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Potential of ground source heat pump systems in cooling-dominated environments: Residential buildings

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ABSTRACT

For countries in the Arabian Peninsula, air conditioning (A/C) systems account for 65% of the energy consumption, all of which comes from fossil fuel. Given the preparation for the 2022 World Cup, which will be held in Qatar, the possibility of implementing ground source heat pump systems (GSHP) for A/C purposes is investigated. Due to its high thermal performance, GSHP is considered a viable solution for reducing the energy consumption of heating and A/C systems. However, for the GSHP system to gain popularity in cooling-dominated environments such as Qatar, financial and environmental benefits need to be demonstrated. These benefits strongly depend on local design practices and standards and on working conditions.

The work presented in this paper demonstrates the energy savings by using GSHP systems in the residential buildings sector in cooling-dominated environments. To achieve this goal, a common type of residential house located in Doha, Qatar, was chosen as a case study. The cooling load of the case study and the driving energy of two different air conditioning systems were estimated. The two considered air conditioning systems are the conventional air source heat pump system (reference system) and the ground source heat pump system. Finally, economic analysis of the proposed system for construction practices in Qatar was carried out.

The performed analyses show that the reduction in the prime energy demand and, consequently, the greenhouse gas emissions for the GSHP is 19% when compared to the conventional air source heat pump system. In addition, the analyses show that for the local conditions in Qatar the payback time of GSHP is 9 years.

1. Introduction

The global energy demand has exceeded 15×10^{10} MWh/year, 85% of which comes from fossil fuels, while renewable energy sources supply only about 6% (Seyboth et al., 2008; Moomaw et al., 2011; Jaber et al., 2011). Given the strong belief that climate change is anthropogenic and attributed to fossil fuel consumption, improving the performance of existing energy systems is a major challenge.

Heating and air-conditioning (A/C) systems account for about 33% of the world's total energy consumption (Wong et al., 2010; IEA, 2007; Seyboth et al., 2008). In hot, cooling-dominated, and underdeveloped countries, such as those in the Arabian Peninsula, A/C systems are the biggest energy consumer. In Saudi Arabia, for instance, A/C systems account for 65% of the total energy consumption in buildings (Said, 2010; Hasnain, 1999). Therefore, investigating the possibility for improving the performance of A/C systems in cooling-dominated environments is of great potential to save energy and reduce environmental impacts of fossil fuel.

Ground source heat pump (GSHP) system might be considered as a viable solution to reduce the energy consumptions of A/C systems. Several studies have been conducted to investigated the feasibility of GSHP systems in residential and commercial buildings (e.g., Esen and Yuksel, 2013; Balbay and Esen, 2010). In 2010, the total capacity of installed GSHP systems in the world was 51 GW producing 122 TWh/year with a capacity factor of 0.27 (actual operation hours/annual hours) (Lund et al., 2010). The GSHP system is one of the fastest growing applications of renewable energy, with installed capacity annual growth of 12.3% (Lund et al., 2010). A comparison with energy consumption of conventional A/C systems (i.e. air source heat pump) shows that GSHP system may results in a reduction of energy consumption by 60%, which is

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Nomenclature

$C_{d,an}$	the annual saving in driving energy of A/C system (\$)
C_{inv}	the total ground heat exchanger cost (\$)
C_p	the present value of the income of the first year of operation (\$)
d	the nominal discount rate (%)
E	required driving energy of the air conditioning system (MWh)
er	the escalation rate of electricity price (%)
L_b	the total borehole depth (m)
PBT	the payback time of GSHP system (year)
PW(GSHP)	the present worth of the cash inflows from the GSHP system (\$)
Q_c	cooling demand (MWh)
$q_{hc,i}$	the cooling demand at hour i (MWh)
$q_{mc,j}$	the cooling load of the month j (MWh)
RCOE	the current real cost of electricity in Qatar (\$/kWh)
$SCOP_A$	seasonal coefficient of performance of ASHP (dimensionless)
$SCOP_G$	seasonal coefficient of performance of GSHP (dimensionless)

expected to improve in the future (Jaber et al., 2011; Seyboth et al., 2008; Michopoulos et al., 2011). However, the benefits of GSHP systems in saving energy and construction costs strongly depends on local working conditions. These conditions include buildings thermal performance, ground thermal characteristics, and annual air temperature amplitude. In other words, the viability of GSHP systems may significantly differ from one region to another. For example, under the operation conditions in Saudi Arabia, it was shown that the implementation of GSHP systems in residential buildings could result in energy saving of A/C systems by 14–20% (Said, 2010). Another example, the utilization of GSHP systems in agricultural applications in Syria leads to 31% saving in energy consumption of heating and A/C system (Kharseh and Nordell, 2011; Kharseh, 2011). It is worth mentioning that, unlike Qatar where the ground water is shallow, the groundwater depth in Saudi Arabia is relatively large and, therefore, the geothermal boreholes are commonly backfilled (Sharqawy et al., 2009; Kharseh, 2011). In cooling-dominated environments, like Saudi Arabia, heat injection into the ground may lead to an increase of the ground temperature and, consequently, a decrease of the performance of GSHP systems. However, the presence of groundwater at shallow depths enhances the thermal dispersion, which helps in recovering the ground temperature and improving the performance of the GSHP systems (Diao et al., 2004; Sutton et al., 2003; Lee and Lam, 2007; Choi et al., 2013). Fortunately, the groundwater level in Qatar is only few meters below the ground surface, eliminating or reducing the need to backfill geothermal boreholes. In such conditions, the temperature plume is minor and, the long-term performance GSHP systems is expected to be better than backfilled ones.

Given the significant needs for air-cooling in Qatar, significant energy saving and environmental benefits could be realized by improving the performance of A/C systems. Therefore, the objectives of this study are to investigate the potential of energy saving of GSHP systems and evaluate their economic viability in cooling-dominated environment like Qatar.

The scope of this study is limited to space cooling in residential buildings and vertical closed-loop GSHP systems. The study will provide valuable reference for future evaluations of groundwater-filed GSHP systems in cooling-dominated environments.

2. Outline of ground source heat pump system

The heat pumping technology has been used for heating and A/C since mechanical heat pumping technology was invented. During winter, such system extract energy from a relatively cold source to be injected into the conditioned space. During summer, the system extract energy from conditioned spaces to be injected into a relatively warm sink. The temperature difference between the conditioned space and the heat source/sink is referred to as temperature lift. This temperature plays a major role in determining of the coefficient of performance (COP) and, consequently, the energy consumption of the heat pump. More specifically, extracting heat from a warmer source during winter or injecting heat into a colder sink during summer results in less energy consumption by the heat pump.

Due to the thermal inertia of the ground, the ground temperature below a certain depth (usually between 12 and 15 m) is almost constant throughout the year. Thus, the ground is warmer than the outdoor air during winter and colder than the outdoor air during summer. Therefore, using the ground as a heat source during winter or as a heat sink during summer leads to a reduced energy consumption of the heating and A/C systems. This fact has increasingly introduced GSHP systems as a smart solution for reducing energy consumption of HVAC systems.

Essentially GSHPs refer to a combination of a heat pump and a system for exchanging heat with the ground. The GSHP system extracts heat from the ground to heat buildings during winter or alternatively, inject heat from the buildings into the ground during summer. This heat transfer process is achieved by circulating a heat carrier (water or a water–antifreeze mixture) between a ground heat exchanger (GHE) and heat pump. The GHE is usually plastic pipe buried vertically or horizontally under the ground surface (Esen and Yuksel, 2013).

3. Methodology

Two stand-alone residential houses with the same specification were chosen as a case study. The thermal quality of the houses' envelope complies with the current building regulations in Qatar. An hourly analysis-based model was designed to simulate the cooling requirements of the two houses. For this purpose, weather data for Doha city was obtained from Meteonorm (METEONORM, 2004). Space cooling was provided by either air-source heat pump (ASHP) system (representing a reference system) or GSHP system (proposed system). Earth energy designer (Blomberg et al., 2000), which is a well-known commercial software, was utilized to design the GSHP system. Hour-by-hour energy simulations of the ASHP and GSHP systems were conducted for each house and the energy consumptions were compared. Finally, economic analysis was utilized to assess the merit of the GSHP systems including net present value, internal rate of return, and the payback time.

3.1. Case study

To investigate the potential of GSHP systems in Qatar, two common types of residential houses located in Doha were chosen as a case study. The model houses have a floor area of 144 m^2 and consist of four identical external walls, 12 m in length and 3 m in height, with a total window opening area of 5 m^2 on each wall. The houses were treated as one zone and were assumed to have a flat roof. The thermal quality of the buildings envelope complies with the current building regulations in Qatar. Table 1 shows the summary of the specifications of the modeled houses and the key design parameters.

Table 1
Specifications of studied building.

Indoor temperature (°C)	24	Outdoor ventilation air flow (l/s)		53
Throttling range (°C)	1	Designing outdoor temperature (°C)		46
Building area (m^2)	144	Number of people		4
Wall *U*-value (W/m^2 K)	0.57	Unoccupied indoor temperature (°C)		27
Roof *U*-value (W/m^2 K)	0.57	Absorptivity	Wall	0.67
Window *U*-value (W/m^2 K)	2.5		Roof	0.67
Widows shade coefficient	0.85	Internal load (W/m^2)	Lighting	2
Windows area (m^2)	20		Equipment	2
External walls area (m^2)	144	Building weight (kg/m^2)	External wall	500
Building volume (m^3)	388.8		Roof	623
Wall heat capacity (kJ/kg K)	0.864	Roof heat capacity (kJ/kg K)		0.852

3.2. Cooling load calculation

The estimation of cooling load was performed using the Hourly Analysis Program (HAP), which is a commercial model developed by Carrier Corporation (Carrier, 2012). HAP uses the ASHRAE-endorsed transfer function method for the calculations and hour-by-hour energy simulation techniques for the energy analysis. HAP can provide the cooling loads arising from all parts of the building (i.e. walls, windows, flat roofs and floors). The building specifications summarized in Table 1 and hourly weather data of Doha city shown in Fig. 1, which was obtained from Meteonorm (METEONORM, 2004), were utilized in the analysis.

3.3. Design of ground source heat pump

Designing GSHP systems involve the determination of the total borehole length required to provide the cooling need of a building at a satisfactory coefficient of performance (COP). The Earth Energy Designer (EED) (Blomberg et al., 2000), which is a commonly used software for designing GSHP systems, was used in this study. In the current study, the parameters summarized in Table 2 were utilized in the analyses. The following procedure was followed to design the GSHP system:

- Use the parameters in Table 2 and the annual and monthly cooling loads, which were obtained using the procedure outlined in Section 3.2 above, to run the EED model.
- Assuming a value of COP the heat pump (e.g., 2), and use the geofluid temperature from the EED model to calculate coefficient of performance (COP) using Eq. (4) that will discussed later.
- The calculated of COP is re-used in the EED instead of the value assumed at the beginning.
- Repeat the last two steps until a constant COP is reached.

It should be noted that the ground thermal conductivity was approximated using the analysis by Al-Rantisi et al. (2012). As part of ongoing research, the ground thermal properties will be determined using in situ thermal response tests, and the current assumptions will be validated or adjusted for future studies.

3.4. Assessment of COP

In the current work, engineering equation solver (EES) model was created to simulate a heat pump working at different condensing temperatures. The assumed values used in this model are summarized in Table 3. The parasitic power including the energy consumption of the evaporator and the condenser fans (or water circulating pump) were assumed to be 20% of compressor capacity (Esen et al., 2007).

To verify the model an experimental study on THIBAR22C heat pump unit (Edibon) was carried out at Qatar University. The values summarized in Table 3 were chosen so that the best correlation between the experimental and simulation results can be obtained. Table 4 shows a comparison between experimental and simulation.

In the lab, the temperature and the pressure in the condenser and the temperature and the pressure in the evaporator were measured. The calculated uncertainty in determining the heat pump COP was 2.7%. The calculation was performed considering that THIBAR22C uses J-type thermal couple as temperature sensor with an error of 0.75%, while pressure sensors are 1.6 accuracy class (grade-B) with deviation tolerance of 2.4% (OMEGA, 2014; Takashimakeiki, 2009). It is worth mentioning that the uncertainty calculation is based on the following conditions: temperature and pressure in the evaporator are 0 °C and 2.93 bar, respectively, while the temperature and pressure in the condenser are 55 °C and 14.92 bar, respectively. Therefore, the estimation of uncertainty may change with different testing. However, Esen et al. (2007) have shown that the uncertainty is not significantly affected by the temperature and pressure in evaporator and condenser. Fig. 2 shows the COP of a heat pump system working as a cooling machine at different condensing temperatures.

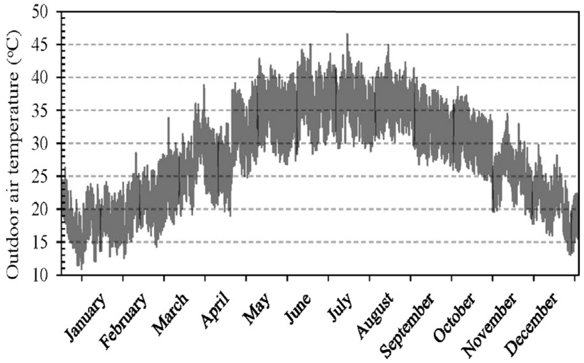

Fig. 1. Outdoor air temperature in Doha.

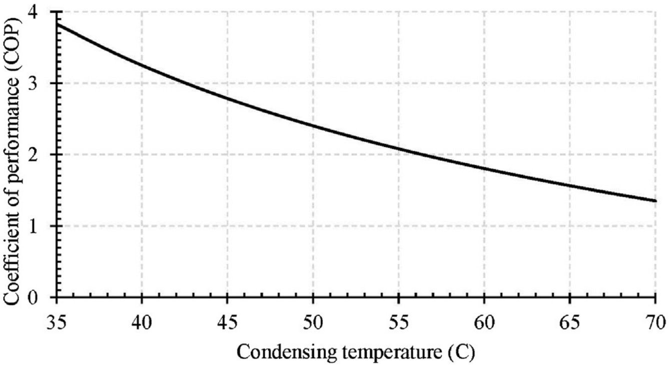

Fig. 2. Coefficient of performance of a heat pump working as a cooling machine along with condensing temperatures.

Table 2
Specifications of ground heat exchanger design.

Ground temp. (°C)	29	Pipe outer diameter of pipe (m)	0.032
Borehole type	Single-U	Pipe wall thickness (m)	0.003
Borehole configuration	1 (line)	Thermal conductivity of pipe (W/m, K)	0.42
Borehole spacing (m)	17	Pipe shank spacing (m)	0.07
Borehole diameter (m)	0.11	Filling thermal conductivity (W/m, K)	0.622
Flow rate (m^3/s)	0.002	Ground thermal conductivity (W/m, K)	2.63
Contact resistance (m, K/W)	0	Ground heat capacity (MJ/m^3, K)	2.45

Table 3
The assumptions made for assessing coefficient of performance of a heat pump.

Refrigerant	Evaporating temp. (°C)	Pressure drop (kPa)		Mechanical efficiency	Isentropic efficiency	Parasitic power (%)
		Condenser	Evaporator			
R134a	0	15	25	90	84	20

3.5. Driving energy of A/C system

To determine the energy consumption of the heat pump, the cooling load and the COP of the heat pump must be known. In ASHP systems, the condensing temperature is assumed to be 20 °C higher than outdoor air temperature (Kharseh, 2011; Kharseh and Altorkmany, 2012; Kharseh et al., 2011). Using Figs. 1 and 2, COP can be calculated for any hour, and the driving energy of ASHP system to provide the cooling requirements of the building is:

$$E_{\text{ASHP}} = \sum_{i=1}^{8760} \frac{q_{hc,i}}{\text{COP}_{A,i}} \tag{1}$$

where E_{ASHP} is driving energy; $q_{hc,i}$ is the cooling load during the hour '*i*' (from HAP); $\text{COP}_{A,i}$ is the corresponding coefficient of performance of ASHP working as cooling machine. The seasonal coefficient of performance ASHP (SCOP_A) is given by Eq. (2), where Q_c is annual cooling load of the house.

$$\text{SCOP}_A = \frac{Q_c}{E_{\text{ASHP}}} \tag{2}$$

For GSHP system, and due to the thermal characteristics of water, the temperature difference between condensation and the geofluid entering the condenser was assumed to be 10 °C (Kharseh, 2011; Kharseh and Altorkmany, 2012; Kharseh et al., 2011). Taking into account that temperature difference between extracted and re-injected geofluid is 5 °C, the difference between the condensing and mean geofluid temperatures (Fig. 4) becomes 7.5 °C. Hence, the annual driving energy of GSHP is given by Eq. (3):

$$E_{\text{GSHP}} = \sum_{j=1}^{12} \frac{q_{mc,j}}{\text{COP}_{G,j}} \tag{3}$$

where $q_{mc,j}$ is the cooling load during month '*j*' (from HAP); $\text{COP}_{G,j}$ is the coefficient of performance of GSHP system during month '*j*', which is determined by using the temperature of geofluid during month *j* (from EED) and Fig. 2. Finally, the seasonal coefficient of performance of the GSHP system (SCOP_G) is:

$$\text{SCOP}_G = \frac{Q_c}{E_{\text{GSHP}}} \tag{4}$$

The annual saving in driving energy of A/C system, $C_{d,an}$, due to replacing the conventional ASHP system with GSHP system in kWh is given by:

$$C_{d,an} = Q_c \cdot \left(\frac{1}{\text{SCOP}_A} - \frac{1}{\text{SCOP}_G} \right) \tag{5}$$

3.6. Economic analysis

Since GSHP system is a new technology in Qatar, financial and environmental benefits should be demonstrated in order to gain popularity. The economic analysis results in determining the different figures of merit including net present value, internal rate of return, and the payback time. Different methods can be used to evaluate the economic performance of the system: net present value method, internal rate of return method, annual cost method (Thuesen, 1989; Esen and Yuksel, 2013).

To carry out the economic analysis of GSHP project, the following terms have to be known: the initial investment cost, the annual saving (income), discount rate, and the escalation rate of electricity price. Survey in local industry shows that the drilling costs is about $8.24 per meter, while the price of polyethylene pipe of nominal diameter of 32 mm and thickness of 3 mm is $0.412 per meter (Al-Rantisi et al., 2012). Thus, the additional investment of the GSHP system over that of the conventional ASHP system, namely, the total ground heat exchanger cost in the single U-pipe type becomes:

$$C_{inv} = 9.1 \cdot L_b \tag{6}$$

The annual income from GSHP is the real cost of electricity (RCOE) times the annual energy saving. In 2001, RCOE was calculated for Qatar working conditions and found to equal $0.0573/kWh (Marafia, 2001). Marafia (2001) estimation of RCOE was based on the following assumptions: The capital cost is $275/kW, while the maintenance and fuel cost is $0.005 and $0.045/kWh, respectively. Taking into account the inflation rate in Qatar equals 1.9% (CIA, Page last updated on June 5, 2013), the current real capital cost is $351/kW, while the current maintenance cost becomes $0.0064/kWh. In addition, in 2001 natural gas price was $3.876 per standard cubic foot, while the current price is $3.947. Hence, current fuel cost of the gas-fired turbine in Qatar is $0.046/kWh. Following the same approach used by Marafia (2001), but with the nominal discount rate (d) = 4.5% (real discount is 2.5% and inflation

Table 4
Experimental and modeling calculations of COP of cooling machine.

Temperature (°C)		Pressure (bar)		Coefficient of performance	
Evaporation	Condensing	Evaporation	Condensing	Excremental	Modeling
1.3	43.2	11	1.9	2.6	2.7

is 1.9%), one can see the current real cost of electricity generation from gas turbine in Qatar is \$0.0684/kWh. Taking into account the carbon dioxide emissions cost, which is \$0.024/kWh (Ramadhan et al., 2013), the current real cost of electricity in Qatar becomes:

$$\text{RCOE} = \$0.0924 \text{ per kWh} \tag{7}$$

As a result, the present value of the income of the first year of operation (in USD) (i.e., the present value of the cash flow of the first year (C_p) due to replacing the conventional ASHP system with GSHP) is:

$$C_p = \frac{1+\text{er}}{1+d} \cdot \text{RCOE}_{gt} \cdot C_{d,an} \tag{8}$$

where '*er*' is the escalation rate of electricity price. So, the present worth of the cash inflows from the GSHP project during the lifetime of the system becomes:

$$\text{PW}\left(\text{GSHP}\right) = \sum_{n=1}^{N} \left(\frac{1+\text{er}}{1+d}\right)^{n} \text{RCOE} \cdot Q_c \cdot \left(\frac{1}{\text{COP}_A} - \frac{1}{\text{COP}_G}\right) \tag{9}$$

where '*N*' is lifetime of the GSHP system. In finance, net present value (NPV) of a project is used to help the decision maker to distinguish between different investment opportunities. It is always better to invest in the project with a higher NPV. The NPV is defined as the sum of the investment costs (negative) and the present worth of the cash inflows (positive) over the life of the project:

$$\text{NPV} = -C_{inv} + \text{PW}\left(\text{GSHP}\right) = -C_{inv} + \sum_{n=1}^{N} \left(\frac{1+\text{er}}{1+d}\right)^{n} \text{RCOE} \cdot Q_c \cdot \left(\frac{1}{\text{COP}_A} - \frac{1}{\text{COP}_G}\right) \tag{10}$$

where '*d*' is the nominal discount rate. Obviously, the NPV provides the total net profit updated to the initial moment.

In order to prioritize different projects the internal rate of return (IRR) can be used. The latter is the discount rate that makes the net present value (Eq. (10)) equals zero. The higher a project's internal rate of return, the more desirable it is to undertake the project.

Finally, the viability of a renewable energy project is usually evaluated by estimation of the payback time (PBT) of the installation in years. The PBT is defined as the period necessary to recover the project cost of an investment while accounting for the time value of money. In other word, the PBT is the time required to make the accumulated present value of the cash flows covers the initial investment cost (Yard, 2000). In the current work, a mathematical expression of the payback time is obtained by solving Eq. (16) reported by Esen et al. (2006). Thus, the payback time becomes:

$$\text{PBT} = \frac{\ln\left[1 + \frac{C_{inv} \cdot \left(\frac{1+\text{er}}{1+d} - 1\right)}{C_p}\right]}{\ln\left(\frac{1+\text{er}}{1+d}\right)} \tag{11}$$

where 'C_{inv}' is the total ground heat exchanger cost; '*d*' is the nominal discount rate; 'er' is the escalation rate of electricity price; 'C_p' is the present value of the income of the first year of operation.

4. Results and discussion

The cooling load and the monthly cooling share (ratio of monthly load to the annual load) of the case study were simulated using HAP software. The results are shown in Table 5 and Fig. 3.

The simulation shows that ground heat exchanger of four boreholes at line-configuration 1 × 2 with a total borehole length of 250 m is enough to provide the case study with the cooling requirements. In other words, required borehole's length per MWh of cooling load is 6.9 m or 1.7 m per square meter of the building area.

Table 5
Result of cooling load calculation.

Annual Cooling load (MWh)	36.3
Number of cooling hours (h)	6107
Maximum cooling capacity (kW)	11.7
Time of occur max. cooling capacity	On 16 July at 15:00

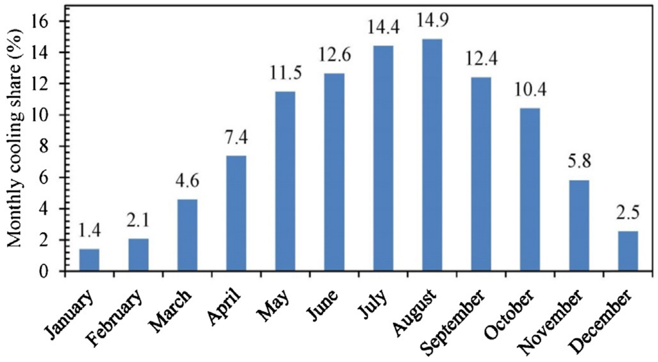

Fig. 3. Monthly cooling share and monthly cooling load of the case study.

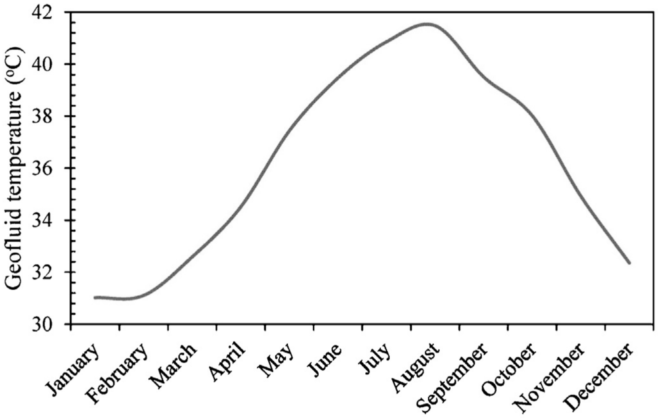

Fig. 4. Mean geofluid temperature from the borehole.

The mean geofluid temperature from the borehole is illustrated in Fig. 4. It is worth mentioning that economic optimization has been made to select the optimal total borehole depth. The examined borehole depths and configurations are shown in Table 6.

Considering that the condensing temperature is 20 °C higher than outdoor air temperature (Fig. 1) in ASHP systems, and 7.5 °C higher than the mean geofluid temperature (Fig. 4) in GSHP systems, the monthly condensing temperature of ASHP and GSHP systems for each month can be calculated. Fig. 5 illustrates the condensing temperature (operation temperature) of the conventional ASHP system and the proposed GSHP system.

Combining the results of Fig. 5 into Fig. 2, the average monthly COP_A of ASHP system and the average monthly COP_G of GSHP system can be assessed, and the results are presented in Fig. 6. As it

Table 6
The examined borehole depths and configuration.

Configuration	Depth (total depth) (m)	Payback time (years)
233	150 (600)	16
233	125 (500)	13.5
233	100 (400)	11.2
21	150 (450)	12.2
21	100 (300)	9.5
1	125 (250)	9
1	100 (200)	9.4

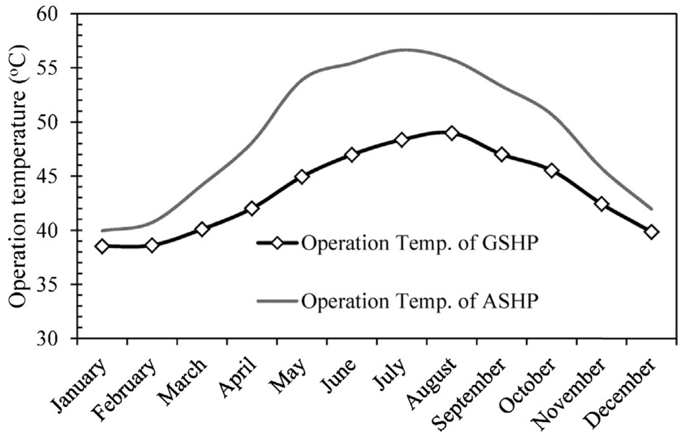

Fig. 5. The operation temperature (condensing temperature) of the GSHP and of ASHP.

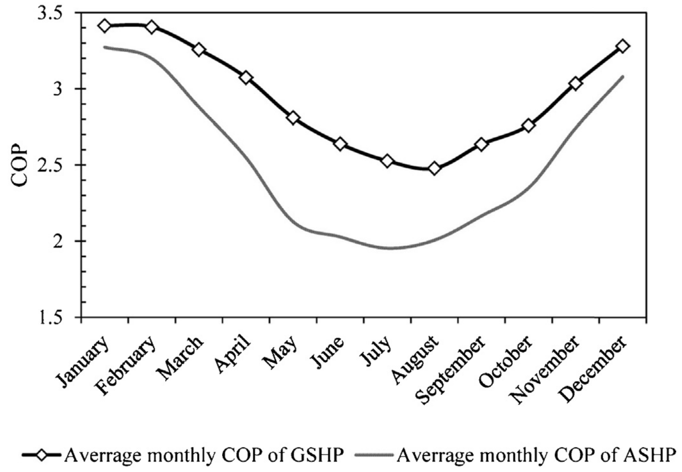

Fig. 6. Monthly average coefficient of performance of GSHP and ASHP.

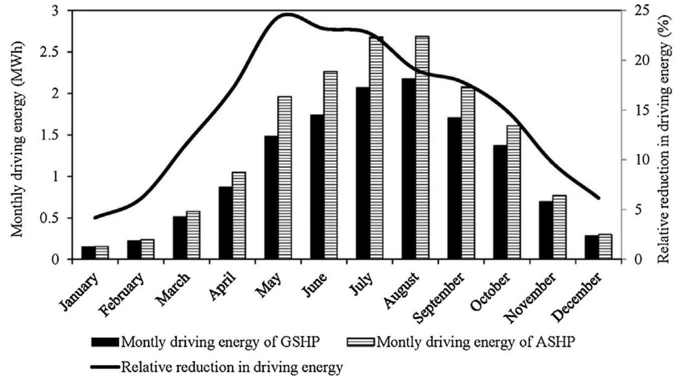

Fig. 7. The monthly driving energy of A/C system for both ASHPs and GSHPs and relative reduction in driving energy of A/C system due to replacing ASHPs with GSHPs.

can be seen the improvements in COP due to utilizing of GSHPs is the highest during the summer months when the cooling load is high.

This way the monthly driving energy of the ASHP and GSHP systems can be assessed using Eqs. (1) and (3). The monthly driving energy of ASHP and GSHP systems and the relative reduction in the driving energy is shown in Fig. 7.

At current local price of drilling and plastic pipe, the economic analysis shows that the additional investment of GSHP over that of the conventional ASHP system is $2275 (Eq. (6)). Particularly, the construction cost of GSHP system in Qatar is $15.8 per square meter of the building area or $62.7 per MWh of cooling load. For 30 years lifetime of the project with inflation rate of 1.9% and the discount rate is 2.5%, the net present value of the project equals $3705, while the internal rate of return equals 14.3%. Fig. 8 shows the cumulative cash flow of the proposed system. Using Fig. 8 it can be seen that the payback time (PBT) of GSHP system is slightly more than 9 year (9.1 year using Eq. (11)).

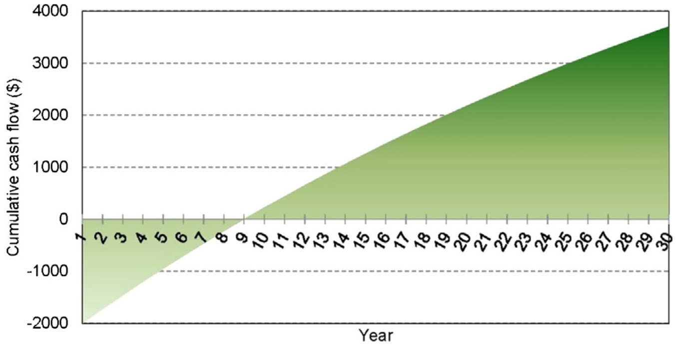

Fig. 8. Cumulative cash flow rate of GSHP system at working conditions of Qatar.

5. Conclusion

This study presents an investigation of alternative renewable energy option for reducing energy consumption of air conditioning systems of buildings in cooling-dominated environments such as Qatar. The proposed option is the ground source heat pump. It is worth pointing out that despite the present study is limited to Doha climate conditions, it is expected that the approach could be extended to all Arabian Gulf countries where heating requirements are very low. The analyses presented in the paper show that:

- The annual cooling load of a residential building is quite high and in the order of 251 kWh/m^2.
- The required length of the borehole is 6.9 m per MWh of cooling load, 21.4 meter per kW of cooling capacity, or 1.7 m per square meter of the building area.
- The incremental construction cost of GSHP system in Qatar is $62.7 per MWh of cooling load, $194.4 per kW of cooling capacity, or $15.8 per square meter of the building area.
- The implementation of GSHP systems results in reducing energy consumption and, consequently, the greenhouse gas emissions of A/C systems in Qatar by 19%.
- The internal rate of return of GSHP system for residential buildings in Qatar is 14.3%.
- The payback time of the proposed systems is 9 year.

In future work the possibility of improving the viability of GSHP system will be investigated at Qatar conditions by improving the thermal performance of the external shell of the building or using geothermal deep foundations (energy piles).

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