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Techno-economic analysis of ground and air source heat pumps in hot dry climates

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Abstract

The use of ground source heat pump (GSHP) systems in cold climates, such as those in parts of North America, Scandinavian countries and China has been discussed for decades. However, hot and dry climates are encountered in vast regions across the globe but, unfortunately, not much research has taken place in the use of GSHP systems in hot and dry regions. This paper aims to investigate the feasibility of using GSHP systems in hot and dry regions, and Saudi Arabia is an example. This paper introduces for the first time of a techno-economic analysis to evaluate the use of GSHPs compared to the conventional air source heat pump (ASHP) systems in this type of climate.

In order to compare the economics of geothermal heat pump systems to other HVAC alternatives, a direct capital cost comparison is made between an example GSHP and ASHP. This is based on the initial investment, payback period, cost energy saving and length of the ground loop, which was calculated for an simple case using the ASHRAE method. Despite the increase in the initial capital costs of GSHP, because of the extra expensive drilling costs for the ground loop heat exchanger and piping the feasibility of GSHP system is worthy of investigates.

It is concluded that the GSHP is feasible, albeit with a long payback period, typically 10-20 years, depending on the conditions, setup and predictions. Also it will be seen that there is a savings in CO_2 emissions and there may be a substantially decrease in the total costs using GSHP compared to ASHP.

Keywords:
Ground source heat pump - Air source heat pump- Hot/dry climates

Introduction

Throughout the world there has been and will continue to be for the foreseeable future a move to the use of renewal energy. In hot dry climates an untapped form of renewal energy is from the ground. To demonstrate this idea we will use as a approximated building in Saudi Arabia. to investigate and test the performance of vertical ground source heat pumps as a new facet of renewable and sustainable energy in hot/dry climates, which predominates in Saudi Arabia, in order to reduce costs and CO_2 emissions from HVAC systems along with saving energy.

Over the last five years, Saudi Arabia's domestic energy consumption has rapidly increased by about 10% annually. This is due to the growth in the population and the current energy demands. In addition, research has projected that the increase in peak demand for electricity will reach about 70% in 2030 [1], and 70% of the consumption of the electrical energy per building will be consumed by ventilation, heating, and air conditioning purposes (HVAC). Also, the price will increase due to govenment policies [2]. Therefore, the assessment of a new method of cooling and heating is very important in achieving the national goal to reduce the waste of energy and CO_2 emissions.

The National Transformation Program in Saudi Arabia plans to cut public-sector subsidies, as a part of Vision 2030, by 2020. Thus, the Kingdom's government plans to adjust the subsidies for petroleum products, water, and electricity over the next five years in order to achieve the efficient use of energy as well as the conservation of natural resources [2].

In fact, the Saudi government has started implementing the new energy tariff since January 2018. Table 1 shows the electricity consumption tariff for different sectors in Saudi Arabia [3]. The residential segments are expected to be the most affected by the new electricity tariff and Table 2 shows a comparison of the old and new tariffs for residential buildings. However, the new tariff might increase by the year 2020. Therefore new strategies should be considered to reduce the electricty consumption.

Table 1
The new electricity consumption tariff for different sectors in Saudi Arabia applied from 1 January 2018.

Sectors (H/kWh)	Consumption categories (kWh)	
	1-6000	More than 6000
Residential	18	30
Commercial	20	30
Agricultural & Charities	16	20
Governmental	32	
Industrial	18	
Private educational, medical facilities	18	

Table 2
The comparison of old and new tariffs for residential buildings.

	Total units consumed (kWh)			
	1500	2500	4500	6500
Old tariff, SR	75	150	400	850
New tariff, SR	270	450	810	1230
% Increase	260%	200%	103%	45%

SR= The Saudi riyal; is the currency of Saudi Arabia made up of 100 halala. ($1=3.75 SR)

Despite the heavy use of air conditioning and refrigeration systems in Saudi Arabia, there is extremally limited use of renewable energy. Therefore, the main aim of this paper is to investigate and test the performance of vertical ground source heat pumps as a new facet of renewable and sustainable energy in hot/dry climates, which is the predominant climate in Saudi Arabia in order to reduce the costs and CO_2 emissions from HVACs along with saving energy.

2. Literature review

Geothermal energy has various applications with regard to power generation, heating and cooling, along with industrial and agricultural applications [4]. Geothermal power can be classified into three categories—low depth, intermediate depth, and shallow depth—depending on the resource temperature and regardless of its distance from the Earth's surface. The geothermal heat pump (which pertains to shallow depth) has limited application in the Middle East and North Africa (MENA) countries and therefore the following studies have evaluated the heat exchange process in MENA countries and different hot regions like Arizona,USA.

Said et al. [5] investigated whether ground-based condensers might be used to support air-conditioning systems in the Kingdom of Saudi Arabia, by determining the soil-types and temperatures that would be required. This was done by running thermal response tests. The study found that there were significant differences between the ground temperatures and the ambient temperature with 12°C being recorded. Also, a cost analysis was undertaken, which indicated that the use of ground-source heat pumps in Saudi Arabia would result in about 28% energy savings. However, this was deemed to be not economically viable due to the low electricity prices prevalent in the country due to government subsidies and high drilling costs.

Naili et al. [6] conducted the first evaluation of the potential for geothermal energy in Tunisia, which featured the evaluation of a horizontal ground heat exchanger (GHE), in Bork Cedria, in the north of the country. A heat transfer coefficient was derived based on temperature readings taken at different locations below the surface. The loss of pressure at each depth was determined based on calculated rates of heat exchange. Using a room with a surface area $12m^2$, it was established that a GHE system consisting of 25 m of pipeline located a meter underground could account for 38% of the cooling required for that room. From this, it was concluded that a GHE could provide a novel cooling mechanism for buildings, thus demonstrating the scope that existed for Tunisia to become a leader in the development of geothermal heat pumps.

Serageldin et al. [7] introduced an experimental study of the thermal performance for an Earth-Air Heat Exchanger (EAHE) system under Egyptian weather conditions. The MATLAB code and ANSYS Fluent simulations were validated against experimental data. In this paper, five parameters (pipe diameter, pipe length, pipe spacings, pipe materials and fluid flowing velocity) was investigated. The experimental outcomes show that the if the pipe diameter increases then the outlet air temperature decreases. Also, it was observed that when the fluid velocity increases, the outlet air temperature gradually decreases.

Belatrache et al. [8] investigated the effect of the length of the buried pipe and the air flow rate of the horizontal Earth-Air Heat Exchanger (EAHE). The model and experiment on the EAHE contains primarily a PVC pipe of length 45m and at a depth 5 m and the simulations used climatic conditions of the Algerian Sahara. In the study, the air temperature inside the EAHE drops significantly at a depth 5m from 46°C until it achieves the soil temperature at about 25 °C and the maximum temperature difference in July between the ambient temperature and the buried pipe temperature is about 20.7°C. This indicates the possibility of using the GSHP in such conditions.

Despite the increasing use of GSHPs in cold regions in the USA, GSHPs are a relatively unfamiliar technology in hot and humid climates, such as Arizona and Florida. Zhu et al. [9] investigated the feasibility of using GSHPs in Florida. In this study, a commercial building in Pensacola, FL with GSHPs that have been in operation since 2010 and thus was used as the case study. Actual data has been collected to determine the life-cycle cost, comparing a deterministic life cycle costing method with a probabilistic life cycle costing method for GSHP and conventional systems. The study has shown that installing GSHP to be more feasible than using a conventional system, from a life cycle perspective.

On the other hand, Tambe [10] investigated the feasibility of using GSHPs for a small office building in Phoenix, Arizona. This master's dissertation presented a critical review, as well as a detailed evaluation, of the energy performance and technical feasibility of both a vertical and a horizontal closed loop heat pump in Phoenix. The study showed approximately 40% energy savings from the GSHP system, compared to the ASHPs. In addition, there was a significant difference between the dry soil and saturated soil condition. The saturated soil decreased the length of the GHE by 26% and 25% for the horizontal and vertical ground source heat pumps, respectively. However, the payback periods were found to be 2.3 - 4.7 years for the horizontal system and over 25 years for the vertical system, implying that the option of the vertical system would not be economical.

Regarding the existing literature, much work has been conducted into GSHP systems in many climates, however no modeling has been performed in hot/dry climates, such as Saudi Arabia. However, we are now in a good position to conduct such an investigation as there is now good data on the climate and importantly on the underground temperature in this region. The authors now use this to examine the engineering and economic viability of these systems compared to the ASHP predictions in these conditions.

2.1 The GSHP potential in Saudi Arabia

In order to investigate the feasibility of using vertical GSHPs in Saudi Arabia, the most important parameters that must be considered are the climate conditions, local geological conditions, initial costs and electricity tariffs. Based on the data found in relation to these aspects, the size of the GSHP will be calculated and a basic cost analysis that will be compared to conventional cooling systems will be determined. The following section provides information about these parameters before determining the ground heat exchanger size.

The geology of Saudi Arabia consists of two main parts, the Arabian Shield, which is located in the west of Saudi Arabia, and the Arabian Plate, which extends from the center of Saudi Arabia to the east coast. These two parts contain different geological characteristics of the soil and rocks. In the last two decades, several studies have identified the deep geothermal resources in Saudi Arabia; most of these studies have focused on exploring the location where geothermal power is generally stored [11]. Volcanic regions and hot spring waters are considered by researchers when understanding the capacity for geothermal power. Deep geothermal resources however, are beyond the scope of this paper but, regarding the exploitation of shallow geothermal energy using GSHP, there is a lack of research that addresses this issue in Saudi Arabia.

In 1978, a detailed cooperative study between the Ministry of Petroleum and Mineral Resources in Saudi Arabia and the US Geological Survey investigated the heat-flow measurements. Five sites were selected in the region between the Riyadh provinces in the direction towards the southwest and the Farasan Islands [12]. Each site was mapped and sampled in detail. At each site, 15-20 wells were drilled with an average depth of 60 meters; the distance between each site was approximately 200 km, see Fig.1.

Fig. 1: The location of the five sites that were selected for the drilling of the boreholes by the Ministry of Petroleum and Mineral Resources in Saudi Arabia and the US Geological Survey to investigate the heat-flow measurements adopted from [12].

The thermal conductivity and underground temperature were computed in all boreholes. Table.3 summarises some of the most important information regarding this building and its environment. The most important information from this study relates to the GSHP design was the average thermal conductivity for site 1 is 2.6 W/m.K and the average underground temperature at 60m depth is 28.5°C.

Table 3
Heat flow and thermal conductivity estimates from the five sites selected [12].

shot point	Altitude (m)	Depth (m)	Thermal conductivity W/m·K
1	692	70	2.62
2	887	69	3.26
3	946	62	2.60
4	1144	58	3
5	179	58	4.22

In addition, the feasibility of using ground-coupled condensers for air-conditioning (A/C) systems in Saudi Arabia was investigated by Said et al. [5], where the temperatures and soil properties required for the performance analysis of GSHPs was determined experimentally. The most important information from this study related to the GSHP design was that the main fluid temperature from the borehole was 32.5°C, the thermal resistance 0.315 (m k/W), the maximum difference in temperature of about 12 °C was observed between the ground temperature and the dry bulk temperature of the ambient air and the outlet temperature from the ground loop was 36.5°C. All these values will be used to estimate the ground heat exchanger length based on ASHRAE methods.

Finally, ASHRAE and many simulation programs, such as TRNSYS use equation (1) as developed by Kasuda [13] to calculate the underground temperature at different depths. Fig.1. show the underground temperature for Riyadh city at different depths based on the daily weather data collected for Riyadh city, 2018.

$$T_{soil(D,tyear)} = T_{men} - T_{amp} * exp\left(-D\sqrt{\frac{\pi}{365 * \alpha}}\right) * \cos\left(\frac{2\pi}{365}\left(t_{year} - t_{shift} - \frac{D}{2}\sqrt{\frac{365}{\pi * \alpha}}\right)\right) \quad (1)$$

where:

$T_{soil(D,tyear)}$ = soil temperature at depth D and time of year, T_{mean} = mean surface temperature (average air temperature). The temperature of the ground at an infinite depth will be at this temperature
T_{amp} = amplitude of surface temperature [(maximum air temperature - minimum air temperature)/2]
D = depth below the surface (surface=0)
α = thermal diffusivity of the ground (soil)
t_{year} = current time (day)
t_{shift} = day of the year of the minimum surface temperature

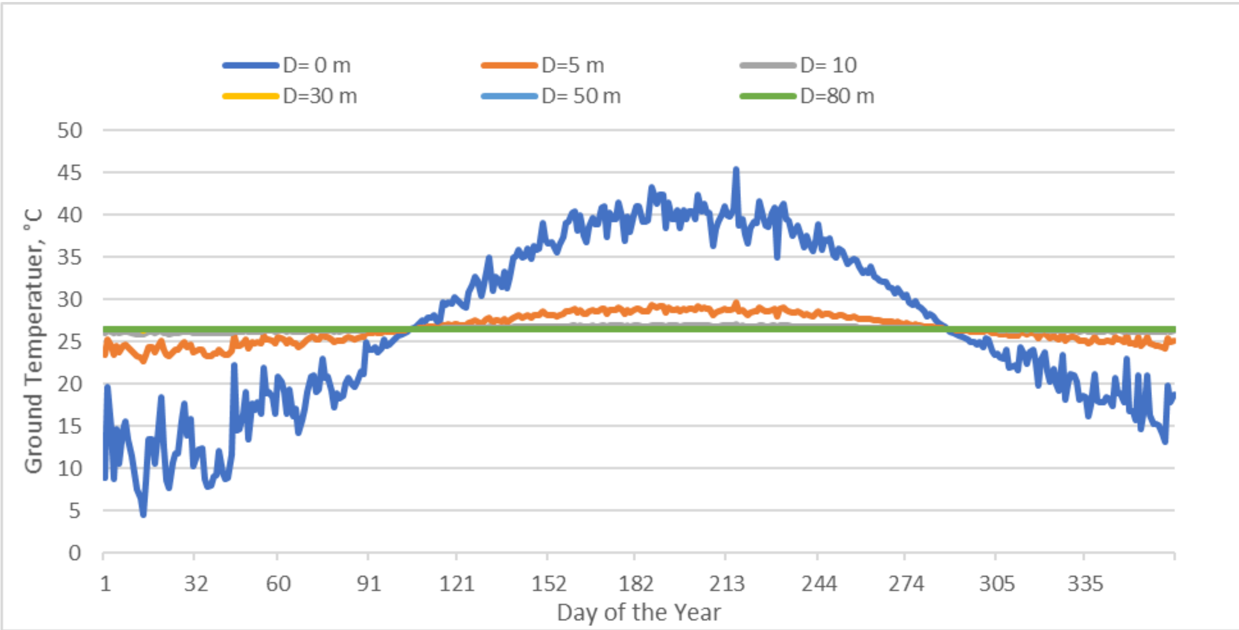


Fig.2. Underground temperature for Riyadh city at different depths

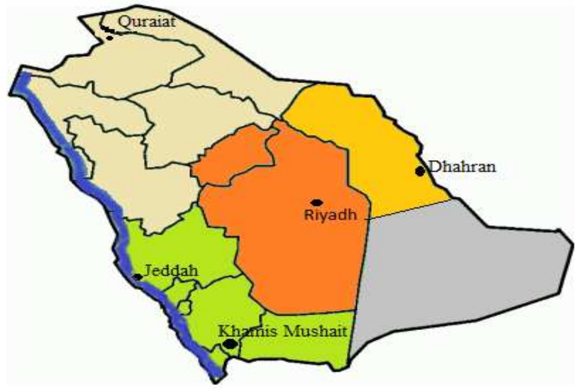
2.2 Climatic zones in Saudi Arabia

Knowledge of the climatic zone is one of the basic steps required to examine the application of the potential for renewable energy, to determine green home design, zero energy designs and energy consumption. Alrashed and Asif [14] evaluated the climatic zones in Saudi Arabia by dividing the country into five inhabited regions, including the following major cities: Dhahran, Quraiat, Riyadh, Jeddah and Khamis Mushait, see Fig.3. Also, this study compared these five sites with the 18 global sites on the basis of four main parameters that affect the energy performance of zero energy homes, ZEHs: air temperature, relative humidity, wind speed and solar radiation. The IES-VE software was used to model a virtual house for all the relevant locations. The findings of the sensitivity analysis indicated that the Saudi climate is not an obstacle to the application of ZEHs in the country. Also, the locations were compared with their corresponding Saudi locations, as shown in Table 4.

Table 4
The climatic parameters for the identified and represented locations [14].

Location	Temperature, °C		
	Min.	Max	Mean
Dhahran, SA	5	45.7	25.8
Borrego Springs, California, US	2.3	48.4	24.7
Quraiat, SA	-3.3	43.9	19.8
Tucson, Arizona, US	-2.1	43.2	20.4

Riyadh, SA	2.2	43.7	25.1
Phoenix, Arizona, US	-2.8	46.1	22.5
Jeddah, AS	13.9	41.7	27.9
Lake Bennett, Austrail	15.6	35.8	27.7
Khamis Mushait, AS	2.7	34.3	18.9
Cupertion , California, US	-0.2	37.2	16.6



Cold- Dry with a desert subzone.
Subtropical with Mediterranean subzone and mountainous subtype.
Hot-Dry Maritime subzone.
Hot- Dry with a desert subzone.
Hot-Dry with a maritime desert subzone.
Empty Quarter.

Fig. 3. The climatic zones in Saudi Arabia adopted from [14].

3. Sizing a geothermal heat pump in Saudi Arabia

The performance and initial cost of the geothermal pump depends on the calculation of the ground heat exchange (GHE). In North America, it is estimated that, on average 10% ~ 30% of the GHEs are oversized [15]. The high initial cost of a vertical GSHP is linked to its oversized nature. The design of BHEs depends on many factors (cooling/heating load, soil type and climate conditions) that are more or less controllable by the designer; for example, the heat transfer through the GHE and surrounding soil or rock, which is difficult to quantify. Thus, sizing a geothermal heat pump is a complex process, and therefore it is important for the accurate sizing of the vertical GSHP before making any decisions. Therefore, in order to make GSHPs economically feasible it is very important that there is a good estimation of its size so that the amount of drilling can be limited and there are fewer operational problems.

3.1 Methods of calculating the length of a vertical GHE

Generally, various factors affect the design of GSHPs including but not limited to, peak heating/cooling load, characteristics of the heat pump, ground parameters and climate conditions. Thus, there are many methods that can be applied to estimate the length of a vertical GHE; the ASHRAE method, based on the work of Carslaw and Jaeger (1947), is one of the most widely used. This method is also known as the cylinder source solution, which assumes that the borehole is infinitely long, and the ground is homogeneous along its depth. The geometry and the thermal properties of the materials inside the borehole are ignored, including the thermal mass of the fluid. This approach was developed and evaluated by Ingersoll and Zobel (1954) and Kavanaugh and Rafferty (1997) [16]. In order to determine the feasibility of using GSHPs versus ASHPs see Fig.4 in Saudi Arabia, the following steps are performed:

(i) Calculate the length of the GHE based on the ASHRAE handbook ASHRAE (2017).
(ii) Perform a basic cost analysis compared to a conventional cooling system (air source heat pump

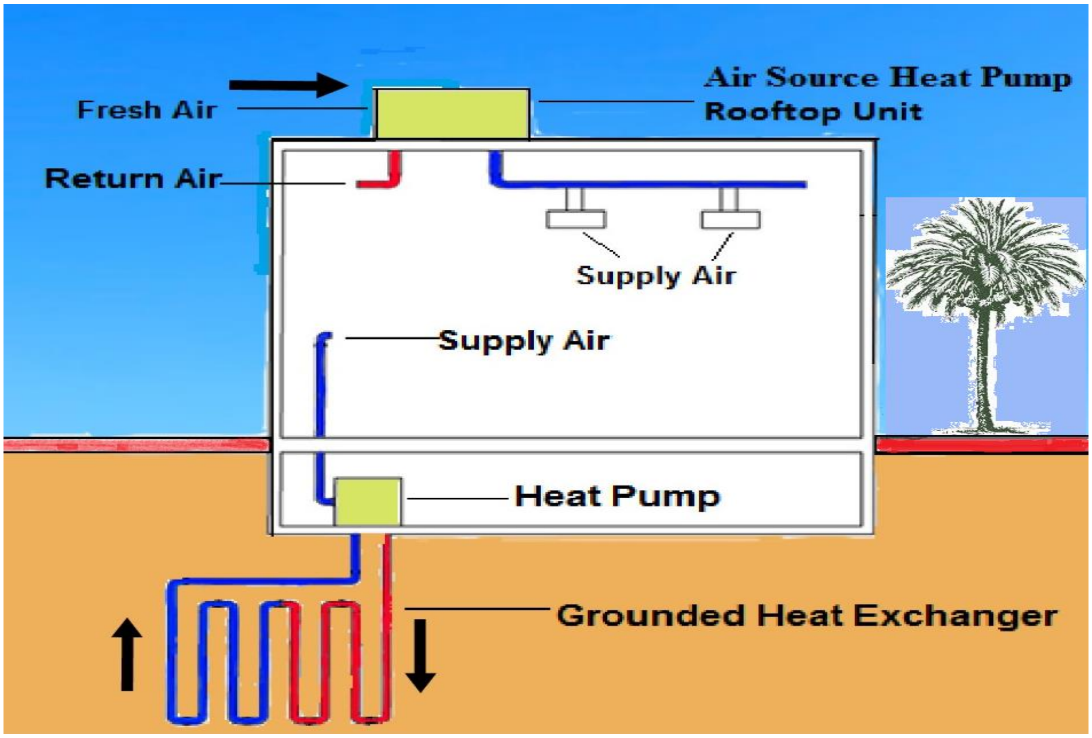


Fig.4. Schematics of a Ground and Air source heat pump systems for a typical house in Saudi Arabia.

3.2 Description of generic model

To perform a basic cost analysis, Table 5 shows the data that has been collected from the literature review and from the actual project for the bank building located in Riyadh Saudi Arabia as follows:

- The soil properties (thermal conductivity and underground temperature) collected from the report prepared for the Ministry of Petroleum and Mineral Resources in Saudi Arabia and the US Geological Survey to investigate the heat-flow measurements [12].
- The cooling and heating load collected from the actual project for the bank building located in Riyadh Saudi Arabia performed by an engineering consultant [17].
- The costs of the heating pump unit were estimated by the Water Furnace Company [18]. Construction and the installation cost (drilling, pipe and labour) is estimated based on the average price of three local contractors that we have been in contact with.
- The liquid temperature at the heat pump inlet/outlet, thermal resistance of the bore and pipe properties were collected from Sharqawy et al. [19].

Table 5
The data collected for the design calculation for the length of the GHE.

Parameters	Value
Average Thermal conductivity for the soil, W/m·K	2.6
Underground temperature at 60 m of depth, °C	29
Outside Temperature, °C	45
Average Annual Temperature (ASHRAE Handbook-2013), °C	26.5
Liquid temperature at heat pump inlet, °C	32.8
Liquid temperature at heat pump outlet, °C	39.5
Thermal diffusivity, m^2 /day	0.54
Total cooling load (Actual data), kW	196
Total heating load (Actual data), kW	38

Also, in terms of the estimated total borehole length, by use of the sizing equation (1), all the variables or factors have been obtained from the ASHREA hand-book (2017), HVAC Application: Chapter 34. Also, in terms of the city of Riyadh the climatic parameters will be compared to the city of Phoenix, Arizona, US.

Multiple approach methods have been tested to increase the efficiency of GSHPs. For example, Qi et al. [20] theoretically and experimentally studied the different connection configurations of GSHPs. The parallel configuration of the GHEs achieved a better heating performance compared to a series connection. Similarly, Pu et al. [21] investigated using new shape and material to reach the optimal design. However, energy efficiency and high performance of GSHPs are based on a realistic design.

3.3 Calculation of the length of the GHE

In this work, the equations employed to estimate the length of the GSHP systems are based on the ASHRAE (2017) online Handbook – HVAC Application: Chapter 34.

The length to satisfy the cooling loads was calculated using the following relation:

$$L_c = \frac{q_a R_{ga} + (q_{lc} - 3.41 W_c)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p} \quad (2)$$

More information about the above parameters can be obtained from the ASHRAE (2017) online Handbook – HVAC application, Chapter 34.

Based on the data in Tables 5 and 6, the collection of data from the previous studies and the actual project for the bank building located in Riyadh Saudi Arabia, the required length of the GHX in order to satisfy the cooling loads was estimate as follows:
Lc = 4082 m is the total length for the heat exchanger loop at 26°C, or
Lc = 5831 m at the ground temperature 29°C.

It should be noted that a difference of two degrees in the ground temperature led to an increase of approximately 30% in the loop length.

Despite the wide use of equation (2), three studies have focused on the ASHRAE Handbook length method by comparing the total length to the results obtained using the simulation tool or actual project. Cullin et al.[22] made a performance assessment of a GSHP, using a simulation tool for four cities, namely Valencia, Leicester, Atlanta and Stillwater, suggested that, while the simulation-based design tool predicted the borehole length to within ± 6% in all cases, the ASHRAE Handbook design equation yielded systems with errors ranging from -21% to 167%.

Ruan & Horton [15], on the other hand, estimated that, in North America, on average, 10% ~ 30% of the GHEs were oversized. Another study [23] compared two methods, namely the ASHRAE analytical method of Kavanaugh & Rafferty and the GLHEPRO commercial tool, based on the g-functions method by Eskilson. The comparative analysis of the two methods showed that the ASHRAE method tends to overestimate BHE size by up to 27%, as compared to GLHEPRO.

Based on the above three studies, it is possible that the ground loop length calculated using the ASHRAE handbook results in oversizing by about 20%, which, if factored in, would result in reduced bore lengths, thereby resulting in decreased boring costs.

4. Cost analysis

4.1 Savings on the power consumption

The cooling and heating load collected from the actual project for the bank building located in Riyadh Saudi Arabia was performed by engineering consultants [17]. Table 6 shows the design conditions for the estimation of the cooling and heating load. These input data were used to select the Air Source Heat Pump (ASHP) as a conventional cooling system and the HAP software was used as the design tool to calculate the heating/cooling load.

Table 6
The design conditions for the estimation of the cooling and heating load.

Parameters	Value
Building Area, m^2	584
Total cooling load, KW	196.2
Total heating load, kW	38.1
Riyadh cooling degree days, °F	5688
Riyadh Heating degree days, °F	291
Outdoor temperature, °F	115
Indoor temperature, °F	73

The results were obtained for the total cooling load 196 kW and the total heating load 38 kW and from the Carrier catalogue, this building requires 3x 20 TR package A/C units. As per catalogue, each unit has a power consumption of 28 kW at a maximum ambient temperature 46°C. In addition, the calculation of the annual cooling power consumption and the cost based on a constant speed compressor (conventional A/C unit).

The power required for the cooling is determined as follows:

$$P = \frac{Q_{cooling} \times 3412 \times 24 hours \times CDD}{EER \times 1000 \times (T_{out} - T_{in})} \quad (3)$$

where Q_c is the cooling load, CDD is the cooling degree days and EER the energy efficiency ratio. The equation (3) becomes:

P = 196 x 3412 x24 x 5688/(9.76x 1000x(115-73))
= 222,935 kW hr per year

The cooling electricity cost per year is determined as follows:

cost per year = power (kWh) x electricity tariff (4)

Saudi electricity cost: SR 0.32 per kW.h
Cooling electricity cost = 222,935 x SR 0.32 per kW hr
= SR 71,340 per year

The power required for the heating is determined as follows:

$$P = \frac{Q_{heating} \times 3412 \times 24h \times HDD}{1000 \times (T_{out} - T_{in})} \quad (5)$$

P_h = 38.1x3412 x24x291/1x1000x76-31= 20,175 kW hr/y

From equation (4), the heating electricity cost = 20,175 kW.h/y x SR 0.32 /kWh = SR 6,456 per year.

Differences in the annual primary energy consumption and the annual electrical cost between the air source heat pump and the underground heat pump are presented in Table 7. It is seen that the net savings in the power consumption for heating and cooling is 97,098 kW.h / year, which is equivalent to SR 31,066.

Table 7
The annual primary power consumption for the ASHP and GSHP

	Air Source heat pump	Underground heat pump
Cooling block load, kW	196	196
Heating block load, kW	38	38
COP for the system	2.3	4.4
EER	9.76	14.9
Power consumption, cooling kWh / y	222,953	146,030
Power consumption, heating kWh / y	20,175	0 (free heating)
Cost of power consumption cooling mood SR/y	71,339	46,729
Cost of power consumption heating mood SR/y	6,456	0 (free heating)
Total cost, SR	77,795	46,729
Net saving on power consumption. SR/y		31,066

It is important to note that the heating period in most regions in Saudi Arabia is short. For example, Riyadh heating degree days is 291°F compared to 5688 °F cooling degree days. This short period represents 9% of the total annual energy consumption. However, due to the high underground temperature, typically 29℃, which is above the indoor design temperature 26℃ in winter, then the heating load may be considered to be free (passive heating). Also, GSHPs can produce hot water without separate boiler unit, thus leading to the saving in costs for domestic hot water equipment.

Another potential factor related to the use of GSHPs in Saudi Arabia is the reduction in CO_2 emissions. For the next decade, the emissions of CO_2 are estimated to increase rapidly. In G-20 (the Group of Twenty countries), Saudi Arabia has the second highest per capita emissions in CO_2 in the last two decades where the CO_2 has increased by about 75% [24]. Liu et al. [25] compared the air source CO_2 heat pump system to three alternative systems (wall-hanging gas boiler, direct electric heating and coalfired boiler) used in heating mode in China. Their results showed that there is significant energy efficiency and cost effect to use air source CO2 heat pump which leads to using ground source CO2 heat pump will be more energy efficiency.

To estimate the annual CO_2 emissions then we multiply the power consumption in kilowatt hours (kWh) by the Emissions Factor (EF) for the state. In Saudi Arabia 1 kW.h = 0.7 kg CO_2. As a result, when the GSHPs saving is 97,000 kWh /year then this leads to a saving of 67,900 Kg CO_2/ year. approximately 40%.

4.2 Initial cost analysis

The initial cost price is fundamental in determining the HVAC system. Song et al. [26] investigated the techno-economic on operation performance of using ASHPs. From Table 8, it can be seen that the unit price for GSHP is about twice the ASHP. However, this price is variable depending on the manufacturing company, taxes and location. In addition, the initial installation cost for the GSHP leads to an increase in the investment costs of GSHP because of the extra expensive drilling costs. However, over a period (22 years) then it is predicted that the GSHP will be more feasibly.

From Table 8, it can be observed that the life expectancy of the ASHPs (air source heat pumps) is rather limited in Saudi Arabia, due to the high ambient temperatures, dust and the saline coastal environment, and in the cities near the sea, which rapidly corrodes the aluminum heat transfer fins, and this leads to a shorter life span. The typical life-span of an ASHP is 10-15 years; for the current assessment, a lifetime of 11 years has been assumed because of the harsh climate. However, the GSHP does not have the corrosion problems that are generally encountered with the ASHP. This is due to the fact that the heat pump unit is located indoors, and the loop pipes are buried in the ground and therefore the plant is not exposed to the ambient air. Thus, GSHPs have a typical life-span of 25 years and beyond, but for this study a lifetime of a GSHP has been assumed to be 22 years, namely twice the life-span of an ASHP.

Table 8
The initial cost analysis for ASHP and GSHP.

	ASHP	GSHP		Notes
Ground Temp. °C	----------	26.5	29	26.5 °C from equ (1)
GHE Loop length, m	----------	4082	5831	@29 °C from experimental [13].
Unit price, SR	160,000	240,000		
Drilling cost, SR	--------	326,560	466,480	SR80/m (Ground loop cost)
Pipe price, SR	--------	10,613	15,160	SR2.6/m (Ground loop cost)
Installation GHE, SR	---------	8,000	10,000	Estimated (Ground loop cost)
Total initial cost, SR	160,000	585,173	731,640	
Power consumption cost, SR /22 y From equ.3 (cooling)	71,339*22 =1,569,462	46,729*22 =1,028,038		Life cycle for the unit Estimated 11 years for ASHP and 22 years for GSHP. We assumed the cost of installing the two systems is equal.
Power consumption cost, SR /22 y From equ.3 (heating)	6,456*22 =142,000	0 (free heating)		
Total Cost, SR /22 y	1,711,500	1,613,211	1,759,678	
Power saving, SR /22 y	0	31,066*22= 683,460		
Net total cost /22 y	1,712,000	929,750	1,076,217	
Saving % /22y	0	45.67 %	37.11 %	

Soil temperature and soil thermal conductivity are crucial for the selection and sizing of GSHP, and a slight difference in thermal conductivity can result in ground loop lengths to be 20-30% longer, thus increasing the payback periods. Accurate soil temperatures and thermal conductivity would result in savings in the pipe length.

The current study assumes a constant electrical tariff over the 25-year period; if a 2% year-on inflation is applied then the total saving by using a GSHP increases by about 40%.

4.3 Simple payback periods

The payback period (PBP) is the easy way to determine the time required to cover the costs. The PBP is the ratio between the differences in the total cost to the difference in the operation cost. The cost and energy performance are the only two parameters considered in the PBP. The Department of Energy, USA (DOE) does not consider PBP as a cost-effectiveness tool because it does not include the long-term factors such as the replacement costs and the time value of money. The simple payback period [10] can be summarized in the following equation:

$$PBP = \frac{K2 - K1}{(E+M)_1 - (E+M)_2} \qquad (6)$$

where,
PBP = payback time, years.
K = capital investment.
E = annual energy cost.
M = annual maintenance cost.
1 = system under consideration (ASHP).
2 = alternative system (GSHP).

The annual maintenance cost, M, is given by

$$M = \frac{0.5 * K}{year\ of\ life\ cycle} \quad (7)$$

M_2= (0.5*240000)/22 = 5454

where we have assumed that the maintenance cost for ASHP M_1 is double M_2.

From Tables 7 and 8, equation (7) becomes:

$$PBP = \frac{731{,}640 \ - 160000}{(77795 + 10909)_1 - \ (46729 + 5454)_2}$$

PBP = 15.7 years.

4.4 Underground thermal imbalance

For the GSHP to operate effectively and efficiently there has to be a balance in the underground thermal conditions. This balance means that heat released into the ground by heat exchangers on an annual basis should equal that extracted from the ground. This stability, however, can easily be disrupted by climatic conditions surrounding the buildings. In a cold climate, more heat will be taken from the ground to keep the buildings warm and less will be replaced [27]. In a hotter climate, where internal cooling is the priority, the reverse will take place. If these fluctuations are not properly controlled, then a thermal imbalance will occur in the soil due to reductions or increases in the ground temperature. This in turn will cause deterioration in the performance of the heat exchangers and heat pumps, leading eventually to failure of the systems. In addition, groundwater and soil type play an important role in the thermal load imbalance rate [27].

Ignoring the lack of thermal balance in the design stage leads to low system efficiency [28]. The imbalance ratio (IR) is defined as:

$$IR = \frac{Q_{inj} \ - \ Q_{ext}}{max(Q_{inj}\ ,Q_{ext})} * 100\% \quad (8)$$

where Q_{inj} is the accumulated heat rejected to the soil in the cooling seasons and Q_{ext} is the accumulated heat extracted from the soil in the heating seasons.

To determine the accumulated heat for the GSHP the COP and EER for the GSHP is assumed to be 4.4 and 14.9 respectively based on the catalogue and the ground load is determined as follows:

Cooling load, Q_{lc} = 196.2 kW/h*3412.142 = 669,462 Btu/h
Heating load, Q_{lh} = 38.1 kW/h *3412.142 =130,002 Btu/h
In the cooling mode, the condenser rejects heat to the ground heat exchanger, and the evaporator extracts heat from the load. The heat rejected at the condenser is given by

Q_{cond} = Q_{lc} ((EER + 3.412) /EER))
= 669,462 Btu/h * (14.9 + 3.412)/14.9
= 882,762 Btu/h

The heat extracted at the evaporator is given by
Q_{evap} = Q_{lh} * (COP -1)/COP
= 130002 * (4.4 – 1)/4.4
= 123000 Btu/h

Thus, the thermal imbalance ratio is given by

$$IR = \frac{100456 - 882762}{882762} X100\% = -88\%$$

The negative IR indicates that the heat transfer to the soil is more than the heat extraction which normally occurs in cooling dominated situations. A lower IR means a smaller difference between the heating and cooling loads. However, the thermal balance is the subject of our further investigations where we are attempting to simulate the whole system by using TRNSYS, but this is a very challenging and novel approach.

5. Discussion of the results of this Saudi Arabi application

The data for this example on the viability of GCHPs for small commercial buildings in a hot/dry climate, exemplified by Saudi Arabia gives a useful comparison of the energy consumption between ASHPs and GSHPs and indicates the relative effectiveness of both systems. The ASHRAE method was used to determine the length of the GHX and from the results detailed above the following can be drawn:

- The thermal properties of the soil and climate conditions has been analyzed and this study shows that the soil temperature is high, with an average 2.6 W/m.K.
- Accurate soil temperatures and thermal conductivity would result in savings of 20-30 % in the bore lengths and a 3°C increase in the soil temperature from 26°C to 29°C would lead to an increase of 43% in the length of the GHX from 4082m to 5831m.
- In the heating season, the GSHPs are able to heat the building as free heating (passive heating) due to the high temperature of the ground.
- The total cost savings of 22 years were determined for 45% and 37% at underground temperatures $26°C$ and $29°C$, respectively.
- The total annual cost of the power consumption for the GSHP is less than for the ASHP by 34.6%.
- GSHPs have been proven to be more cost efficient in the long term.
- The payback period would exceed 15.6 years when compared to the ASHP system. This may be due to the high initial cost required for the installation of GSHPs.
- One of the key challenges of GSHP systems in hot dry climates is the thermal imbalance.

6. Conclusion and Future work

6.1 Conclusion

In this study, comparison between GSHP and ASHP systems shows that GSHPs are technically feasible to use for air conditioning systems in hot dry region due to the significant temperature difference between the ambient air and the ground. However, the underground temperature is the most important factor in determining the GHX length which led to the lengthy payback period and increase in the initial cost.

This study also clearly shows that with the GSHP approach to cooling and heating, there will be a reduction in the energy consumption in buildings in Saudi Arabia and hence the cost. It will also help to minimize the CO_2 emissions in the region. The same result may be applicable to similar environmental conditions both in the Middle East and in other hot, dry climates with cool periods.

6.2 Future work

In this paper, we have addressed the problem of using GSHP in hot dry climates. In the future work, a sensitivity analysis of the whole GSHPs in the hot temperature range is required by using simulation software, such as TRNSYS to determine the most important parameters that influence the GSHPs efficiency such as: heat exchanger sizes, thermal imbalance, separation distance of pipe, life cycle for the system and hybrid GSHPs.

It is also suggested that the impact of the government's adoption of a new policy for using renewable energy technology, namely by subsidizing and encouraging residents to use alternative energy conservation methods such as solar, wind and geothermal energy is considered.

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