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Improving the Efficiency of a Conventional Vapor-Compression Refrigeration System used for Geothermal and Evaporative Cooling Techniques: A Case Study in Iraq

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ABSTRACT

A conventional vapor compression refrigeration cycle is among the most effective technology in refrigeration systems. In the present experimental study, thermal performance and the effect of the condenser temperature have been analyzed. With the decrease in the condenser temperature, the overall performance of the refrigeration cycle is increased. However, the cooling power and efficiency of conventional vapor pressure air conditioning units can experience a significant reduction when operating in extreme weather (hot and dry). This drop is mainly affected by the increase in the temperature (and pressure) of the condenser with an increase in the ambient air temperature. Unfortunately, Iraq experiences the most extreme summer seasons especially in the months of June and July when the temperature reaches or exceeds 50° C. So, ground cooling has been used in areas with a hot environment for split system air conditioners. Evaporative cooling was also performed to lower the coolant temperature of the AC unit used inside the condenser area. Experimental results showed that when using a geothermal heat exchanger, the temperature of the condenser is reduced from 116 to 110 ° C and the coefficient of performance (COP) is improved by 41%. In addition to this when the system uses evaporative cooling the temperature of the condenser is reduced from 110 ° C to 88° C. Moreover, a 65% improvement was made in the COP of the conventional vapor compression refrigeration cycle. Furthermore, with a decrease in the evaporator temperature from 6 to 3.5 °C there was an increase in refrigeration capacity by an average of 52%.

1. Introduction

The use of air conditioning systems for human living standards increases quickly as the ambient temperature rises. This makes air cooling more necessary and increases energy usage. To reduce the air conditioning system's energy use, there are numerous methods used in modern technology. First, the air conditioning systems of thermal performance are enhanced using an earth air heat exchanger (EAHE). The system known as EAHE is used in many different applications, including the heating and air cooling of greenhouses, commercial buildings, and residential constructions. EAHE often includes pipes that are buried in a vertical or horizontal arrangement. The side addition is air-open, and the supply end of the fan is connected to the pipe's other end. In the summer, heat is transmitted from the air to the neighboring soil when the air is passing through

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the burnt pipes, and in the winter, the process is reversed. Some studies have suggested that EAHE linked to buildings is a useful passive energy supply for the Heating and Air Conditioning systems. The earth air heat exchanger pipe's length was researched by Sodha et al. [1]. They deduced from the findings that a long tunnel was needed for a dry sunny surface to meet the cooling load requirements, whereas a short tunnel was needed for a moist shady surface. The researchers concluded from their study's model that soil with higher moisture levels quickly raises the temperature of the profiles. In India's Ahmedabad, where the yearly average temperature ranges between (23°C and 43°C), Sharan and Jadhav [2] developed an earth air heat exchanger system to provide hot and cold. The EAHE system had a pipe with a nominal radius of 0.5 m and a length of 50 m, as well as a thickness and depth of 3 m and 0.003m, respectively. A 400 W electro-pump was utilized to force air through the pipe at a velocity of 11 m/s. Trials for cooling and heating were run over the course of the next three days in May and January, respectively. Temperatures were observed at the beginning, middle, and end of the tube. They discovered that the system could raise the temperature in January by around 14°C. To investigate the possibility of the EAHE system's application to the greenhouse in Delhi, India, Ghosal et al. [3] developed an advanced computational model for exploiting the thermal energy stored in the ground for space heating. In that experiment, the buried pipes' diameter and length were 0.06 m and 39 m, respectively. EAHE also took into account the 1 m-deep PVC pipes (polyvinyl chloride) lying underground. When the identical greenhouse was operating without EAHE, the air temperature was found to be on average 7°C to 8°C higher. The earth air thermal heat exchanger system was the subject of numerical analysis by Bansal et al. [4] during the winter. Their findings demonstrated that a 23.4 m long earth air thermal heat exchanger system was capable of raising air temperature by 4.1°C to 4.8°C for flow rates between 2 m/s to 5 m/s. Choi et al. [5] investigated the geothermal heat pumps for chicken house heating. In comparison to a traditional heater, a heat pump causes a rise in body weight, has no effect on mortality rates, improves indoor air quality, minimizes fuel costs, and uses less electricity. In actuality, geothermal heat pumps provide lower heating costs and improved industrial efficiency with decreased gas discharges. The impact of wall thickness and pipe material on the general effectiveness of EAHE was numerically examined by Hasan and Noori [6]. The length, inner diameter, and depth of a pipe in the city of Nasiriyah in southern Iraq are 3m, 0.1016 m, and 50 m respectively. PVC and steel are the materials used to make the pipe, and the system comes in three different thicknesses (2, 3, and 6). The findings indicated that PVC pipe is better (suitable for use) than steel pipe since it is less expensive and non-corrosive. The pressure decreases and increasing air velocity led to a rise in exit air temperature for the two materials. Wall thickness has less impact on overall performance and can be disregarded.

Throughout the winter, Che and Tiwari [7] conducted an experimental thermal investigation using an integrated EAHE system. Building air temperature measurements showed that the EAHE is suitable for an axillary system for heating and cooling buildings increasing building air temperature by 5°C to 15.8°C when compared to ambient air temperature while building air temperature decreases with the same period during summer. Kabashnikov et al. [8] developed a mathematical design to calculate the temperatures of the air and soil in a soil heat exchanger. The design was based on the representation of temperature by the Fourier integral. The effect of pipe materials on the EAPHE system as a passive ground cooling method was examined by Noor Aziah et al. [9]. The study was designed for Malaysia's hot, humid climate. The difference between this study and the experimental research was noted where the degree of decrease in the efficiency of the heat exchanger was evaluated with a decrease in the spacing between its tubes. The thermal energy dependencies of the system on pipe length and diameter, burial depth, and airflow rate were calculated in this study. As for the experimental research, the specific depth when burial, increasing the length of the tube, the spacing between the tubes, and reducing its diameter led to an improvement in efficiency. Sanusi et al. [10] conducted research to assess the unique characteristics of Malaysian soil temperature in order to demonstrate the potential of employing the EAHE technology in Malaysia. To reduce greenhouse gas emissions and construction energy utilization, recently, Yusof et al. [11] investigated the potential and benefits of deploying ground heat exchangers (GHE) in Malaysia's environment for cooling purposes and determine if a shallow geothermal energy pile system can be constructed in Malaysia's climate. To ascertain the impact of moisture content on the thermal conductivity, thermal resistivity, and volumetric specific heat values of various cohesive soils, Amaludin et al. [12] researched the use of an evaporative cooler as the second strategy to increase the coefficient of performance COP and decrease energy usage.

The idea behind evaporative cooling is that some water from a wet surface that is hotter than the air's dew point will evaporate into the surrounding atmosphere when moist, but unsaturated air comes into contact with it. Water, air, or both can provide the latent heat of evaporation. The air loses sensible heat but accumulates latent heat as a result of the transfer of water vapor during this process. As a result, the air is cooled and made humid. Thermal comfort can be achieved using cooled and humidified air. Air conditioning is frequently utilized in a variety of settings, including homes, buildings, workplaces, and hotels. Most air conditioners used for this purpose are of the "split type" in which the condensing unit and fan coil unit are each separated into two pieces, one of which is placed within the room and the other outside. Air-cooled, evaporative, and water-cooled condensers are the three types of condensers used in air conditioning systems. Most of the condensers in a traditional small-tonnage home split air conditioners are air-cooled. The airflow and heat transmission between the coils determine a split air conditioner's efficiency. This is because air-cooled condensers periodically experience noise problems since they occasionally need a high airflow rate for optimal performance. To raise the coefficient of performance, it is generally possible to minimize the power consumption of the compressor, the cooling and heat rejection capacity, the refrigerant pressure loss, or the pressure difference between the condenser and evaporator. The most successful technique among those mentioned above is decreasing the pressure differential between the condenser and evaporator [13]. A refrigerant evaporator lowers the temperature of the heat source below that of its surroundings and a condenser transports the extracted heat and any additional energy needs to a heat sink like ambient air or water [14]. One of the key interests is to improve the refrigeration systems' performance coefficient and minimize electrical power usage. If the condenser is being cooled by air in an environment with high temperatures, the issue is greatly heightened. Since the temperature of the surrounding air directly affects the condenser's ability to cool. In regions with very hot summers, significant increases in condenser temperature and pressure are observed, which will increase the refrigeration system's workload due to the rise of resulting pressure ratios. The compressor may be shut off in the refrigeration system if the pressure is increased significantly [15]. To assess the energy savings in a split-type air conditioner that utilized several types of evaporative cooling systems, Chainarong and Doungsong [16] proposed an experimental study. The findings demonstrated that increases in ambient temperature had a considerable impact on both electrical consumption and performance coefficient. Goswami et al. [17] used a media pad to implement evaporative cooling on an existing 2.5 TR air conditioning system. They surround the condenser with four media pads and use a small water pump to inject water from the top. When the air temperature was 34 ºC, they reported a 20 % electric energy savings for the upgraded system. Ozgoli & Seiedi Niaki [18] investigated the effect of wet evaporation for the condenser on the performance of a split air conditioning system. The function of an evaporative layer was to reduce the air temperature before entering the condenser by using desalinated water. This technique of evaporative cooling proved that the energy consumption of the system decreased to 12% by increasing the COP by 15%. Besides, the effectiveness of the proposed condenser was influenced by changing the ambient air temperature and the relative humidity. Where the effectiveness dropped from 18.22 % to 15.05% when the ambient temperature increased from 30.5 °C to 44.5 °C and declined from 18.14% to 6.4% with decreasing the relative humidity 35% to 70 %. In 2021, an experimental study was conducted by Yang et al. [19] to improve the performance of a split-type air conditioning system. The experimental investigation was summarized by using a fan with an atomization cooling unit around the outdoor unit. The modified unit was tested under various ranges of ambient temperatures to compare with the traditional outdoor unit. The results showed that the modified unit reduced 2.2°C temperature when the outdoor temperature was 35 °C. In addition, it enhanced the refrigerating capacity, power consumption, and energy efficiency ratio by 8.1%, -9.5%, and 20%, respectively at the ambient temperature of 43 °C. Lim & Lee [20] conducted an experimental investigation to improve the thermal performance characteristics of a proposed geothermal system using a standing column well (SCW) and cross-mixing balancing well heat exchanger methods. The analysis was done by preventing underground water discharge and maintaining a constant temperature of the underground heat exchanger. The results of testing indicate that the operation of the proposed system in the case of a well-intersected heat exchange improved the coefficient of performance of heating and cooling more than a regular SCW-type heat exchange. Di Donna et al. [21] developed the charts of energy capacity for energy walls by using coupled thermo-hydro finite element analysis. The effect of ground properties such as hydraulic and thermal conductivities and ground conditions like groundwater temperature and flow velocity were taken into account. The analysis of results showed that the hydrogeological conditions and the temperature difference between the ground source and application temperature are important in determining the performance of the energy wall. Mathur et al. [22] performed a numerical simulation to analyze the thermal performance and soil temperature during the summer of India. The results of simulation indicated that the thermal saturation was investigated at end of the summer. Additionally, the COPs in cases of summer, summer with night purging, winter, and winter night operation were 4.23, 3.68, 5.01, and 6.65, respectively.

The aim of the study was to improve the thermal and overall performance of the vapor pressure refrigeration cycle by reducing the temperature and pressure of the condenser and using the land as a heat sink in summer to cool spaces in residential and commercial buildings. Moreover, the stability of soil temperature, as well as how the thermal performance of EAHE systems is affected by air flow rate, length, pipe diameter change, buried pipe depth, and pipe spacing were evaluated.

2. Methodology and experimental work

A refrigerator's coefficient of performance (COP) is determined by:

$$\mathrm{COP} = \left(\frac{\dot{\mathrm{Q}}_{\mathrm{e}}}{\dot{W}_C}\right) = \frac{(\mathrm{h}_1 - \mathrm{h}_4)}{(\mathrm{h}_2 - \mathrm{h}_1)} \qquad (1)$$

Where Q_e is the refrigeration capacity and $\dot{W}_C$ is the work required to compress the vapor refrigerant; h_1 and h_4 are the specific enthalpies (kJ/kg) at the exit and intake of the evaporator; h_2 and h_1 are the specific enthalpies (kJ/kg) at the output and input of the compressor, respectively.

A buried (pipe) heat exchanger as shown in Figure 1 was used in this study. Figure 1 also illustrates an improved subsurface pressure cooling system that may absorb heat from the floor and/or disperse it. A semi constant ground temperature was considered to heat or cool the air for residential use. Due to the absence of compressors, chemicals, or stoves, floor pipes are frequently an efficient and affordable replacement for or in addition to conventional central heating or air conditioning systems. These are used for either partial or complete cooling. Earth tube heat exchanger (ETHE or EAHE) is a tool that allows heat to be transferred from the surrounding air to the deep soil layers and vice versa. The EAHE used consists of 10 rings of tubes buried vertically in the ground because the vertical rings are deeper.

The EAHE system is buried 3 m underground, the inner tube is 5 mm in diameter and 50 m long as shown in Figure 1. These dimensions and formations were obtained by going deep into the previous researchers' studies to find the best ways to improve efficiency with the need to improve the previous research in choosing the appropriate dimensions to get the best results and repeating the experiment more than once until a noticeable improvement is achieved. The vertical rings are buried between one unit and the other at a distance of 50 mm. EAHE consists of vertically buried pipes in the ground. The tube is joined at one end to the outlet ends of the condenser added to circulate the water inside the underground tubes, and at the other end to the inlet end of the additive condenser. A photo of the coiled pipe and aesthetic view is shown in Figure 2. In the summer and winter, heat is transmitted from the air to the surrounding soil when water passes through subterranean pipes. Several studies have praised the effectiveness of Earth-to-air heat exchangers (EAHE) used in conjunction with structures. This depth and beyond have a temperature regime that without daily swings and with little seasonal or yearly change, the system is stable. Convection and to some extent ground-air conduction are used to acquire or lose heat when heated outside air is driven along the length of tube heat exchangers. As a result, the flowing air either gets cooler or warmer depending on how the soil temperate is. In a hot environment, the soil acts as a heat sink, absorbing heat that is then released back into the tubes to cool the area. As a consequence, if the room's temperature is low or high enough and there is enough airflow to provide the end user with thermal comfort, the air exiting EAHE may be utilized directly to cool or heat the area. Widely utilized in a variety of applications, the ground air heat exchanger is a passive heating and cooling device, such as greenhouse cooling and heating.

In this study, the experimental setup that is depicted in Figure 3 was conceived and produced. In this test, a split unit device served as a representation of the vapor compression cycle (specifications: single cooling tone, 2700W, 220V rotary compressor, R-22 coolant). Dimensions of the outdoor unit 55 x 80 x 55 cm^3. Evaporative cooling of the split unit condenser is achieved using new technology in the aluminum casing, which also houses the split unit and an evaporative cooling pad. A water tank made of galvanized sheet with a thickness of 10 cm was used. The dimensions of the tank are 35 x 75 x 65 cm^3. The water is prepared for the evaporative cooling pad by the DC pump as shown in Figures 3a, 3b, and 3c. Pumping water into the evaporative media pad, positioned so that it covers the air around the condenser and produces cooling by evaporating the water and thus cooling the area.

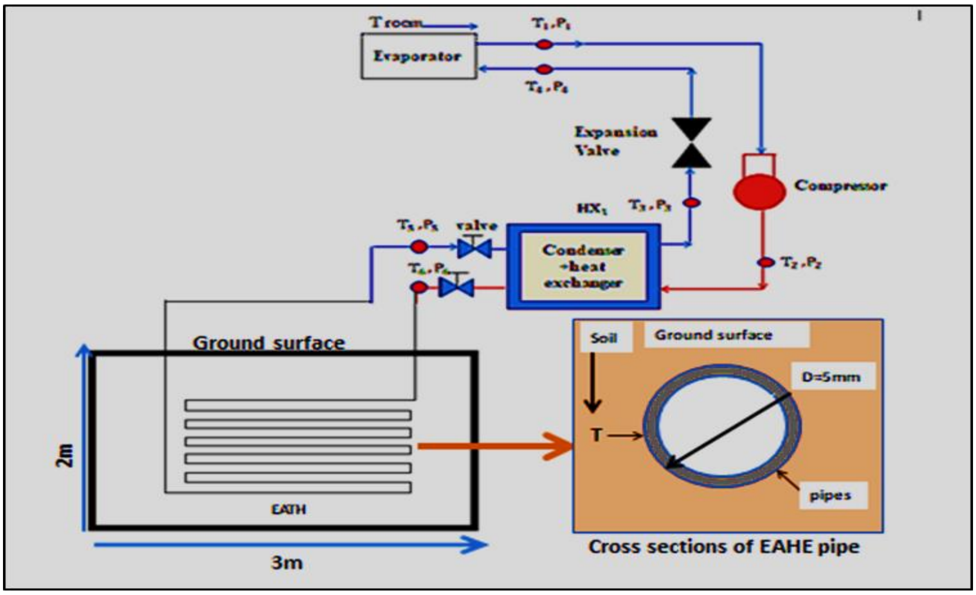


Figure 1. Schematic of EAHE system of earth tube heat exchanger and cross sections of EAHE pipe

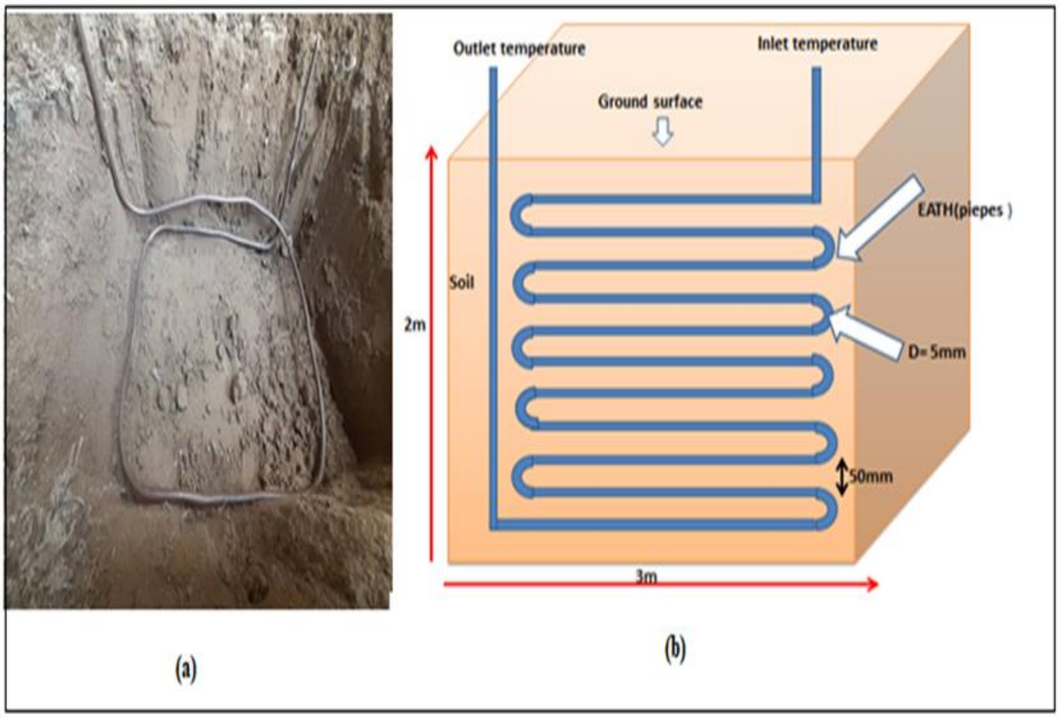


Figure 2. (a) A photo of the coiled pipes before being buried and (b) aesthetic view

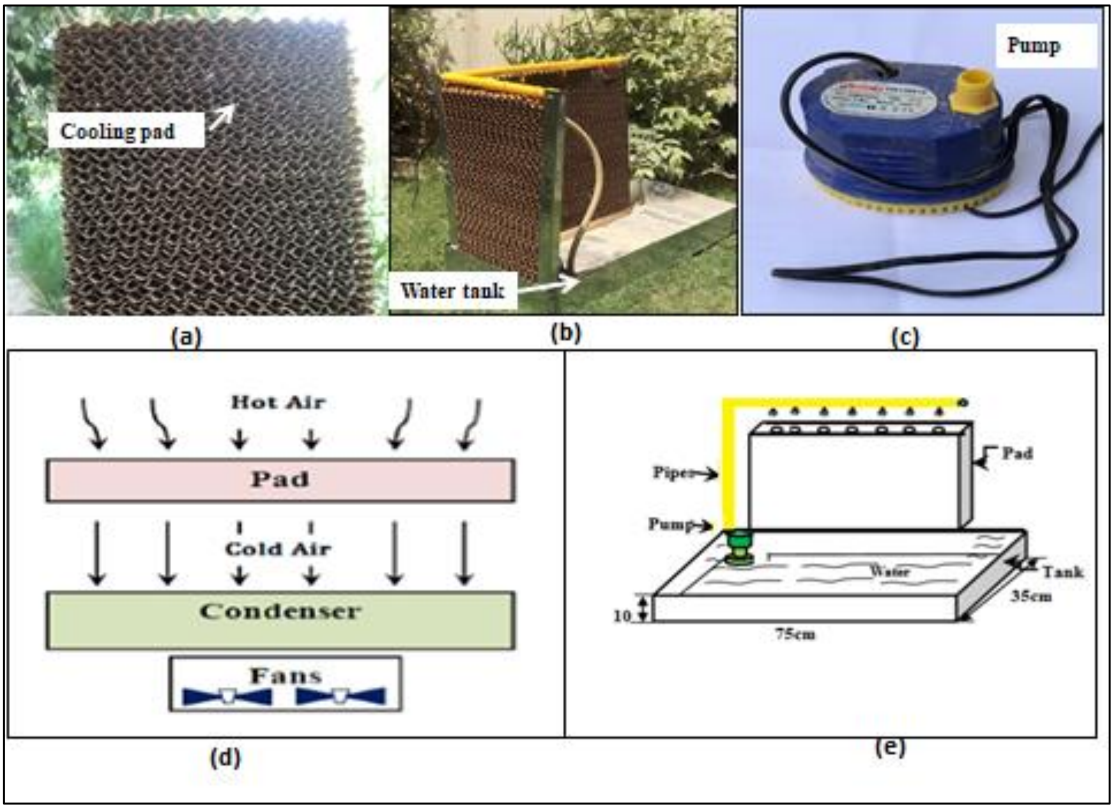


Figure 3. Experimental setup diagram, including (a) Cooling pad, (b) Water tank, (c) pump, (d) air circulation, (e) water circulation in the evaporative unit

The location of the media pad should be installed in such a way as to give a good cooling effect and also occupy a small space in the outer section of the equipment. The space's definition is crucial to the design consideration. An evaporative media pad and related structures in this work are 65 cm high, the long side is 75 cm long and the short side is 35 cm, 10 cm thick, and this pad is installed in the back of the condenser and the distance between them is 2.5 cm to give enough available area for cooling without increasing the overall size of the device's external partition. Hot ambient air is circulated by passing over an evaporative media pad, cooling, then passing over a condenser before being expelled by a fan in front of the condenser. The water circulation system contains a tiny pump, a straightforward tank, and tubing as illustrated in Figure 3e. It is designed to spray water on top of the media pad in the way seen in Figure 3d. At several locations, thermocouples and pressure gauges took temperature readings of the coolant and the air pressure in the circulation. By tracking the decline in water level in the tank during the test, it was possible to calculate the rate of water consumption resulting from evaporation.

3. Uncertainty analysis

Verification of the uncertainty in the experimental measurements is necessary to ensure the accuracy of the results. In the current experimental investigation, thermocouples were used to measure the temperatures of the refrigerant at the inlets and outlets of the compressor, condenser, evaporator, and other locations. These thermocouples were originally calibrated by the manufacturer with an uncertainty of 5-7%. In addition, pressure gauges with uncertainty measurements of 5 up to 10 %, were used to measure the pressure of the refrigerant at the desired positions.

4. Results and discussion

4.1 First method (Earth-To-Air Heat Exchanger (EAHE))

All experiments were conducted during the summer season (June, July, and August) at the laboratory of Mechanical Engineering, College of Engineering, University of Diyala, Iraq. Both temperatures of the external environment (ambient temperature) and the laboratory in which the experiment was conducted were taken into account. The data were recorded and plotted every 5 minutes for a period between 09:30 AM and 01:30 PM. The temperature of the ambient air used to cool the condenser is one of the key elements determining the performance of the cooling system as a whole. Accordingly, earth air heat exchanger EAHE was used through which water passes to cool the condenser and reject more heat to the surroundings. As shown in Figure 4. It can be simply noticed that there is a huge decrease in the value of the temperature of the condenser (at the inlet) going from 116 ºC to reach 110 ºC and the value of the temperature of the condenser (at the exit) has been dropped from 58.5 ºC to 54.3 ºC. This confirms the effectiveness of the first method in reducing the temperature of the condenser, which in turn should improve the thermal performance of the vapor-compression refrigerator system.

The thermocouple is not used indiscriminately, rather it is placed at the entry, middle, and exit points of each part of the system

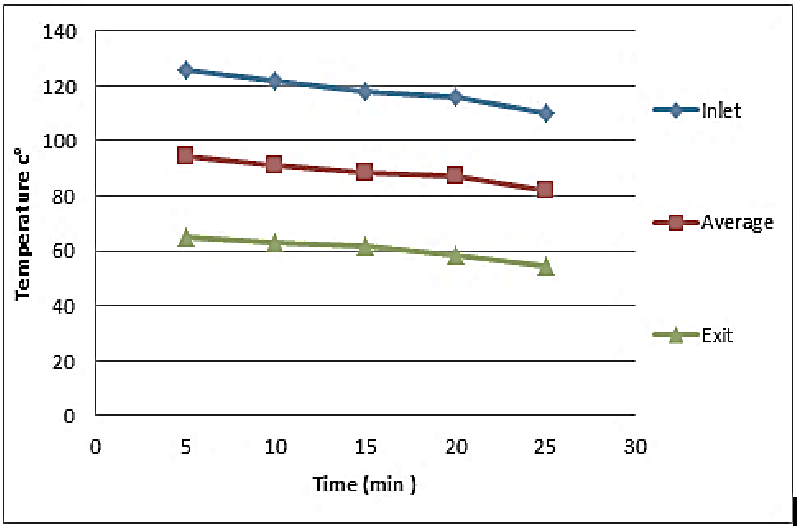


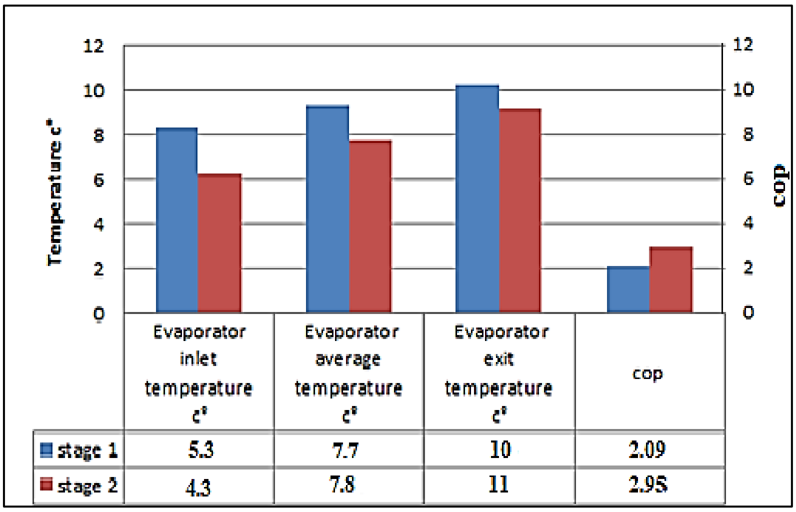
Figure 4. Experimentally measured temperature(s) at the inlet and exit of the condenser over the time of the modified A/C unit (First method: after the utilization of earth to air heat exchange technique).

Figure 5 demonstrates the change in the values of COP of the A/C unit as time passes after the manipulation of the geothermal cooling (first method: EAHE technique). The evolution in the performance of COP of the refrigeration cycle after the utilization of the EAHE is highly remarkable. Given that the heat transfer rate increases as the external air conditions vary dropped down by the EAHE. Additionally, it was discovered that the EAHE system performed at its peak in hot weather conditions as the difference between the outside air temperature and geothermal temperature increased.

Figure 6 supports the success of using EAHE technique in improving the performance of the conventional vapor-compression refrigeration system in the summer time as the cooling capacity and COP were increased by 21% and 41%, respectively. As shown in Figure 6, the cooling load has been increased from 4521(W) to 5472(W) affected by the change in the temperature of the condenser after being linked to geothermal temperature using EAHE.

4.2 Second Method (Evaporating Cooling)

The temperature of the air used to cool the system capacitor is the primary element influencing system performance. Evaporative cooling was used to cool the air condenser.



	Evaporator inlet temperature c°	Evaporator average temperature c°	Evaporator exit temperature c°	cop
🟦 stage 1	5.3	7.7	10	2.09
🟥 stage 2	4.3	7.8	11	2.95

Figure 5. The experimentally measured COP (coefficient of performance) over specific time after the utilization of EAHE technique

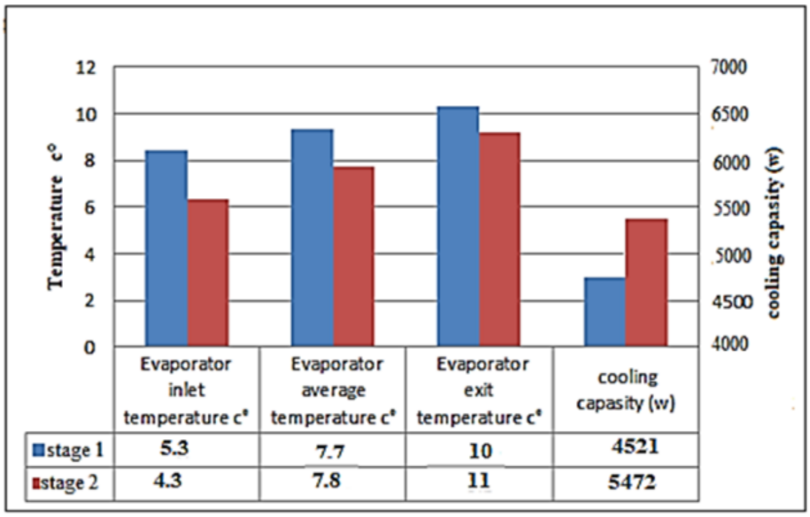


Figure 6. The experimentally measured cooling capacity over a specific time after the utilization of the EAHE technique.

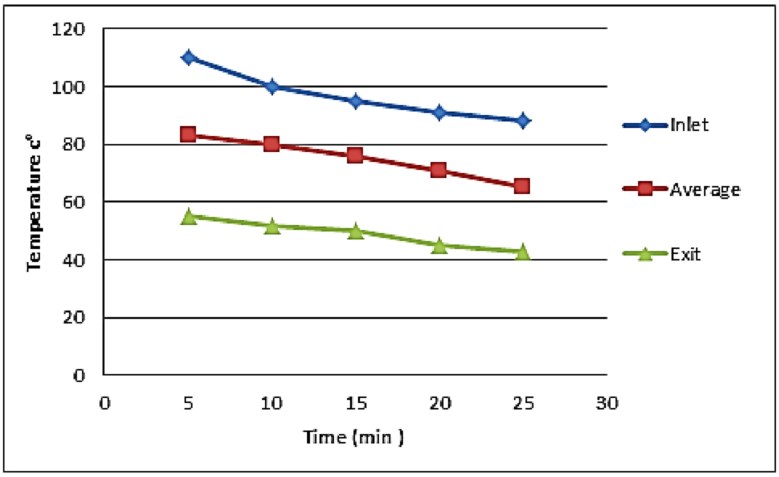


Figure 7. The experimentally measured temperature at the inlet, average, and exit of the condenser over a certain time

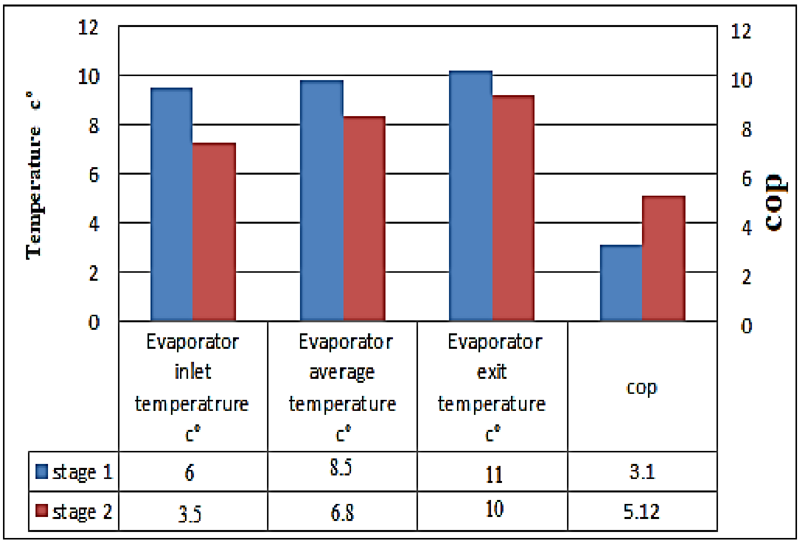


Figure 8. The experimentally measured COP over a specific time after the utilization of evaporative cooling

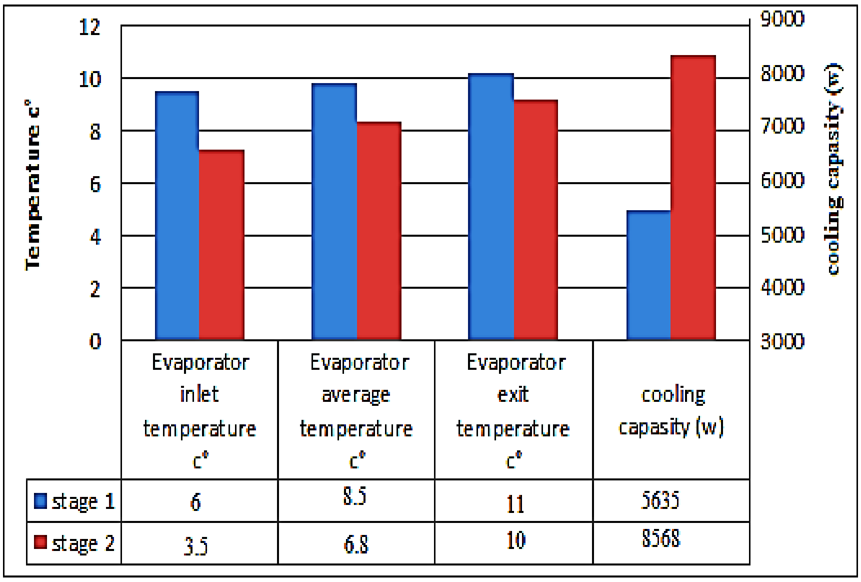


Figure 9. The experimentally measured cooling capacity over a specific time after the utilization of evaporative cooling

The measured values of refrigerant (R-22) and temperature were plotted on the graphs as shown in Figure 7. The use of a ground air heat exchanger results in an improvement of COP less than that obtained in evaporative cooling. So, there is a decrease in the temperature of the condenser resulting from cooling of the condenser by the evaporator condenser (water) has a high heat transfer coefficient which makes cooling the condenser efficient.

Figure 7 shows the significant drop in temperature for the condenser at the inlet, average, and exit as a result of using the evaporative cooling method. This decrease is caused by the decrease in the ambient temperature of the air that leaves the evaporative pad towards the condenser. The experimental results suggest that the used evaporative cooling mechanism is sufficient for this A/C system and it may handle even higher ambient temperatures. Both the laboratory temperature and the surrounding surface temperature outside were measured. The effect of cooling air on the temperature of the condenser leads to a decrease in the cooling point temperature from 110 °C to 88 °C for T2 and 55 °C to 43 °C for T3, which correspond to the entry and exit points of the condenser, respectively as shown in Figure 7.

Figure 8 demonstrates the change in the values of COP of the A/C unit as time passes after the manipulation of the evaporative cooling (third method). The evolution in the performance of COP of the refrigeration cycle after the utilization of the evaporative pad is highly remarkable. Given that the heat transfer rate increases as the external air conditions vary (dropped down by the manipulation of the evaporative pad). The COP of the A/C unit has dramatically increased by 65%.

The findings of the cooling effect calculation indicated an increase in the cooling capacity of the cycle. Since the refrigerant starts to evaporate at T4 (due to the occurrence of sub-cooling), this effectively lowers the enthalpy, and when the enthalpy is low, the cooling capacity increases, as illustrated in Figure 9. The cooling load has been increased by nearly 52% going from 5635 (W) to 8568(W) affected by the change in the temperature of the condenser after the evaporative cooling method was in action.

5. Conclusion

The use of geothermal cooling in extremely hot climatic conditions was studied to improve the performance of conventional vapor pressure cooling systems. To support the success and effectiveness of geothermal cooling technology, evaporative cooling was also performed to lower the coolant temperature of the AC unit used within the condenser area. The following conclusions reached from this study:

1. For the modified split air conditioning unit, methods were used to evaluate the overall performance. Modifications have been made to take advantage of both geothermal and evaporative cooling. The overall efficiency of the device in increasing cooling and reducing both temperatures and the electrical energy consumption is greatly improved due to the use of geothermal evaporative cooling technologies.
2. Experimental results while using EAHE technology to improve the performance of conventional vapor pressure refrigeration systems in summer are increased cooling capacity and condition by 21% and 41%, respectively.
3. The experimental results during the utilization of evaporative cooling showed that the temperature of the condenser decreased from 110 to 88ºC. In addition, an improvement of 65% was made on the performance coefficient of the vapor-compression refrigerator cycle, as well as a decrease in the evaporator temperature from 6 to 3.5 ºC and an increase in the cooling capacity at the rate of 52%.
4. The methods used (methods one and two) showed that a reduction in energy consumption was achieved with a significant increase in cooling capacity and performance factor.
5. COP improvement is observed in evaporative cooling compared to using a geothermal heat exchanger. This improvement is due to the fact that the input temperature of the condenser decreased from 110 ° C to 88 in evaporative cooling, while it decreased from 116 to 110 when using EAHE.

Future Scope and Recommendation:

Recommendations to enhance system performance: The design of a novel condenser with a thermally integrated heat exchanger for small refrigeration systems that incorporates geothermal cooling is essential for future research. The depth of the created geothermal whole has limited the current investigation, which may be expanded upon by going to deeper depths as some earlier researchers have indicated. It is also suggested that future research should focus on the influence of soil properties, such as moisture content, density, and soil type on the thermal performance of geothermal cooling. It is suggested to use different geometries, layouts, and materials for buried pipes within the EAHE system/system which may produce different (better) results for further future experiments. It is also suggested to investigate the use of shade trees to cool the ground around the geothermal test area. One suggestion is that the two cooling technologies can also be represented on a separate plot and compared with the current empirical research.

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