the capital cost of a GSHP system with no upper limit. If such a policy were to be adopted in Australia it would mean that even in the short term it would become much more economically attractive to install a GSHP system as compared to other conventional systems available. This can be seen in Table 7 which shows the results from the various economic methods used above, when taking into account both climate change and a tax credit of 30% of the capital cost.

Supportive measures by the government should not only take the form of financial incentives but also clear government regulations. For instance, Blum et al. suggested that advanced government regulation would contribute to the growth of the GSHP industry [18]. In Australia no such regulation/standards exist for the GSHP industry and potential buyers may feel wary of the claims made by sales people. The minimum meaningful threshold of government incentive (% reduction of capital cost) that would make GSHP a more attractive option over the alternatives (resulting an AW of greater than $100) would be only 8%.

## 6. Further observations

In Australia, the HVAC market for residential properties is dominated by conventional heating/cooling systems. GSHP systems are still quite rare in the residential housing sector, hence the shortage of well-documented experience. The capital cost for a typical Melbourne residential property was found to be $31,041 ± 1,506 in this study. Studies in other countries, especially in Europe, have reported similar figures. For example, in 1999 Rawlings et al. reported the typical cost of installing of a GSHP to be in the range €15,300 ($23,390) to €23,500€ ($35,924) across Europe and between US$7,500 ($10,374) and US$10,000 ($13,832) in the US [8]. In 2010, Blum et al. reported an average capital cost of €23,500 ($35,924) in Germany [18]. Hence the capital cost for a GSHP system in Australia is similar to those in Europe. However, considering the average European GSHP systems have a peak design load of 11 kW with a total GHEX length of 180 m [18] the cost of installing a GSHP system would still be considered high in Australia ($3,880 per kW of installed capacity in Australia as compared to $3,265 per kW in Germany). The high capital cost would deter potential buyers, resulting in a barrier to the GSHP industry. The reasons for the high installation cost include (a) limited competition for the supply of heat pumps (most heat pumps were American made and shipped to Australia) (b) the relatively high drilling and ground loop installation cost and (c) limited competition for qualified GSHP system installers. It is important to note that the capital costs reported in this article represents an upper bound cost, given the current small market, lack of competition, the premium paid for systems installed under a non-continuous commercial operation and lack of government incentives.

The economic analyses enabled the assessment of a GSHP system when compared to two popular heating/cooling options, an ASHP system or an ASHP system with a gas furnace. The result suggests that, under a design life of 20 years, installing a GSHP system would be marginally inferior to an ASHP system. When comparing this result to other GSHP systems around the word, it is clear that systems here are less financially attractive. The relatively high capital cost per kW of system capacity is certainly part of the reason. Another more critical factor is the mild weather in Melbourne. As shown in Table 8, both heating and cooling demands in Melbourne are small compared to other parts of the world. As a result, the relatively low annual operational saving makes the GSHP system less of an economical option in the short-to-medium term.

Even though the economic analysis provided in this research intends to represent the actual cost and possible scenarios to be encountered in the future, there are still some limitations, which need to be further explored in further research. First, the appreciation in property value as a result of the installations was not included in this study due to the uncertainties of the amount of increase. Nonetheless, such an effect would be expected and has been reported in the literature [34]. Second, the relatively low maintenance cost is not factored into this economic analysis, although it has been reported in several studies that GSHP systems typically have a 54–68% lower maintenance cost than conventional systems [8,35,36]. The reason for not including the maintenance cost is that quantifying the average annual maintenance cost is difficult, especially as the installations under the SEPD program are all quite recent. However, this will become feasible after a

**Table 7**
Results for different economic methods when taking into account climate change and a government incentive of 30% of the capital cost.

| | PW ($) | AW ($) | IRR (%) | ERR (%) |
|---|---|---|---|---|
| GSHP against ASHP (20yrs) | 8,237 | 580 | 7.39 | 6.10 |
| GSHP against ASHP (40yrs) | 21,265 | 996 | 8.58 | 6.06 |
| GSHP against ASHP & piped gas furnace (20yrs) | 11,158 | 785 | 10.13 | 7.85 |
| GSHP against ASHP & piped gas furnace (40yrs) | 22,182 | 1,039 | 10.73 | 6.82 |

**Table 8**
Typical heating and cooling requirement indices for cities around the world.

| Country | City | Typical values | |
|---|---|---|---|
| | | Heating degree day (°days)[a] | Cooling degree day (°days)[a] |
| Australia | Melbourne | 1,270 | 530 |
| Germany | Berlin | 2,889 | 320 |
| UK | London | 2,303 | 129 |
| US | New York | 3,168 | 503 |
| US | Oklahoma City | 1,698 | 1,227 |

[a] For 18 °C base temperature. Source: [5].

few years of operation. Third, this analysis has not considered depreciation. Depreciation of a heating/cooling system would be applicable in the case of profitable small to medium sized businesses operated from home. By depreciating the energy system, the company effectively reduces its company tax. Fourth, the improved COP of a GSHP system due to climate change (i.e. more balanced thermal loading) is not considered in the analysis. Fifth, the carbon tax credit arising from the reduced emission levels of greenhouse gases are not considered into the analysis. All of these limitations tend to make this economic analysis very conservative. However, it does provide clients and planners with a basic cost framework for conducting their feasibility study for installing a GSHP system.

Finally, government plays a critical role for roll-out of GSHP systems. As Rawlings et al. [8] have pointed out, in the majority of countries where sales of GSHPs are significant, the government either subsidises the systems or provides incentives for the households. The economic analysis conducted in this paper certainly shows a significantly improved rate of return for the GSHP system once government incentives, as low as 8%, are introduced. As the Australian government aims to reduce greenhouse gas emission and promote sustainable living, a more active role in the GSHP industry would be desirable.

## 7. Conclusion

This study analyses the economic factors which influence the market for residential vertical GSHP systems in Melbourne, Australia. There is a general review of the literature with some experimental work presented. The financial data gathered from 20 GSHP systems revealed a typical cost for a residential property is approximately \$31,000, an upper bound cost arising from the emerging market status of GSHP systems in Australia. A detailed up-to-date cost breakdown of a GSHP system in Melbourne has been summarised in Table 2. It is particular important to identify items whose costing is overpriced and where further savings could be achieved to improve the overall economic attractiveness of installing GSHP systems. This information is of major interest to designers and installers of these systems, as well as for land developers. A subsequent detailed economic analysis using these recorded cost and operational performance data reveals the attractiveness of installing a GSHP system, an annual equivalent gain of \$592 over a design life of 40 years. Given that the benefits of GSHP systems realise through their operation over time, this result is of practical use for households which are interested in new (or retrofit) GSHP systems.

This study also suggests that climate change would not significantly affect the economic feasibility of a GSHP system. In addition, this research shows the importance of a government's role in promoting residential GSHP systems, with tax credits as low as 8% on capital cost making GSHP technology an attractive option. Owing to the realisation of the economic and environmental benefits of GSHP systems over time and their high initial costs – a main barrier for adoption of the technology, the result on minimum incentive threshold for a design life of 20 years would be beneficial for guiding high level policy makers. Indeed, it provides a basis to quantify potential public investment to widely promote GSHP technology by a government to realise its benefits; or by energy producers and/or distributors who may subside GSHP installations to offset upgrades to their infrastructure. Future research would be devoted to examine whether such incentives are worthwhile in the residential sector, given the relatively reduced energy demand in temperate climates and lower running fractions observed in comparison to the industrial and commercial sectors, where economic and environmental benefits could be much greater than in the residential sector.

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