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Effect of a geothermal heat pump system on cooling residential buildings in a hot, dry climate

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ABSTRACT

In the last century, electricity demand has doubled due to urban expansion, which has contributed to the formation of more urban heat islands (UHI) and the appearance of environmental hazards such as the global climate change phenomenon. Since residential buildings are considered the main electricity consumer sector in Egypt, they consume up to 42% of total energy consumption, which contributes to increasing temperatures and constitutes UHI in cities. In this context, the research aims to examine the effectiveness of using the closed vertical loop geothermal system ($GSHP_{CV}$) for cooling residential buildings in a hot, dry climate, such as Cairo, Egypt. In addition to determining its effect on carbon emissions and the amount of energy consumed for cooling, this was done using TRNSYS-17 software as a simulation tool to compare the traditional building in a hot, dry climate before and after adding $GSHP_{CV}$ in Cairo, Egypt. The simulation revealed that using $GSHP_{CV}$ in hot, dry climate zones has a significant impact on residential buildings. It reduced the electricity consumption up to 19.7% of the electricity consumed for cooling, and it reduced temperatures indoors for buildings up to 15.8% on the ground floor, up to 11.3% on the first floor, and up to 3.5% on the roof floor. In addition, it reduced up to 19.7% of the carbon emissions and reached human thermal comfort on the ground floor for the study case at peak times during the summer period. Which provide a solution to reduce UHI and environmental hazards such as climate change.

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KEYWORDS Cooling using geothermal energy; geothermal closed vertical loop system ($GSHP_{CV}$); hot, dry climate; residential buildings; TRNSYS-17 software; temperature reduction; carbon emission reduction; electricity consumption reduction

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Introduction

The cities are now characterized by human density, a lack of vegetation, and an abundance of impermeable surfaces. Which contributes to the increase in temperatures, the formation of urban heat islands (UHI), which causes the increase in energy consumption, and the phenomenon of global climate change to emerge [1].

Today, the two biggest challenges facing the entire world are climate change and energy supply [2]. In developing nations, one of the main reasons for increasing energy consumption is the cooling of buildings. Due to population growth and industrialization, it is believed that more than a third of the energy spent in buildings is spent on cooling systems [3]. According to previous studies, an increase of 2°C in temperature will lead to an increase of 1–9% in electricity demand. This increase in electricity demand will increase fossil fuel combustion, which produces greenhouse gas emissions and causes climate change (EPA.gov [4].

Using alternative energy resources, such as renewables, especially in countries with a hot, dry climate, such as Egypt, is essential due to the negative effects of greenhouse gases, which cause environmental hazards, and the exhaustion of fossil fuel resources, in addition to the growing need for energy to achieve thermal comfort in indoor environments [5].

Today, the challenges facing architects are not only to preserve and improve the thermal performance of buildings but also to reduce the energy consumption needed for cooling buildings in hot, dry regions, which often increases in the summer season [6].

Using geothermal energy as a sustainable technique for cooling buildings in hot, dry climatic zones could be one of the solutions for cooling indoor spaces and overcoming the environmental problems caused by energy generation nowadays [7; 8].

This research tackles the effect of geothermal heat pump systems on cooling residential buildings in a hot, dry climate zone and partial replacing the HVAC cooling system, which will reduce greenhouse gas emissions. This research used a simulation method to measure the effect of installing geothermal systems to cool residential buildings located in hot, dry climates such as Egypt. While space heating and cooling comprise over 50% of the global energy demand [ReN21].

The main goal of this research is to examine the effectiveness of using the closed vertical loop geothermal system for cooling residential buildings in a hot, dry climate, such as Cairo, Egypt. In addition to determining its effect on temperature and carbon emissions reduction, as well as the amount of energy consumed for cooling, create an environmentally friendly building. The research assumes that if the proposed system is applied in urban areas, it will reduce global carbon emissions, as it will help reduce the formation of urban heat islands and reduce the impact of global climate change.

Geothermal energy

The noun geothermal can be divided into two words: geo, which means earth, and thermal, which means heat. The soil is a stable temperature at an approximate 6–10 m in the range of 16–29°C all year round; it can be exploited for energy generation, cooling and heating buildings, or using direct underground heat, as explained in Table 1 [9].

The geothermal system, also called a geothermal heat pump system (GHP's), ground source heat pump system (GSPH's), or geo-exchange system, works on the basic heat pump principle of stable earth temperature to provide heating and cooling. Ground loops are used to connect the ground and the space for heating or cooling applications. One promising approach is the use of geothermal or ground-source heat pump (GSHP) systems, which use the ground as a heat source or sink to provide heating and cooling to buildings [9].

Geothermal energy systems are characterized by a high initial cost during the construction period, but their long-term environmental and economic benefits compared to other renewable energy sources make them more suitable for many uses [12]. It is also environmentally friendly and helps reduce carbon emissions by more than 7 kg/m^2, but its growth is slower due to the high initial cost of installation and the shortage of professionals for the implementation [13].

There are many different types of geothermal systems used in cooling buildings; they differ in design, implementation method, drilling method, and pipe thickness. Geothermal systems can be divided into two categories: geothermal systems with open loops and geothermal systems with closed loops (vertical, horizontal, submerged in a pond or lake, with geothermal substrates), as explained in Table 3 [13]. Table 3 shows that ground-closed loops are the most common system used because they are the easiest to install and cheapest than the surface-open loop. Recently, a new system was issued. It is a hybrid system between renewable energies and geothermal energy, and it is considered one of the most efficient systems.

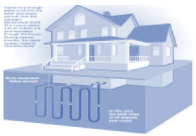
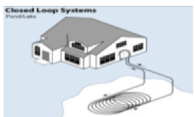
According to previous studies, geothermal energy systems have been used in many countries around the world in different climatic zones as shown in Table 2 [13].

There are previous studies that have proven that there are about 15 hot springs and 52 thermal wells in Egypt that can be exploited to generate electrical energy using geothermal power systems (GSHP) [22], but there are no studies showing the possibility of using geothermal energy in buildings in Cairo or Egypt due to the lack of awareness of its technologies in Egypt. But based on studies that have demonstrated its potential in buildings in hot and dry climates, such as those in Riyadh in Saudi Arabia, Abu Dhabi in the United

Table 1. The earth's layers, their effectiveness, and ways to exploit each of them.

	Earth's surface layer	The layer under the Earth's surface	The Earth's interior	Reference
Location & thickness	From the surface of the earth to a depth of 4 to 5 m.	From 6 to 10 m from the surface of the earth.	The temperature increases as depth increases: for every 100 m, the average soil temperature rises by 3.3 degrees Celsius all over the world.	[9]
Its effectiveness	Stored energy is strongly affected by the sun ruling the earth's surface. If the sun's temperature increases, the surface temperature increases, and if it decreases, the earth's surface temperature decreases.	The temperature is constant throughout the year, ranging from 16° C to 29° C.	The earth's heat spreads from the interior to the surface by convection at a rate of 44.2 terawatts. Radioactivity in the Earth's core is considered its most important source, reaching a rate of 30 terawatts. The difference between the two rates is due to the amount of energy stored in the Earth during its formation from cosmic dust under the influence of gravity about 4.5 billion years ago.	[10]
Sources & ways to use them	Hot springs can be used for direct uses, such as bathing and cleaning, as before.	It is the most common use, as it is used to heat and cool buildings and heat water in them.	It can be exploited in geothermal power plants where the turbines of the electric power plant are operated with steam or hot water generated from the ground, such as: (dry steam, evaporation, double-circuit) plants.	[11]

Table 2. Different types of geothermal systems.

Type	Configuration	Formation	Description	Site Requirements	Advantages	Disadvantages	References
Closed loop system	**Horizontal**		Pipe network is in the ground, at a depth of about 1m-2m below the freezing line, depending on local conditions.	A large area of open land, preferably not shaded	Simple installation, lower construction cost and almost zero operating cost	Large open space required for installation	[14]
	Vertical		Vertical pipes are inserted into holes dug at a depth of 15m-120m	Suitable for most sites	It can be installed in a small space, with almost no operating cost	Higher cost (drilling); It requires the approval of the concerned authorities before implementation.	[11]
	Obscure		A coiled tube or plate heat exchanger placed in water such as a river or lake.	Near to water bodies to support the system	Land space is limited, lowest cost of all closed loop systems	Possibly Requiring Supplier Approval for River/Lake Stream Works	[15]

(*Continued*)

Table 2. (Continued).

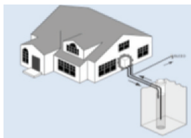
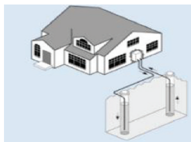
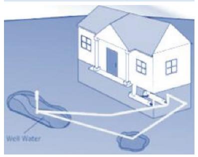
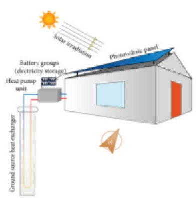
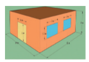
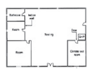
Type	Configuration	Formation	Description	Site Requirements	Advantages	Disadvantages	References
Open loop system	**Groundwater (one well and drainage field)**		Access to the aquifer and lands suitable for receiving wastewater	Access to the aquifer and lands suitable for receiving wastewater	Thermally efficient, limited floor space required	high cost (drilling); taking and draining spent groundwater; Likely to require supplier approval	[15].
	Groundwater (double well)		A well is drilled to reach the groundwater, and then another well is drilled to drain the groundwater back into the same reservoir or groundwater	access to the aquifer	Thermally efficient, limited land area required, takes up unused water	high cost (drilling); likely to require supplier approval	[14]
	Surface water		Direct intake of surface water from a stream/river/lake. Wastewater is returned to the source	Near to bodies of water of sufficient size to support the system	Thermally efficient, limited land area, utilization of unconsumed water, less expensive if it is close to a water source than construction and more expensive when operating	The approval of the concerned authorities is required to take the water and drain it on the course of the river/lake	[11]
Hybrid system	**Closed system (Horizontal) + Solar energy systems**		A horizontal or vertical pipe network is dug into the ground, as well as a solar or wind system, etc., on the roof of the building	Suitable for most sites	Can be installed in a small space, thermally efficient,	Higher cost (drilling); It requires the approval of the concerned authorities before implementation	[16]

Table 3. The previous studies that show the possibility of using geothermal energy in buildings.

Project	Location	Building type	Project image	Building height	The followed geothermal system	Reduction and savings	Reference
V&A Museum	Dundee, England	Cultural		19.8m	Open-Loop System	-Safes 800,000 kilowatt-hours of energy for heating -Safes 500,000 kilowatt of cooling energy annually	[17]
Residential complex	Nova Scotia, Canada	Residential		Two floor	Open-Loop System	50% reduction in carbon emissions	[18]
Residential complex	Oregon, USA	Residential		Three floor	Vertical closed geothermal system	-Reduction of 3 million $ -Reduction of cooling energy consumption 49%	[19]
Prototype	Riyadh, Saudi Arabia	Residential		One floor 3 m	Open-Loop System	-The research proved 6,419 kwatt/year reduction of energy -Reduction of 4,606 kilograms annually of carbon emissions.	[18]
Unfinished prototype	Abu Dhabi, UAE	Common		Multiple floors.	Vertical closed geothermal system	It is expected to reduce energy consumption and carbon emissions	[20]
Experimental model	Borj Cédria, Northern Tunisia	Residential		One floor 3 m	Horizontal closed geothermal system	The research proved to reduce the average temperature up to 2 ∘ C, and the GSHP system is a promising solution to reduce electricity consumption in the building sector in Tunisia.	[21]

Arab Emirates, and Borj Cedria in northern Tunisia, it has been concluded that GSHP is effective for reducing temperature and electricity consumption in buildings in hot and dry climates. Therefore, it is expected to prove its potential in Cairo and Egypt, and this is what the research assumes to reach a solution for cooling buildings in hot and dry climates.

Geothermal energy systems are characterized by lower maintenance, operation, and water heating costs than any other renewable energy system. As well as it is an effective tool for heating and cooling the building, since the underground temperature is constant all year, if the underground temperature is higher than the building temperature, the system will be used for heating, while if the underground temperature is lower than the building temperature, it will be used for cooling shown in Figure 1.

Geothermal energy systems can save up to 25% and 75% of the energy consumed, which makes them a very attractive solution for Northern and Central Europe [23]. Although Egypt is facing huge shortages in its basic needs for energy and cooling buildings, it has not yet used geothermal systems [24]. Due to its high cost and lack of experience and studies about it, this is what the research will do, which is a study. The effect of geothermal heat pump systems on cooling residential buildings in Egypt to benefit from their capabilities in cooling buildings

According to previous studies, there are environmental, economic, health, psychological, aesthetic, social, and other benefits to using geothermal systems in buildings. These benefits have been summarized and presented in Table 4. As for the negatives resulting from the exploitation of geothermal energy, they are limited to the occurrence of any damage to any part of the system, especially those located under the surface of the earth, and then its maintenance will be very high, but this only happens rarely.

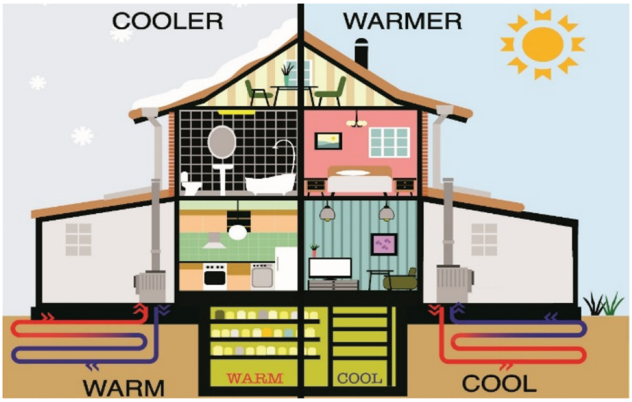


Figure 1. Geothermal energy pumps for heating and cooling purposes. Source: Justin Forrest, Geothermal Heat Pumps, Blue Horizons Project, BHP Education Articles, 2020

Table 4. The advantages of using geothermal systems in residential buildings.

Category	Benefit	Sources
Environmental	• Reducing the use of conventional fossil fuels. • Reducing global warming and gas emissions in cities, as it does not cause any emissions when installed and used.	[25].
Economic	• Reducing energy consumption by 20% to 50% compared to conventional energy. • It has low maintenance costs that are almost nonexistent, as it provides low operation and maintenance costs. The system's life span reaches 50 years. • It can be used to reduce the consumption of electrical energy for cooling and heating buildings by 25% to 50% compared to conventional heating or cooling systems. • It can be used to heat water and swimming pools in buildings.	[26]
Health and psychological	• Contribute to creating a clean environment that helps improve human health and makes him live in a clean environment that protects him from diseases. • Enables the user to reach thermal comfort continuously and with high efficiency. • Provides calmness, which helps a person improve their psychological state and quality of life.	[27]
Aesthetic	• It is possible to benefit from the entire site in various activities beautifully without any obstacles • Prevent the appearance of air conditioning devices in the building or on its roof	[28]
Social	• reducing unemployment rates and creating job opportunities for youth • Maintain good relations with neighbors and increase interdependence between them.	[29]
Other	• Investing untapped resources (the land under the building) • Renewable and always available: it is available permanently and continuously without interruption, because it is not affected by the surrounding climatic conditions compared to other renewable energies.	[27]

Method

The method used in this research is a simulation tool to evaluate the effectiveness of the closed vertical loop geothermal ($GSHP_{CV}$) system and determine its effect on reducing electrical energy consumption, reducing carbon emissions, and achieving human thermal comfort in hot, dry climate zones using TRNSYS-17 software as a simulation tool. ($GSHP_{CV}$) system was chosen to be used in this study because it is considered the most effective and cheapest system among all geothermal systems. This is done by adding $GSHP_{CV}$ to the building, as shown in Figure 2.

The Methodology used in this research for evaluating the geothermal energy systems applied on the case study has been explained and illustrated in Figure 3.

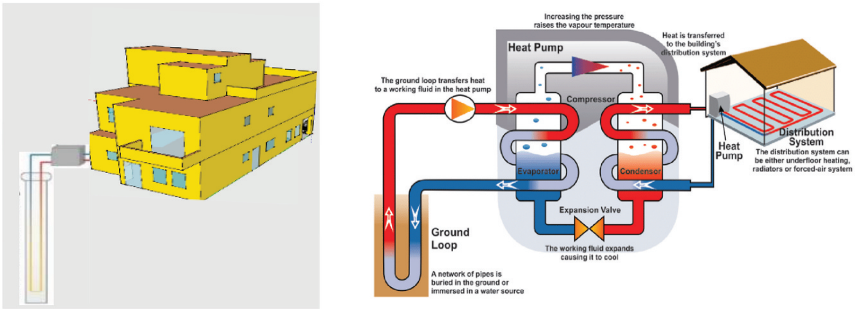


Figure 2. Diagram depicting the geothermal system in relation to the evaluated building after adding a ($GSHP_{CV}$) to the building. Source: Melissa Climo, Lisa Lind, Simon Bendall, Brian Carey, The rise and rise of geothermal heat pumps in New Zealand, New Zealand Geothermal Workshop 2012 Proceedings 19–21 November 2012.

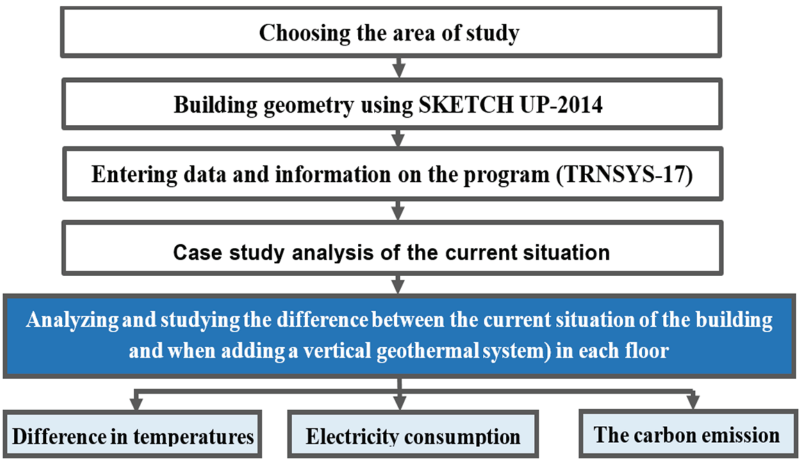


Figure 3. Methodology for evaluating geothermal energy systems on an applied the case.

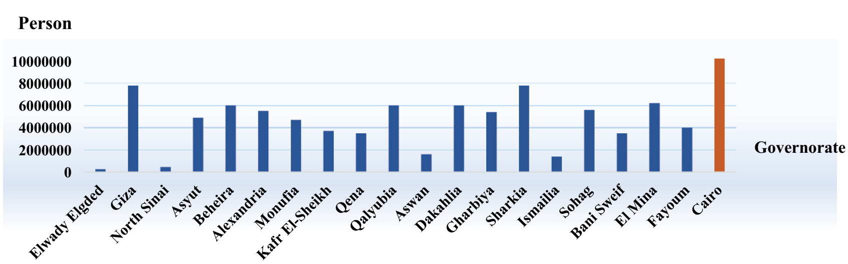


Figure 4. The population of the Egyptian cities. Source: The Central Agency for Public Mobilization and Statistics in Egypt, 2023.

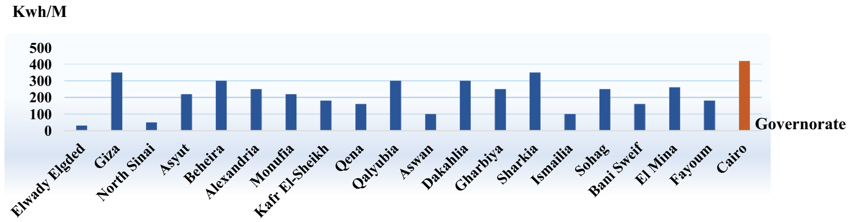


Figure 5. The electricity consumption in kilowatt-hours per month in an Egyptian city. Source: Ministry of Electricity and Energy website, calculate consumption in February 2021.

Study area

Cairo, Egypt, was chosen as a study area because it is located in a hot, dry climatic zone, has the highest population density in Egypt, and has the highest energy consumption, as shown in Figures 4, 5.

Building geometry

The case study is a typical single house (villa) in one of Cairo's new cities or suburbs, as shown in Figure 6. It was chosen randomly to be simulated in this research. The design of the villa is shown in Figure 7.

The villa consists of a ground floor, a first floor, and a roof. It accommodates a large family consisting of six members and two workers, as shown in Figure 8 and described in Table 5. This building, like most of the buildings located in Cairo, has an HVAC system used to cool the building during the hot seasons, which almost always take place between May and September.

Figure 6. Case study location in Cairo's New City, Egypt. Source: google maps for place, 2023.

Figure 7. The case study design and components.

1. Reseption
2. Dining room (1)
3. Guest bathroom
4. kitchen
5. Maid room
6. laundry room
7. Guest room
8. Bathroom Bedroom (1)
9. Bedroom (2)
10. Bedroom (3)
11. Bedroom (4)
12. Living room
13. Dining room (2)
14. Main bathroom
15. Playing room
16. dressing room

Figure 8. The case study design and components.

Table 5. Case study description.

Elements	description
Number of floors	2 floors and a roof
Number of users	6 Persons + 2 occupants
Year of construction	2020
Type of Building	Residential
Land area	250 m^2
Building area	144 m^2

Table 6. The validation and limitations of TRNSYS-17 software.

Validation	Limitation
the software has been successfully validated by several systems: • ASHRAE Standard 140 (BESTEST) • the ANSI/ASHRAE Standard 140 • Currently, TRNSYS is part of the validation project SimQuality. • VDI 6020/6007 (The validation project SimQuality bases its test cases on the systems and reference values of the German VDI 6020/6007) • DGNB (carrying out DGNB certifications for numerous projects with TRNSYS in the past years)	Encountered difficulties with the simulation of high thermal inertia wall, when this one reaches a certain value of thickness. Some other mathematical problems have been also pointed using the transfer method in the case of massive wall

Case study simulation

The TRNSYS-17 software was used as a simulation tool in this research to measure the thermal loads and electricity consumption inside the villa before and after using a closed vertical geothermal loop system ($GSHP_{CV}$). In Table 6, validation and limitations of the software are show

A series of simulations were conducted to capture the effect of the ($GSHP_{CV}$) system on the building's heat, energy consumption, and carbon emissions reduction during the year, especially during the peak period. A 3D model for the case study was built as a primary stage using Sketch up 2014 software, as shown in Figure 9. This model was imported into TRNSYS software for simulation.

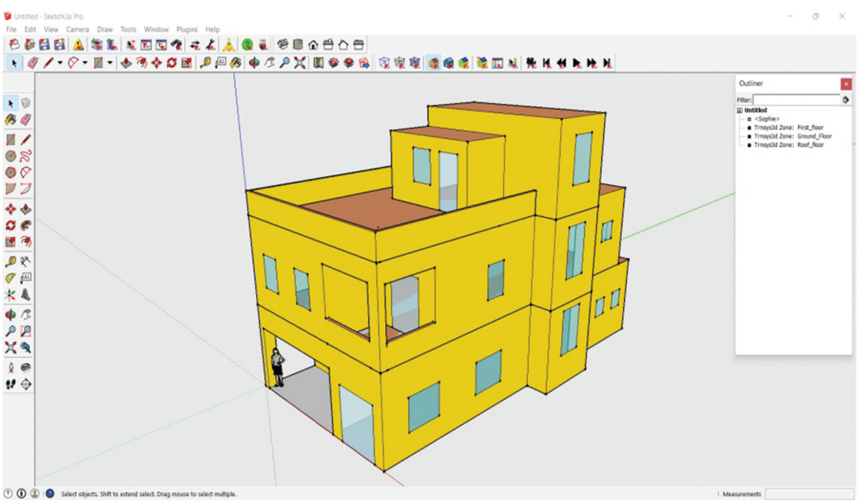


Figure 9. The case study modeling on sketch up software.

Table 7. Modelling parameters in building envelopes and layers.

Ground floor layers	Typical Flooring layers	Roof layers	Building envelop cladding
• Ceramic 50x50x1cm • Cement mortar, 2 cm • 5 cm levelling sand • Fine concrete 10 cm • Moisture seal 2 cm • 15 cm ordinary concrete • Backfill	• Ceramic 50x50x1cm • Cement mortar, 2 cm • 5 cm levelling sand • reinforced concrete 15 cm • Internal mortar, 2 cm • 2 cm of paint	• Ceramic 50x50x1cm • Cement mortar,2cm • 5 cm levelling sand • concrete slopes of 7 cm • Moisture seal: 2 cm • reinforced concrete 15cm • Interna • l mortar: 2 cm • 2 cm of paint	• 1 cm of paint • External clamshell, 2 cm • A brick of 25 cm • External clamshell, 2 cm • 1 cm of paint

Table 8. Physio-thermal properties of wall layers in the case of the study.

Glass Type	VT	SHGC	U-Value (m^2 C°/W)
Clear Single Glass 6 mm	**0.88**	**0.81**	**5.8**

Table 9. Physio-thermal properties of windows.

Wall layers	Thickness (cm)	Thermal conductivity (W/m C°)	Density (kg/m^3)	Thermal resistance m^2 C°/W
External Grout	2	0.88	2800	0.0227
Clay Bricks	25	0.6	1800	0.416
Inner Grout	2	0.88	2800	0.0227

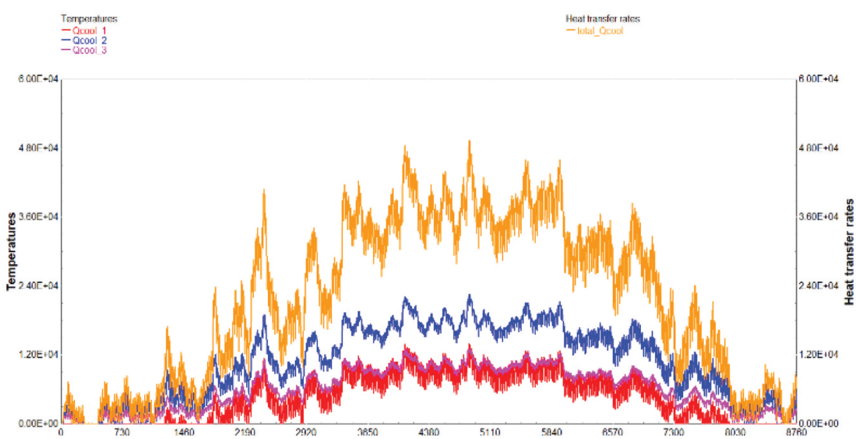


Figure 10. Thermal loads in the current situation in the building.

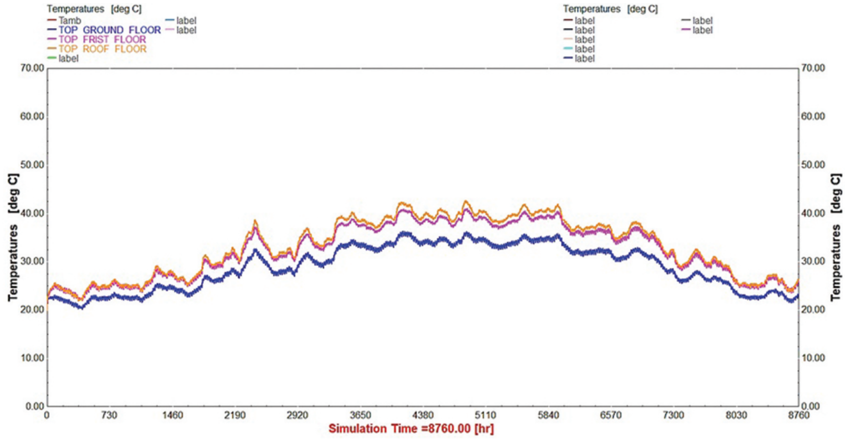


Figure 11. Climatic analysis of the building.

Table 10. Internal earning transactions According to the ASHRAE Guide [30].

Heat gains due to space occupancy	130 watts/1 person
Heat gains due to the internal lighting of the space	10.5 watts/1 person
Heat gains due to equipment, devices and computers	21.5watts/1 person

Modeling parameters

There were some parameters taken into consideration during the modeling process that affected the simulation results. All the modeling parameters were summarized and presented in Tables 7–9. There are many factors affecting the internal thermal loads of the building, such as users, indoor lighting, the effect of sunlight and external solar heat on the building, as shown in Figures 10 and 11, and the heat gain from operating equipment and devices; these factors contributed to

Table 11. GHPS system design in the case study.

Parameters	Values
Loop fluid type	Water
Fluid freezing point (ºC)	0
Fluid specific heat (Cƒ) (kJ/kgºC)	4.184
Fluid density (ρƒ) (kg/m3)	999.6
Fluid thermal conductivity (λƒ) (W/mºC)	0.6023
U tube loop pipe configuration	Double U
Pipe outer diameter (m)	0.0334
Pipe inter diameter (m)	0.0313
Pipe thermal conductivity (λρ) (W/mºC)	0.3913
Pipe flow type	Turbulenst
Borehole radius (rb) (m)	0.10095
Grout thermal conductivity (λg) (W/mºC)	0.6926

increases in the thermal loads inside the indoor spaces. According to the ASHRAE Guide [30], which is presented in Table 10, the thermal loads were calculated in terms of occupancy, lighting features, and electronic devices. Taking into consideration the thermostat set point for the HVAC system, it is assumed to be 24 °C for optimal cooling, with an acceptable range of 23–26 °C.

The parameters set for geothermal heat pump system (GHPS)

The piping of a **GHPS** system has been excavated and designed, as shown in Table 11.

Calculation model

Electricity consumption and temperatures were calculated using TRNSYS-17 software, as shown in Figures 10 and 11.

Carbon emissions were calculated. generating electricity from power stations that operate using natural gas produces 1.22 pounds of CO2 for every 1 kWh, as summarized, and presented in Table 12 and through the following equations, so the percentages of reduction in electricity consumption will be identical to the percentages of reduction in carbon emissions

1kWh = 1.22 pounds of CO_2.

∵ 1 b (pound) = 0.4536 kg

∵ The carbon emissions produced from natural gas are 1.22 b/kWh.

∴ Co2 = 1.22 × 0.4536 = 0.5534 kg/kWh

∵ The energy consumed in buildings is (A) kWh/day [calculated using a TRNSYS-17].

∴ The carbon emissions produced from building = A x 0.5534 = B kg/kWh.

Results and discussion

The results presented in this study were divided into three stages. The first stage presents the difference in temperatures after installing the ($GSHP_{CV}$) in a residential building located in a hot, dry environment; the second stage

Table 12. The amount of carbon emission produced from natural gas.

Fuel	Pounds of CO_2 per million Btu	Heat rate (Btu per kWh)	Pounds of CO_2 per kWh
Coal			
Bituminous	205.691	10,080	2.07
Subbituminous	214.289	10,080	2.16
Lignite	215.392	10,080	2.17
Natural gas	116.999	10,408	1.22
Distillate oil (No. 2)	161.290	10,156	1.64
Residual oil (No. 6)	173.702	10,156	1.76

Source: (EIA, 2016).

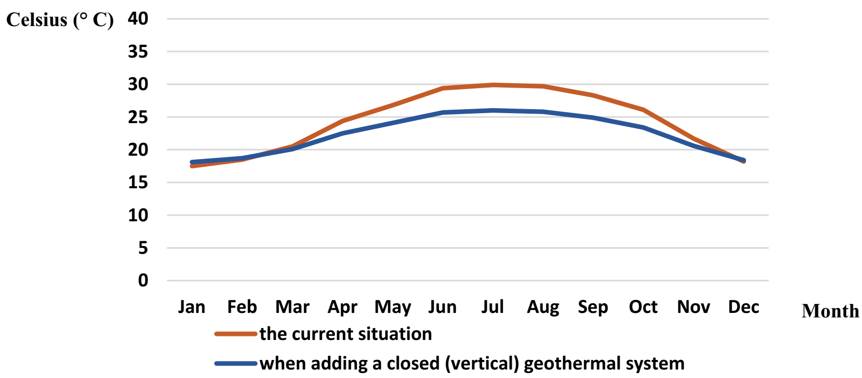


Figure 12. Temperatures before and after installing a $GSHP_{CV}$ on the ground floor.

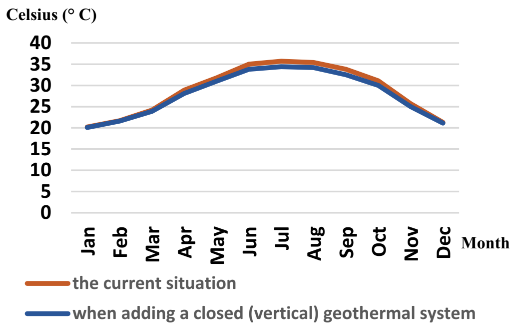


Figure 13. Temperatures before and after installing a $GSHP_{CV}$ on the first floor.

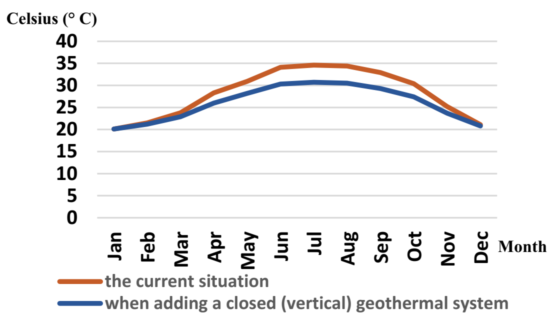


Figure 14. Temperatures before and after installing a $GSHP_{CV}$ on the roof floor.

measures the difference in electricity consumption after using the proposed system. Final Stage 3 calculated the amount of carbon emission reduction after using the proposed system.

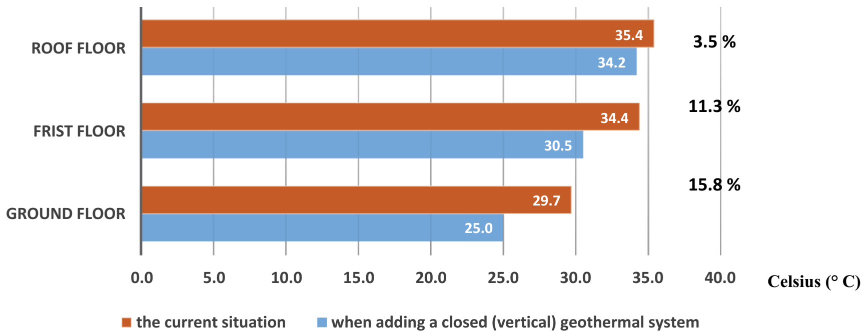


Figure 15. Percentage of reduction in temperature at peak times in each floor after using a $GSHP_{CV}$.

Stage 1: the difference in temperatures between the current situation and after installing a ($GSHP_{CV}$)

The following results were obtained by comparing the current situation and after adding a $GSHP_{CV}$ system in terms of temperatures: reaching 29.9°C and decreasing to 26°C on the ground floor, as shown in Figure 12, 34.6°C and decreasing to 30.7°C on the first floor, as shown in Figure 13, and reaching 35.7°C and becoming 34.4°C on the roof, as shown in Figure 14.

A $GSHP_{CV}$ helped reduce the temperature of the residential building located in a hot dry zone by up to 15.8% on the ground floor, up to 11.3% on the first floor, and up to 3.5% on the roof floor at peak times during the summer period, especially July and August, as shown in Figure 15.

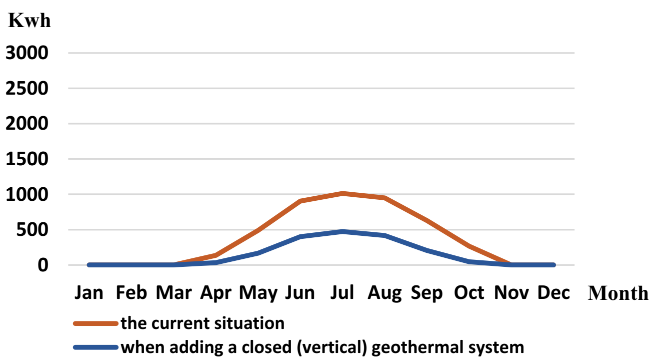


Figure 16. Difference in electricity consumption before and after adding $GSHP_{CV}$ on the ground floor.

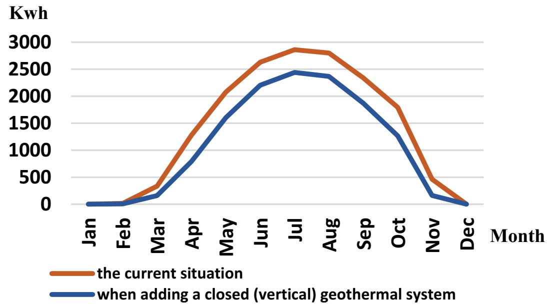


Figure 17. The difference in electricity consumption before and after adding a $GSHP_{CV}$ on the first floor.

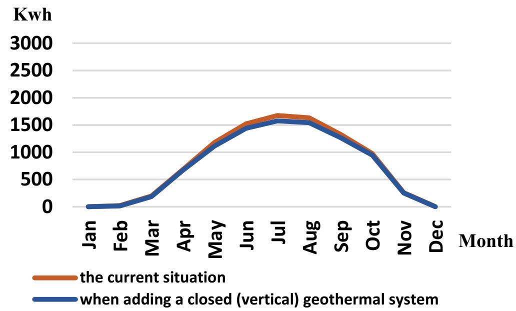


Figure 18. The difference in electricity consumption before and after adding a $GSHP_{CV}$ on the roof floor.

Stage 2: the electricity consumption in residential buildings before and after installing a $GSHP_{CV}$

The following results were obtained by comparing the current situation and after adding a closed vertical geothermal loop system in terms of electricity consumption: reaching 1013.45 kwh and decreasing to 472.87 kwh on the ground floor, as shown in Figure 16, 2631.12 kwh and decreasing to 2245.36 kwh on the first floor, as shown in Figure 17, and reaching 1673.63 kwh and decreasing to 1578.64 kwh on the roof, as shown in Figure 18

Using a GSHPCV in hot, dry climate zones can reduce up to 19.7% of the electricity consumed by buildings for cooling purposes during the summer, as shown in Figure 20. According to the simulation, using a GSHPCV on ground floors will reduce up to 53.3% of the electricity consumed in buildings located in hot, dry climatic zones. In addition, it reduces up to 14.7% of the electricity consumed on the first floor and up to 5.8% on the roof floor at peak times during the summer period between the months of July and August, as shown in Figure 19.

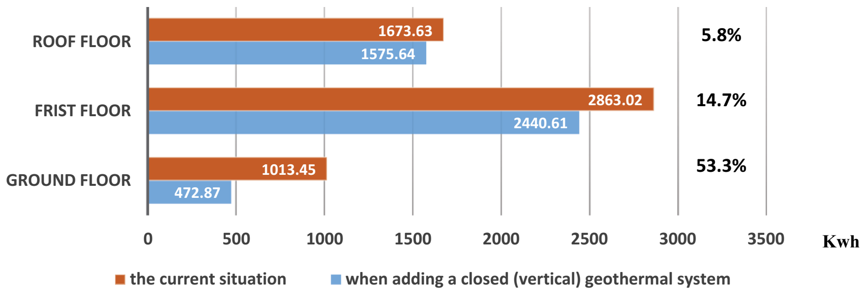


Figure 19. Percentage of reduction in electricity consumption on each floor before and after installing $GSHP_{CV}$.

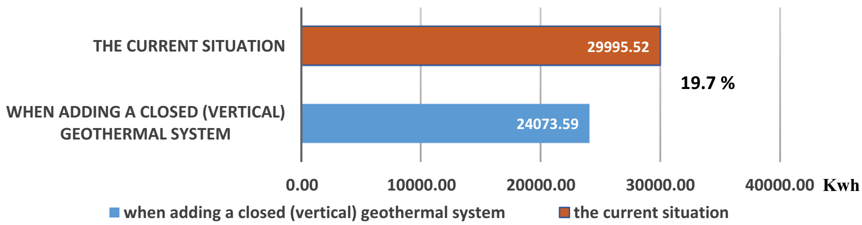


Figure 20. The total percentage of electricity reduction before and after installing $GSHP_{CV}$.

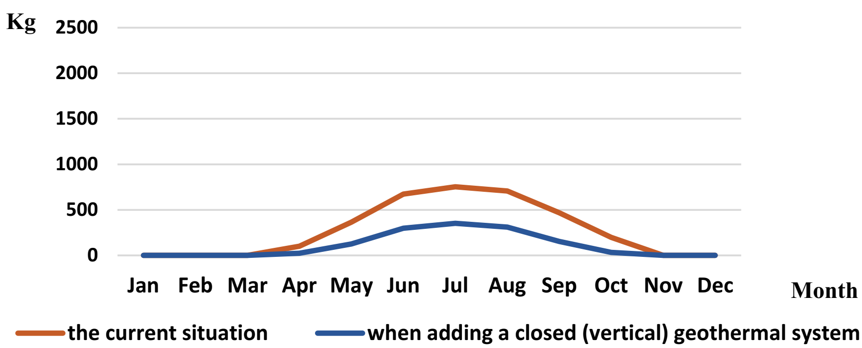


Figure 21. Carbon emissions produced before and after installing $GSHP_{CV}$ on the ground floor.

Stage 3: the percentage of carbon emissions reduction before and after installing a $GSHP_{CV}$

The following results were obtained by comparing the current situation and after adding a $GSHP_{CV}$ in terms of carbon emissions: 932.38 kg and decreases to 435.04 kg on the ground floor, as shown in Figure 21, 2633.97 kg and decreases to 2245.36 kg on the first floor, as shown in

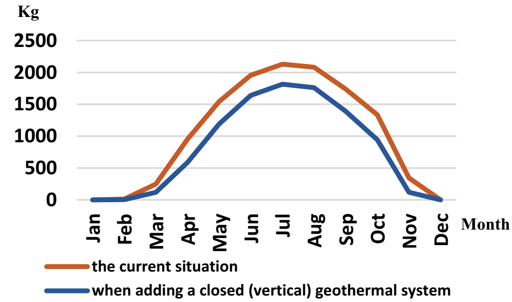


Figure 22. Carbon emissions produced before and after installing $GSHP_{CV}$ on the First floor.

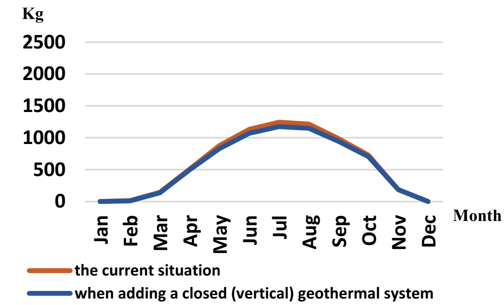


Figure 23. Carbon emissions produced before and after installing $GSHP_{CV}$ on the roof floor.

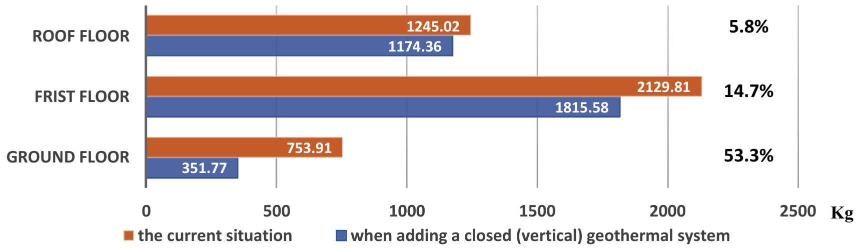


Figure 24. Percentage of reduction in carbon emissions per floor during the peak period before and after using the closed vertical geothermal loop system.

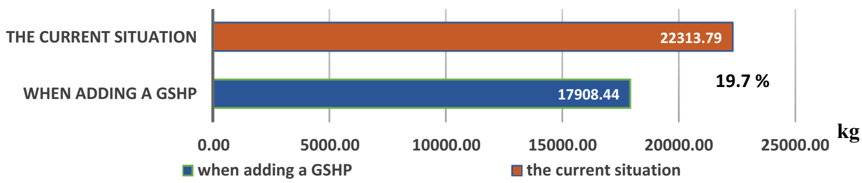


Figure 25. The total percentage of carbon emissions reduction during peak period before and after installing the closed vertical geothermal loop system.

Figure 22, 1539.74 kg and decreases to 1452.35 kg on the roof, as shown in Figure 23.

As a result, the GSHPCV helped reduce the percentage of carbon emissions by up to 53.3% in the ground floor, up to 14.7% in the first floor, and up to 5.8% in the roof floor at peak time during the summer period, as shown in Figure 24, for a total percentage of up to 19.7% carbon reduction in a building located in a hot, dry climatic zone, as shown in Figures 25.

A comparison between previous studies and the applied case study

A comparison between previous case studies and this case study revealed that:

- The V&A Museum saves 800,000 kilowatt-hours of energy for heating. Saves 500,000 kilowatts of cooling energy annually. [17]
- The residential complex in Canada (a 50% reduction in carbon emissions) [18]
- Residential complex in the USA (reduction of $3 million) Reduction of cooling energy consumption by 49% [19]
- Prototype, Saudi Arabia (The research proved a 6,419 kilowatt/year reduction in energy, a reduction of energy, and a reduction of 4,606 kilogrammes annually in carbon issions). [18]
- In Masdar City, in the Emirates, it is expected to reduce the consumption of electrical energy for cooling and carbon emissions. [20]

Hence, we find that in the case of using geothermal systems for heating or cooling, we can reduce energy consumption, thus saving money and reducing carbon emissions.

Conclusion

This research has proven that the use of geothermal closed vertical loop systems contributes to reducing the temperature in the building by 15.8% on the ground floor, 11.3% on the first floor, and 3.5% on the roof floor. In this context, the research proved that using geothermal closed vertical loop systems can reduce an average of 19.7% in electricity consumption and carbon emissions. In addition, the user reaches thermal comfort on the ground floor, mitigates the effect of sunlight and the external heat of the sun on the building, and also reduces the amount of energy consumed for cooling and carbon emissions in each of them.

By spreading the knowledge, using this system in the entire city will be an effective way to reduce the effect of urban heat islands in Cairo, Egypt, and contribute to reducing environmental hazards such as global warming and global climate change.

Better results can be achieved in reducing temperatures and electricity consumption for cooling by studying the depth of excavation and the spacing between pipes and designing the system in a way that is commensurate with hot environments such as Egypt.

These applications still require qualified people and technology in the fields of geothermal energy investigation, design of power generation systems, cooling and heating, management of geothermal energy projects, and monitoring systems that are allocated to the local market in Egypt (according to local conditions). [31–34].

Disclosure statement

No potential conflict of interest was reported by the author(s).

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