Journal of Innovative Construction and Petrochemical Technologies, Vol.3, No.2 (December, 2026), 1-10

P-ISSN: xxxx- xxxx | E-ISSN: 3007-9861 | DOI: https://doi.org/10.71285/icpt.v3i2.26

Journal of Innovative Construction and Petrochemical Technologies
https://icpt.ouk.kz/index.php/icpt/index

Research Article

Al-Shirqat – Iraq Reducing Energy Demand in Iraq Buildings Using Shallow Geothermal

Firas Ahmed Mohammed[1*], Prof. Dr. Fayyadh Mohammed Abed[2], Prof. Dr. Raed Rashad Jasim[3]
Department of Mechanical Engineering, College of Engineering, Tikrit University, Iraq
Salah Al-Din Governorate
* Correspondence: frasa0528@gmail.com

Abstract: This study presents an economic and environmental assessment of a proposed shallow geothermal heating system for building applications under local climatic conditions in Iraq. The analysis was carried out for a room with a total heating load of 905 W, with the performance of the geothermal system compared with two conventional alternatives, namely: a fossil-fuel-based heating system and a direct electric heating system. The total electrical input power of the geothermal system included both the heat pump power and the auxiliary fan power, in order to reach a more realistic economic evaluation. The assessment relied on economic and environmental indicators including annual energy consumption, annual operating cost, life cycle cost, annualized cost, unit thermal energy cost, annual savings, and direct carbon dioxide emissions. The results showed that the geothermal system required a total electrical power of 340.67 W, and an annual electrical energy consumption of 2486.87 kWh/year. By adopting an electricity price of 0.18 USD/kWh, the annual electricity cost reached 447.64 USD/year, while the total annual operating cost reached 496.54 USD/year. As for the conventional fuel-based system, its annual operating cost reached 645.79 USD/year, which led to achieving annual savings of 149.25 USD/year in favor of the geothermal system, with a reduction in operating cost of 23.11%. The annual energy cost difference between the geothermal system and the direct electric heating system also reached 741.53 USD/year. From the environmental point of view, the amount of direct emissions from the conventional system reached approximately 1.41 ton CO_2/year, whereas the geothermal system produced no direct combustion emissions at the point of use. The results confirm that the proposed geothermal system represents an economically and environmentally applicable alternative in building heating applications under local conditions.

Keywords: Shallow geothermal energy; Building heating; Economic feasibility; Life cycle cost; Operating cost; Carbon emissions

INTRODUCTION

Heating systems in buildings are considered among the main energy-consuming applications, and their importance increases in regions characterized by clear climatic variation between the seasons of the year. In Iraq, conventional systems dependent on fossil fuels or direct electric heating are still the most commonly used means in residential and service buildings, despite their high operating costs and their clear environmental effects [7,8].

In contrast, shallow geothermal energy represents one of the promising alternatives for heating and cooling buildings, because it exploits the thermal energy stored in layers close to the earth's surface using heat pump systems with a high coefficient of performance. One of the most important advantages of these systems is that they do not depend on direct fuel combustion at the point of use, and they also make it possible to reduce the electrical power required in comparison with direct electric heating systems, thus reducing operating cost and environmental impact together [4,5].

Although geothermal applications have received wide attention in a number of countries, local studies dealing with the actual economic feasibility of these systems in Iraq are still limited, especially those that link thermal performance with economic and environmental indicators at the same time. From here comes the importance of this study, which aims to evaluate a proposed shallow geothermal heating system for a room with a known thermal load, with comparison against a conventional fuel-based system and a direct electric system [1,3,6].

Objective of the Study

The present study aims to evaluate the economic performance of a proposed shallow geothermal heating system, calculate the annual electrical energy consumption and the annual operating cost of the system, compare the geothermal system with a conventional fossil-fuel-based system and with a direct electric heating system, determine the life cycle cost, annualized cost, and unit thermal energy cost, estimate the annual savings achieved from using the geothermal system, and analyze the environmental impact through comparison of direct carbon dioxide emissions.

Description of the System and Study Assumptions

The study adopted a proposed shallow geothermal heating system to serve a room with a total heating load of 905 W. The system consists of a heat pump, an auxiliary fan, heat exchange components, and supporting parts. The analysis adopted the inclusion of the fan power within the total electrical input power of the system, in order to avoid exaggeration in estimating the economic savings resulting from neglecting the auxiliary electrical loads [9,10].

Table 1. Basic data of the geothermal system

Item	Symbol	Value	Unit
Initial investment cost	C_0	1630	dollar
Total thermal load	$\mathrm{Q}_{\mathrm{load}}$	905	W
Coefficient of performance	COP	7.5	—
Fan power	P_{fan}	220	W
Daily operating hours	t_{day}	20	h/day
Electricity price	P_e	0.18	dollar/kWh

Maintenance and service percentage	f_{m+s}	3%	—
Operating lifetime	n	25	year
Discount rate	i	10%	—

METHOD

Methodology of Economic and Environmental Analysis

Calculation of the electrical power of the heat pump[2,11].

$P_{hp}=\frac{\mathrm{Q}_{\mathrm{load}}}{COP}$

Calculation of the total input electrical power

$P_{in,total}= P_{hp}+P_{fan}$

Calculation of annual electrical energy consumption

$E_{day}=P_{in,total}\times t_{day}$,, $E_{ann}=E_{day}\times 365$

Calculation of the annual thermal energy required[1,6].

$E_{th,ann} = \mathrm{Q}_{\mathrm{load}} * t_{nan}$

Calculation of the annual electricity cost of the geothermal system

$C_{el=} E_{ann} * P_e$

Calculation of annual maintenance and service cost [2,12].

$C_{m+s=} f_{m+s}\times C_0$

Calculation of the total annual operating cost of the geothermal system

$C_{op}=C_{el}+C_{m+s}$

Calculation of the cost of the conventional fossil-fuel-based system

$E_{fuel,ann}= \frac{E_{th,ann}}{\eta}$,, $C_{fuel}=E_{fuel,ann}\times P_{fuel}$,, $C_{conv,op}=C_{fuel}+C_{m,conv}$

Calculation of annual savings[13,14].

$S_{ann}=C_{conv,op}$- $C_{geo,op}$

Calculation of the percentage reduction in operating cost

$R_{op} = \frac{C_{conv,op}- C_{geo,op}}{C_{conv,op}} * 100$

Calculation of life cycle cost

$(\frac{P}{A},i,n) = \frac{(1+i)^n-1}{i(1+i)^n}$,, LCC = $C_0+ C_{op}(\frac{P}{A},i,n)$

Calculation of the annualized cost

$(\frac{A}{P},i,n) = \frac{i(1+i)^n}{i(1+i)^n-1}$,, ALCC = LCC× $(\frac{A}{P},i,n)$

Calculation of unit thermal energy cost [2,15].

$C_E= \frac{ALCC}{E_{th,ann}}$,, $C_{E,op}= \frac{C_{op}}{E_{th,ann}}$

Comparison with the direct electric heating system

$P_{elec,dir}= \mathrm{Q}_{\mathrm{load}}$,, $E_{elec,dir}=P_{elec,dir}* t_{nan}$

$C_{elec,dir}=E_{elec,dir}* P_e$,, $\Delta C_{energy,2}= C_{elec,dir}- C_{el,geo}$

Calculation of carbon dioxide emissions [9,16].

$CO_{2,conv} = E_{fuel,ann}* EF_{fuel}$

RESULT AND DISCUSSION

The results showed that the geothermal system, after including the fan power within the total input electrical power, required a total electrical power of 340.67 W, and its annual electrical energy consumption reached 2486.87 kWh/year. By adopting an electricity price of 0.18 USD/kWh, [6]. the annual electricity cost reached 447.64 USD/year, while the total annual operating cost reached 496.54 USD/year [17].

Table 2. Final economic results of the geothermal system

Indicator	Symbol	Value	Unit
Input electrical power	P_{hp}	120.67	W
Fan power	P_{fan}	220	W
Total input electrical power	$P_{in,total}$	340.67	W
Daily energy consumption	E_{day}	6.8133	kWh/day
Annual energy consumption	E_{ann}	2486.87	kWh/year
Annual thermal energy	$E_{th,ann}$	6606.5	kWh/year
Annual electricity cost	C_{el}	447.64	dollar/year
Maintenance and service cost	C_{m+s}	48.90	dollar/year
Annual operating cost	C_{op}	496.54	dollar/year
Life cycle cost	LCC	6137.06	dollar
Annualized life cycle cost	ALCC	676.12	dollar/year
Unit thermal energy cost	C_E	0.1023	dollar/kWh thermal
Direct operating cost per unit energy	$C_{E,op}$	0.0752	dollar/kWh thermal

On the other hand, the fuel consumption of the conventional system reached 7772.35 kWh/year, and its total annual operating cost became 645.79 USD/year. This means that the geothermal system achieved annual savings of 149.25 USD/year compared with the conventional fuel-based system, with a reduction in operating cost of 23.11% .

Table 3. Operational comparison between the geothermal system and the conventional system

Indicator	Symbol	Geothermal system	Conventional system	Unit
Annual thermal energy	$E_{th,ann}$	6606.5	6606.5	kWh/year
Annual operating cost	C_{op}	496.54	645.79	dollar/year
Operating unit energy cost	$C_{E,op}$	0.0752	0.0978	dollar/kWh thermal
Annual savings	S_{ann}	149.25	—	dollar/year
Percentage reduction in operating cost	R_{op}	23.11	—	%
Direct carbon dioxide emissions	$CO_{2,conv}$	—	1.41	ton/year

At the level of unit energy cost, the direct operating cost of the geothermal system amounted to 0.0752 USD/kWh thermal, compared with 0.0978 USD/kWh thermal for the conventional fuel-based system. This indicates that the geothermal system supplies thermal energy at a lower cost, even after including the electrical load of the fan in the calculations [18].

The comparison with the direct electric heating system also showed that the economic difference is much larger. While the annual energy cost of the geothermal system amounted to 447.64 USD/year, the annual cost of direct electric heating amounted to 1189.17 USD/year, that is, with a difference of 741.53 USD/year in favor of the geothermal system. From a long-term perspective, the life cycle cost of the geothermal system reached 6137.06 USD, and the annualized cost reached 676.12 USD/year, while the unit thermal energy cost on the basis of annualized cost reached 0.1023 USD/kWh thermal. From the environmental point of view, the results showed that the conventional fuel-based system produces about 1.41 ton of carbon dioxide annually, whereas the geothermal system produces no direct combustion emissions at the point of use. The results of the sensitivity analysis also showed that the geothermal system maintains a positive operational advantage in all the studied cases, whether when the electricity price changes or when the fuel price changes. When the electricity price increases by 20%, the geothermal cost rises to 586.26 USD/year and the annual savings decline to 59.53 USD/year, while when it decreases by 20%, the geothermal cost falls to about 407 USD/year and the annual savings increase to about 238.98 USD/year. As for when the fuel price increases by 20%, the annual savings rise to 273.61 USD/year, and when it decreases by 20%, they remain positive at 24.89 USD/year [9].

Table 4. Results of the operational sensitivity analysis

Variable	Case	Geothermal cost (dollar/year)	Conventional cost (dollar/year)	Annual savings (dollar/year)
Base case	—	496.54	645.79	149.25
Electricity price	-20%	407	645.79	238.98
Electricity price	+20%	586.26	645.79	59.53
Fuel price	-20%	496.54	521.43	24.89
Fuel price	+20%	496.54	770.15	273.61

Figure (1): Comparison of annual operating cost between the geothermal system, the fuel-based system, and the direct electric system.

This figure shows the difference in annual operating cost between the three alternatives. The annual operating cost of the geothermal system reached 496.54 USD/year, compared with 645.79 USD/year for the conventional fuel-based system and 1189.17 USD/year for the direct electric system. [19].

Figure (2): Comparison of the direct operating unit thermal energy cost.

This figure shows that the direct operating unit thermal energy cost of the geothermal system reached 0.0752 USD/kWh thermal, whereas it reached 0.0978 USD/kWh thermal for the conventional fuel-based system.

Figure (3): Comparison of direct carbon dioxide emissions.

This figure shows the environmental difference between the two systems. The geothermal system recorded no direct combustion emissions at the point of use, whereas the direct emissions of the conventional fuel-based system reached about 1.41 ton CO_2/year.

Figure (4): Sensitivity analysis of annual savings.

This figure represents the change in annual savings achieved from using the geothermal system under four different operating conditions, namely: a 20% decrease in electricity price, a 20% increase in electricity price, a 20% decrease in fuel price, and a 20% increase in fuel price. The results showed that annual savings remained positive in all studied cases

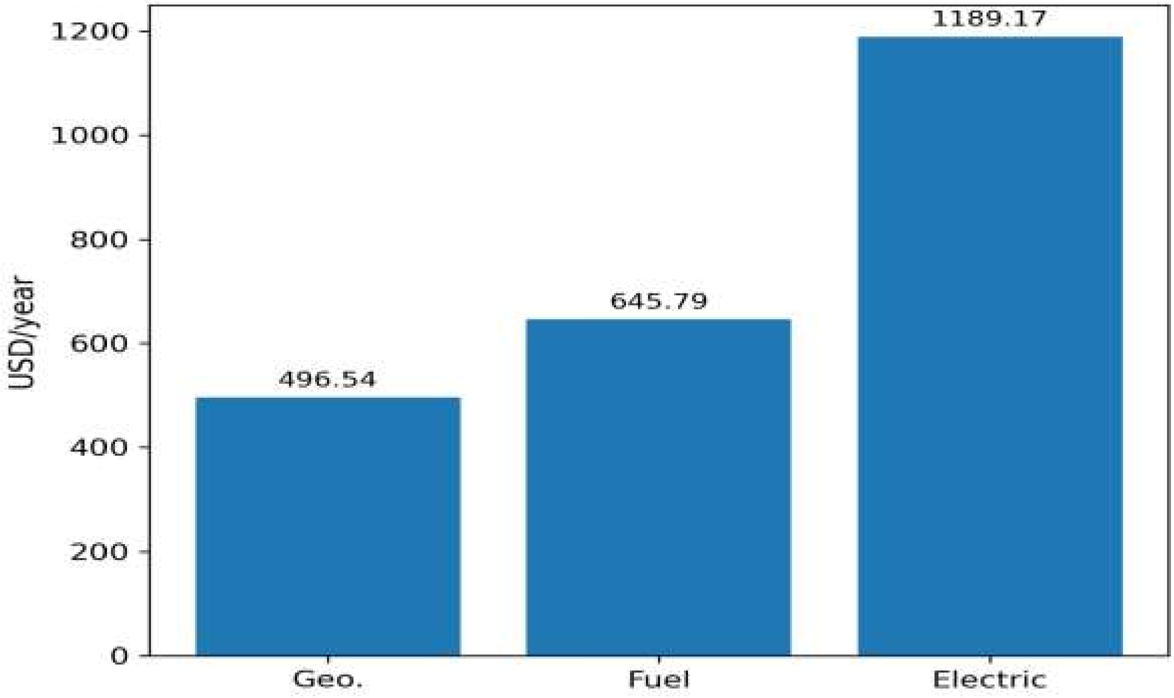

Figure 1. Annual operating cost comparison between geothermal, fuel-based, and direct electric heating systems

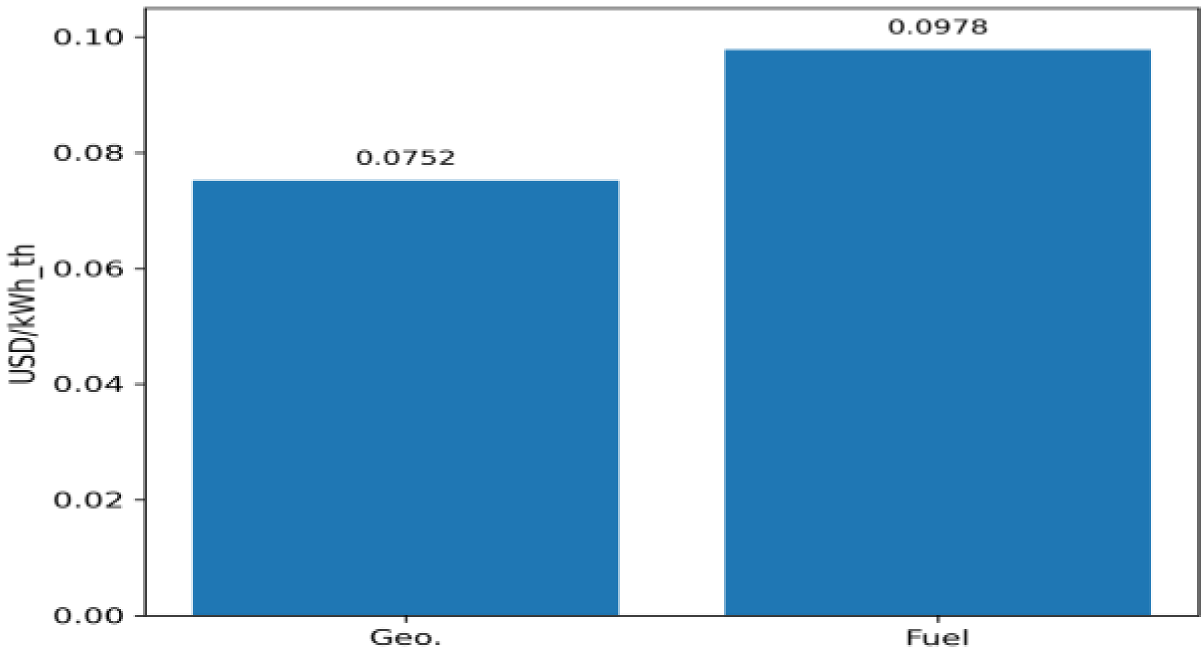

Figure 2. Comparison of unit thermal energy cost between geothermal and fuel-based heating systems

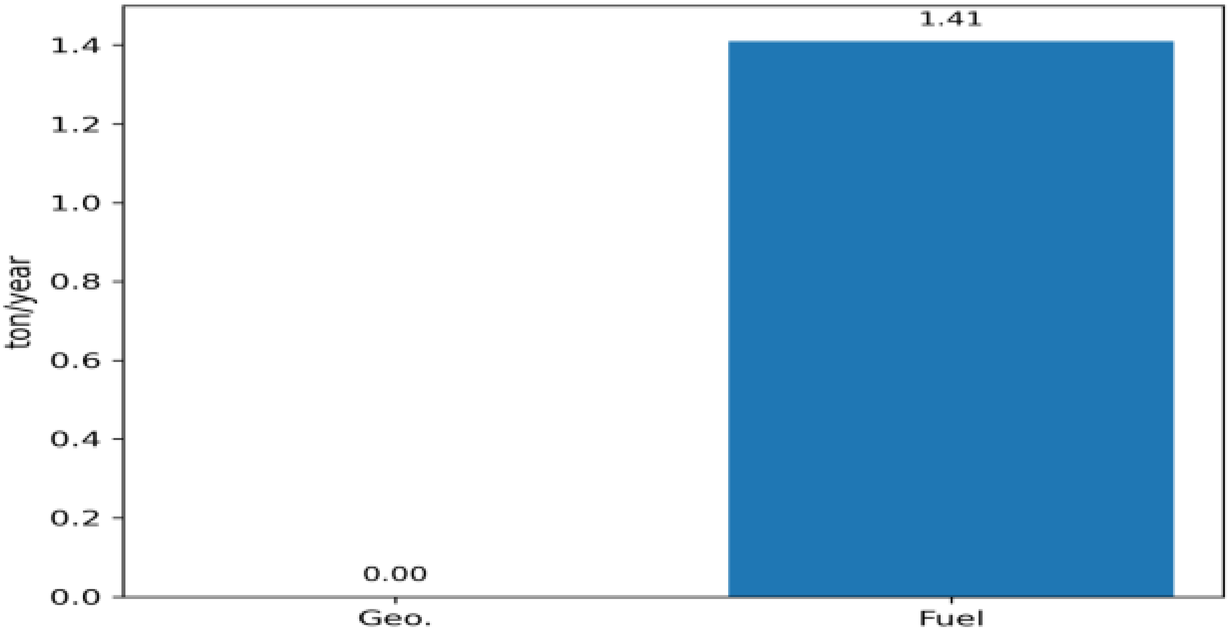

Figure 3. Annual carbon dioxide (CO_2) emissions comparison between geothermal and fuel-based systems

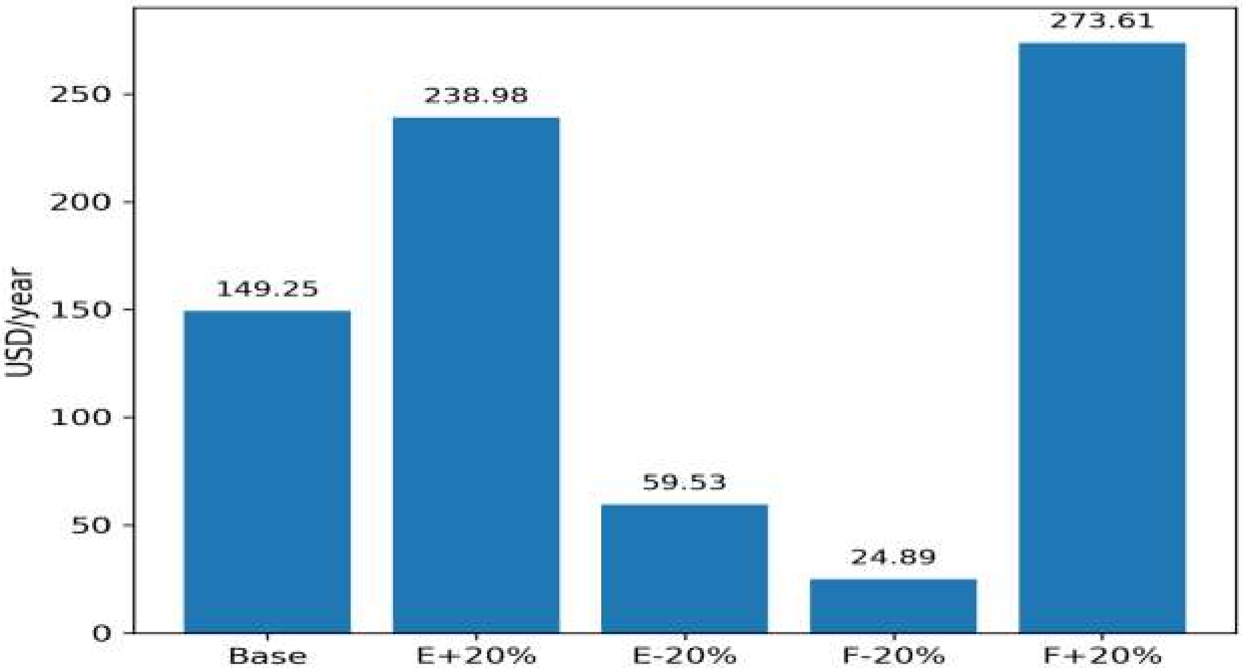

Figure 4. Sensitivity analysis of annual savings under variations in electricity and fuel prices (±20)

Validation and Reliability of the Model

The adopted methodology in this study is based on analytical procedures and thermo-economic indicators that are widely used in the evaluation of geothermal energy systems and heat pump applications, which provides the model with a sound scientific basis and strengthens the credibility of the obtained results. The assessment was developed using standard calculations for annual electrical energy consumption, annual operating cost, life cycle cost, annualized cost, and unit thermal energy cost, in addition to the estimation of direct carbon dioxide emissions. These indicators are commonly employed in previous studies concerned with the economic and environmental evaluation of shallow geothermal systems, and their combined use in the present work makes it possible to assess the system from integrated technical, economic, and environmental perspectives rather than from a single viewpoint only [5].

The reliability of the model was further enhanced through the selection of assumptions and operating parameters that are consistent with values commonly reported in the literature for similar geothermal heating applications. The adopted coefficient of performance, operating hours, discount rate, maintenance percentage, and expected lifetime were all chosen within realistic and practically acceptable ranges [12]. In addition, the total electrical input power of the geothermal system was determined by including not only the heat pump power but also the auxiliary fan power, which improves the realism of the economic analysis and prevents overestimation of the expected savings. This treatment reflects the actual operational behavior of the proposed system more accurately, since auxiliary loads represent a real part of energy consumption in practical heating applications.

The validity of the model is also supported by the logical consistency of the obtained results with the expected behavior of ground-source heat pump systems reported in previous studies. The results showed that the geothermal system provides lower annual operating cost than the conventional fuel-based heating system and significantly lower annual energy cost than direct electric heating. This trend is in agreement with the well-established understanding that shallow geothermal systems can deliver thermal energy more efficiently due to the relatively high coefficient of performance of heat pumps and the stable thermal conditions of the ground [3]. Similarly, the environmental findings of the present study are consistent with the physical operating principle of geothermal systems, since the proposed system does not rely on direct fuel combustion at the point of use and therefore does not produce direct combustion emissions during operation, unlike conventional fossil-fuel-based heating systems.

Additional confidence in the model was obtained through the sensitivity analysis, which examined the effect of changes in electricity and fuel prices on the annual savings. The results demonstrated that the geothermal system maintained a positive economic advantage under all investigated scenarios, including increases and decreases in both electricity and fuel prices. The preservation of the same general trend under varying economic conditions indicates that the model is not overly dependent on a single set of assumptions, but rather remains stable within a realistic range of possible operating conditions. This stability is an important indicator of model robustness and suggests that the conclusions drawn from the analysis are dependable and not the result of narrow or overly idealized assumptions. [11].

Accordingly, the reliability of the present model arises from four main aspects: the use of established analytical equations, the adoption of realistic input assumptions, the agreement of the obtained results with trends reported in previous literature, and the stability of the conclusions under sensitivity analysis. On this basis, the model can be considered sufficiently reliable for evaluating the economic and environmental feasibility of the proposed shallow geothermal heating system under the local conditions of Al-Shirqat and in other regions with comparable climatic and operating characteristics. [20].

CONCLUSION

The results of this study showed that the proposed geothermal heating system required a total electrical power of 340.67 W after including the fan power, and its annual electrical energy consumption reached 2486.87 kWh/year, leading to an annual operating cost of 496.54 USD/year. In comparison, the annual operating cost of the conventional fuel-based system reached 645.79 USD/year, which means that the geothermal system achieved annual savings of 149.25 USD/year and reduced the operating cost by 23.11% relative to the conventional system. In addition, the direct operating unit thermal energy cost of the geothermal system reached 0.0752 USD/kWh thermal, which was lower than that of the conventional system. The comparison with direct electric heating also showed that the annual energy cost difference reached 741.53 USD/year in favor of the geothermal system. From an environmental perspective, the conventional system emitted about 1.41 ton CO_2/year, whereas the geothermal system produced no direct combustion emissions at the point of use. Therefore, the proposed geothermal system can be considered an economically and environmentally suitable alternative for building heating in Al-Shirqat and in other regions with similar local conditions.

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