كلية الهندسة بشبرا
FACULTY OF ENGINEERING AT SHOUBRA
ERJ
PRINT ISSN 3009-6049
ONLINE ISSN 3009-6022

**ENGINEERING RESEARCH JOURNAL (ERJ)**
Volume (53),Issue (3)
July 2024, pp:47-53
https://erjsh.journals.ekb.eg

# Energy Analysis of Solar Central Air Conditioning System

**Rana Salama [1,*], Ashraf Mimi Elsaid [2], Ashraf Lashin [1], Ahmed A.A. Attia [1]**

*[1] Mechanical Department, Faculty of Engineering at Shoubra, Benha University, Cairo, Egypt.*
*[2] RHVAC Technology, Faculty of Technology and Education, Helwan University.*
**Corresponding author*

*E-mail address: ranaslama0@gmail.com , ashrafmimi@live.com , ashraf.lashin@feng.bu.edu.eg , ahmed.attia@feng.bu.edu.eg*

**Abstract:** Reducing dependency on fossil fuels and the corresponding emissions, absorption chiller systems offer a sustainable and eco-friendly alternative to conventional refrigeration systems. To determine the success of a solar thermal air conditioning system, climate data was collected for Cairo, Egypt, between May and September 2023. Many factors affecting the performance of the system were studied, including the area of the solar collector, its inclination angle, the temperature of the hot and chilled water, and the mass flow rate. The results of the simulation demonstrate that at a high system Coefficient of Performance (COP), the solar absorption chiller can consistently generate cooling. The system's cooling load requirement is 26.4 kW, and its maximum COP is 0.52. A system consisting of an 80 °C hot water inlet, a 3780-liter solar water storage tank, a 15-degree solar collector slope, and a 1.19 kg/s hot water flow rate was able to achieve peak performance. The solar-powered cooling system was investigated using a simulation tool known as TRNSYS (Transient System Simulation Software). The compound parabolic solar collector area increases from 20 to 50 $m^2$, resulting in a decrease in the amount of energy required from the auxiliary heater from 23 to 21.5 kW. The outcomes also demonstrated that the coefficient of performance rose until it reached 0.52, when hot and chilled water temperatures rose. When analyzing the energy during a typical summer, it was found that the solar collector can store an average of 15.3 kW of energy. During these periods, the auxiliary heater consumed an average of 20.5 kW of electricity.

**Keywords:** Solar energy, air conditioner, absorption chiller, auxiliary heater, TRNSYS.

| Nomenclature | | Subscripts | |
|---|---|---|---|
| A | Area of collector, $m^2$ | Coll | Collector |
| C | Specific heat, kJ/kg.K | aux | auxiliary |
| I | Solar radiation, W/$m^2$ | hw | Hot water |
| M | Mass flow rate, kg/s | chw | Chilled water |
| T | Temperature, °C | SF | Solar fraction |
| COP | Coefficient of performance | **Greek symbols** | |
| | | $\eta$ | Thermal efficiency |

## 1. Introduction

Globally, more energy is required to cool space. It is estimated that by 2050, the rise in cooling demand will account for over 20% of the world's electrical power use in 2023 [1,2]. Due to the severe strain on regional grids caused by this sudden spike in demand, particularly in extremely hot climates, there is a serious problem [3]. The challenge is even more acute in developing nations, where the budgetary strain caused by the cost of power generated by imported fossil fuels makes the situation worse [4]. More than forty percent of the energy used in the building industry goes toward cooling systems, and demand for these systems is expected to increase as consumers seek out environmental control [5]. Because water is a coolant, its maximum cooling capacity is directly correlated with the amount of potential solar energy. In the space cooling industry, chilled water via vapor compression systems is currently the most widely used cooling technology [6]. These systems use energy-intensive and polluting refrigerants. Cost-effective, green cooling techniques that can lower electricity demand, increase resilience, lessen dependency on fossil fuels, and cut greenhouse gas emissions are desperately needed [7]. Solar-powered absorption cooling systems can effectively replace conventional water vapor compression systems in cooling applications. The strongest solar radiation occurs during the day, which is also typically when the biggest cooling requirements arise. This synchronization provides an important benefit when cooling with solar energy. An absorption chiller system lessens dependency on fossil fuels and the pollutants they produce by offering a sustainable and environmentally friendly substitute for conventional cooling systems [8]. However, there are a variety of challenges associated with the development and operation of these systems. The performance of the absorption chiller system with the auxiliary boiler and different collector loop control strategies was investigated by Ratismith et al. [9] using a simulation model of the system. Furthermore, they evaluated how well auxiliary boilers performed in a parallel and series design in the solar collector loop. One of the main challenges facing scientists studying solar energy technology for air conditioning is that it is considered a national goal. Paulino et al. [10] employed carbon dioxide as a cooling agent during the water heating process to assess the solar-powered water heating system experimentally. Data indicated that there is a significant relationship between the water intake temperature and the gas refrigerant discharge pressure. Because increasing gas cooling output temperatures and pressures always follow higher water inflow temperatures, COP falls. Studies have been conducted on a range of solar-cooling methods, including absorption and adsorption systems [11]. Standard air conditioners work less effectively in humid environments, which lowers their cooling capacity due to the increased moisture content in the ventilation air. A hybrid pressure steam dehumidifier system that addresses this issue by controlling temperature and humidity while using less energy was modeled using TRNSYS (Transient System Simulation Software), by Jani et al. [12]. The recommended approach reduced the total amount of humidity in the air, based on the data gathered. The efficiency of solar-adsorption air conditioners has been the subject of extensive investigation. Examining the solar cooling system with compound parabolic collector type, Cirillo et al. [13]. This led to the discovery of the highest solar COP of roughly 0.3 and the largest COP of 0.55. An investigation into a tiny adsorption chiller without vacuum valves was carried out experimentally by Reda et al. [14]. There was 9.60 kW of cooling power available, and 0.49 kW of COP was present. Chen et al. conducted research on the adsorption chiller system utilizing natural zeolite water [15]. COP for the warmth source temperature was 150 °C, according to the experiment data.

A review of previous research on solar-powered air conditioning was given, which led to the identification of a research gap about system types, components, and performance-influencing factors. The majority of systems had deficiencies in both factors and system components. This study was done because neither the impact nor the effect on the system's performance had been thoroughly examined. The solar collector area, the additional heater exit temperature, and tilt angle were all taken into consideration during the study analysis carried out in TRNSYS to optimize the system. Using a model that replicated the intense heat of Cairo, Egypt, the building demand for air conditioning was established.

## 2. SYSTEM DESCRIPTION

The solar cooling system's design is appropriate for supplying the cooling energy required by a building in Cairo, Egypt. A schematic of the suggested absorption cooling system powered by a collector is shown in Figure 1. The following are the essential parts of the system: 1-Compound parabolic solar collectors, 2- Auxiliary heaters, 3- Storage tanks, 4- Pumps, 5- Absorption chillers, 6- Cooling towers. The system consists of three processes: the processes for producing hot water, cooling water, and chilled water. For the hot loop, there is a solar collector, heater, pump, and storage tank. Pump 1 sends the water to the collector and from the storage tank to the heater as the hot water flows to the chiller at 80 °C. Pump 2 transfers the exit hot water from the chiller to the solar collector so that it can be reheated, preventing any decrease in the amount of hot water entering the chiller. Pump 3 moves the cooling water through the cooling tower, maintaining its temperature at 29 °C. Pump 4 is supplied the chilled water to the cooling coils, where heat is exchanged between the chilled water and the coil air.

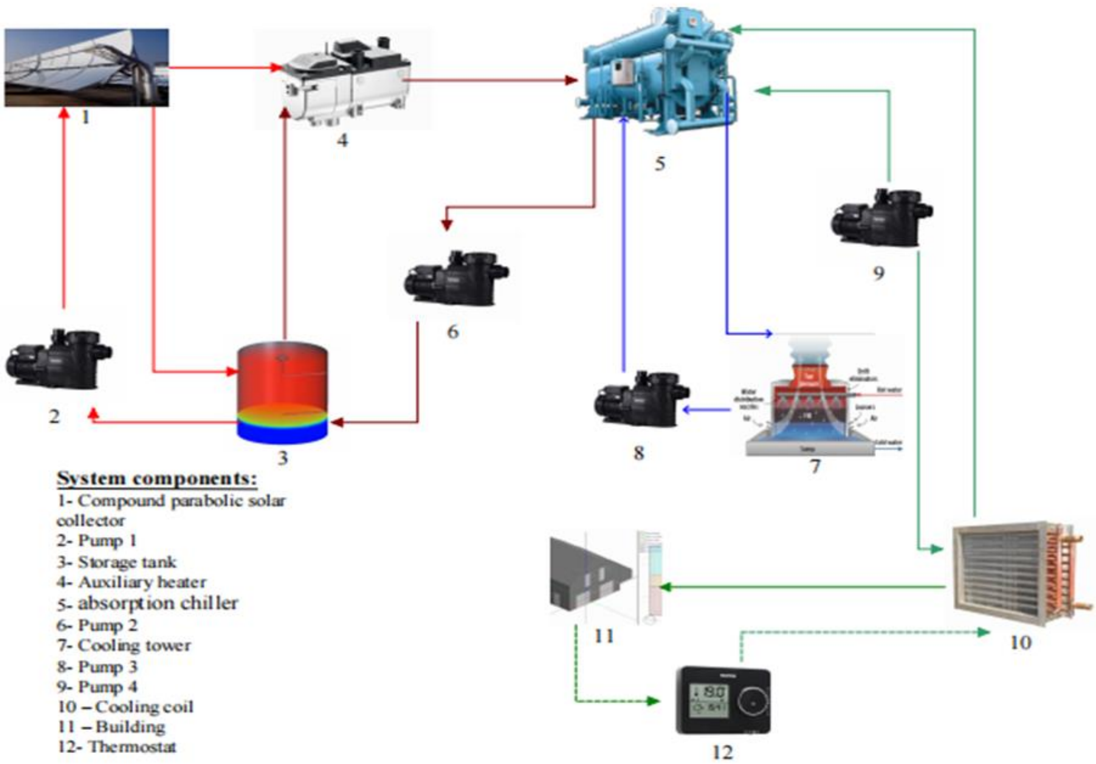



**FIGURE 1.** An illustration of the solar cooling system.

## 3. TRNSYS MODELING

The solar cooling system is fully modeled in TRNSYS, with its foundation being a single-effect absorption chiller. The model utilizes weather data from Cairo, Egypt, as its reference climate. Figure 2 depicts the configuration of the solar cooling system in TRNSYS. By simulating this building model, an hourly timeline indicative of the seasonal cooling needs is produced. Table 1 lists all types that were utilized. Table 2 shows the simulation's operational conditions.

**TABLE 1.** Components of the solar cooling system.

| Components | Type |
|---|---|
| Compound parabolic collector | 74 |
| Auxiliary heater | 6 |
| Storage tank | 4a |
| Pump | 114 |
| Absorption chiller | 107 |
| Cooling tower | 51b |
| Cooling coil | 32 |
| Building | 88 |

**TABLE 2.** The simulation's operating conditions.

| Parameter | Value | Unit |
|---|---|---|
| Inlet hot water to chiller | 80 | °C |
| Hot water flow rate | 1.19 | kg/s |
| The inlet temperature of the chilled water | 7 | °C |
| Chilled water flow rate | 1.262 | kg/s |
| Inlet cooling water temperature to chiller | 29 | °C |
| Cooling water flow rate | 2.6 | kg/s |

## 4. MATHEMATICAL EXPRESSION

The amount of solar radiation incidentally averaged over the same time divided by the collector's usable thermal energy yields the collector's efficiency. Equation (1) provides a mathematical expression for the efficiency of a collector.

$$\eta = \frac{Q_{in}}{Q_{coll}} \tag{1}$$

Equation (2) can be used to explain the received energy by the collector.

$$Q_{in} = I \times A \tag{2}$$

The ratio of usable energy gained to the energy needed from the auxiliary heater is known as the solar fraction. Equation (3) is used to calculate the solar fraction.

$$SF = \frac{Q_{coll}}{Q_{coll}+Q_{aux}} \tag{3}$$

The performance coefficient of the system is computed from Equation (4).

$$COP = \frac{Q_{chw}}{Q_{aux}+Q_{hw}} \tag{4}$$

## 5. RESULTS AND DISCUSSION

The present section introduces the recommended solar absorption air conditioning system's energy analysis and performance attributes under various conditions.

### 5.1 WEATHER INFORMATION

According to Cairo weather, the summertime average monthly ambient temperature is fairly high, ranging from 29.7 °C to 41.7 °C. The summertime average monthly solar radiation is high, surpassing 900 W/m2, as illustrated in Figure 3.

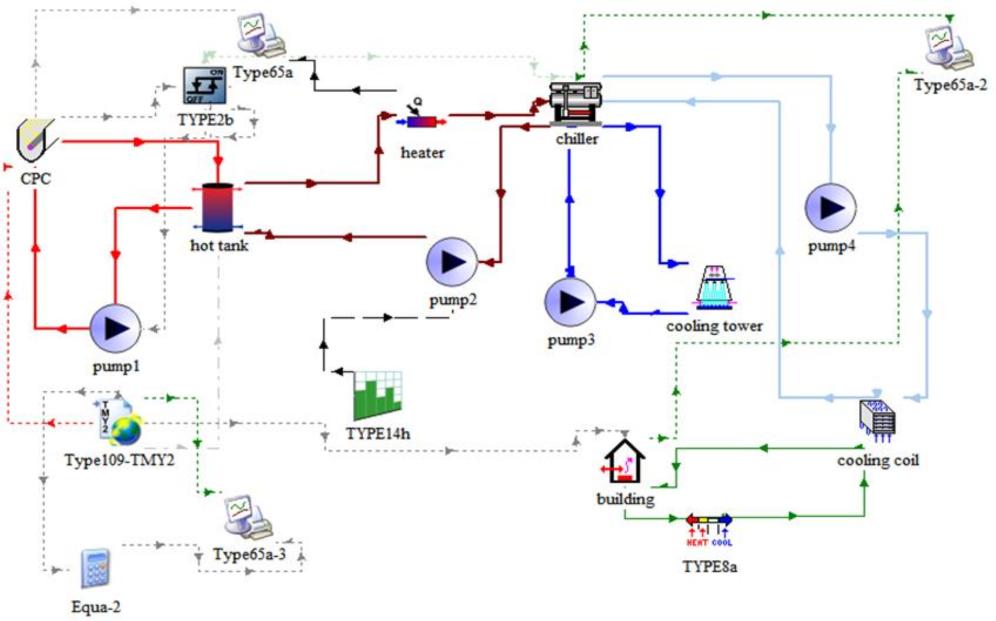



**FIGURE 2.** An illustration of a solar cooling system based on TRNSYS.

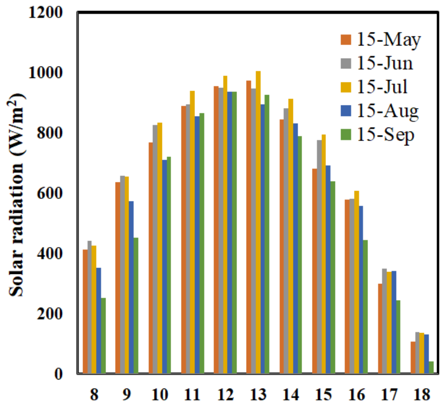
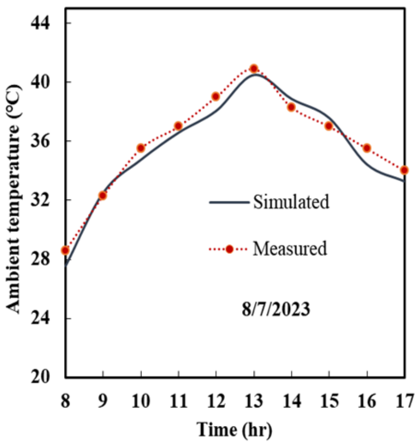



**FIGURE 3.** The annual variation in global radiation from May to September.

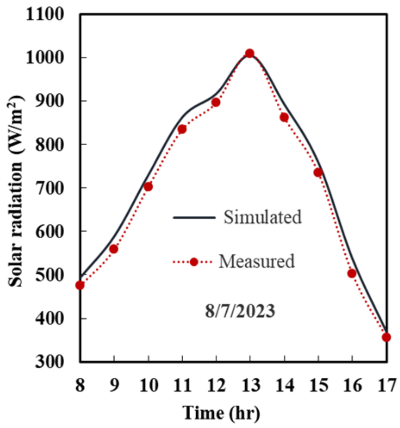
## 5.2 VALIDATION FOR THE SIMULATED DATA

The temperature [°C] and radiation [W/m$^2$] can be measured on July 8 in order to confirm the results with the remote unit SOLAR-02 by using the SOLAR-02 environmental parameters data logger as shown in Figure 4. Figure 5 compares the values of incident solar radiation and the weather, both real and simulated. As the data demonstrate, there was a good agreement between the simulated and measured values.


**FIGURE 4.** SOLAR-02 environmental parameters data logger.




**(a)** Ambient temperature versus time.




**(b)** Solar radiation versus time.

**FIGURE 5.** Comparing measured and simulated values for ambient temperature and solar radiation.

## 5.3 PERFORMANCE PARAMETERS

### *5.3.1 The impact of hot water temperature on system performance*

One of the most important parameters affecting the system's performance is the temperature of the hot water entering the chiller, as it significantly affects the performance of the solar cooling system, as shown in Figure 6, where the temperature of the hot water affects the cooling capacity and the coefficient of performance. The absorption process becomes more complete as the hot water temperature rises, increasing the capacity for absorption in the following batch operation. As a result, cooling capacity and COP rise. The cooling capacity and COP reach 33.3 kW and 0.52, respectively. Although increasing the temperature of the hot water entering the chiller improves system performance, the amount of energy required from the additional heater will also increase, as shown in Figure 7, and this will lead to a decrease in solar fraction.

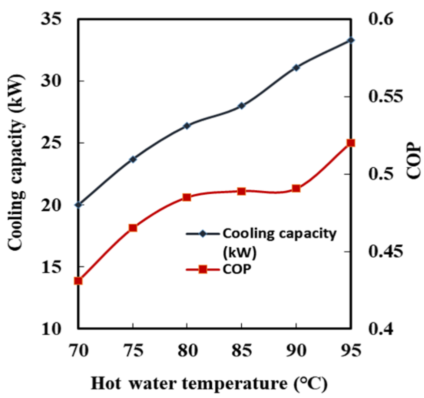



**FIGURE 6.** The influence of hot water inlet temperature on cooling capacity and COP.

### *5.3.2 The auxiliary heater*

As To provide hot water for the absorption chiller when there is not enough solar radiation, a water heater is added to the system as an auxiliary heating system. The hot water temperature for the chiller was 80°C while the system was running. The temperature of the water flowing from the solar collector can reach a maximum temperature of about 75°C at peak time, as shown in Figure 8, so it was necessary to add a solar heater to maintain the temperature of the hot water entering the chiller at 80°C.

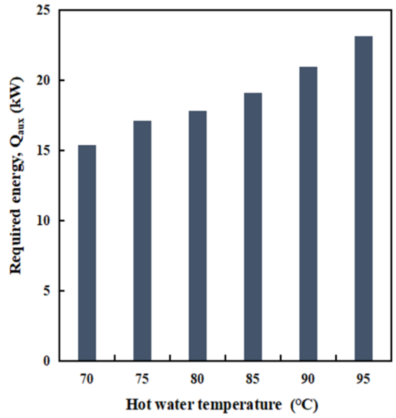



**FIGURE 7.** Variation in the required energy gain with the inlet hot water temperature.

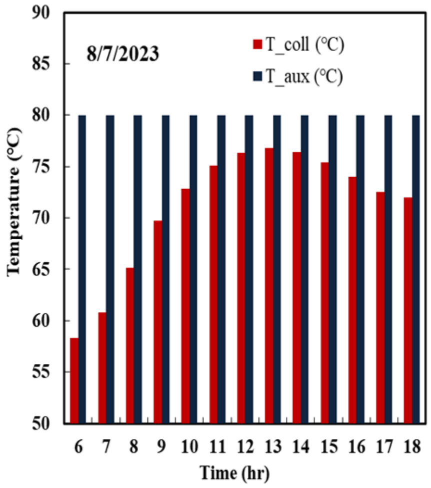



**FIGURE 8.** Temperature variation for solar collector and auxiliary heater water temperature.

### *5.3.3 The impact of chiller water temperature and mass flow rate*

Based on the temperature of the chilled water input, Figure 9 shows how cooling capacity and COP change. The cooling capacity and COP both increase as the chilled water inlet temperature rises from 10 to 15 °C. The reason for this is that higher evaporation pressure causes more water to be absorbed. When more water vapor is absorbed, the absorbent's absorption capacity also increases, which results in a rise in both cooling capacity and COP as the evaporation pressure increases. The cooling load and COP increase to 31.1 kW and 0.48, respectively. As cooling demand is noticeably higher during the warmest month of the summer, it is advisable to adjust the evaporator's flow rate value to create higher values.

## 6. ANALYSIS OF ENERGY

To achieve the study's goal of maintaining the zone temperature in a comfortable range between 23 and 24 °C, an absorption cooling system was linked to the solar collector. From [1-May] to [30-September], the recommended system's average rate of energy storage and consumption for Cairo in the summer is shown in Figure 10. During a typical summer, the solar collector can store an average of 15.3 kW of energy. During these periods, the auxiliary heater consumed an average of 20.5 kW of electricity. The findings demonstrated that when solar radiation is lower early in the day, more heat is needed from the auxiliary heater; conversely, when solar radiation is higher during peak hours, less heat is needed from the auxiliary heater.

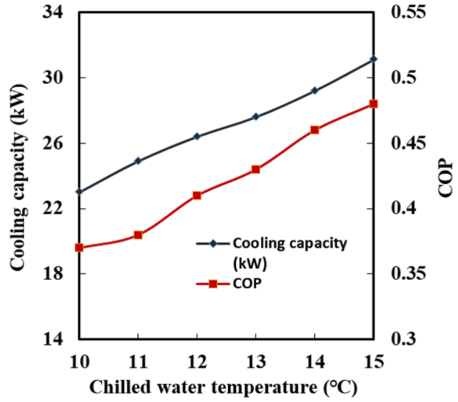
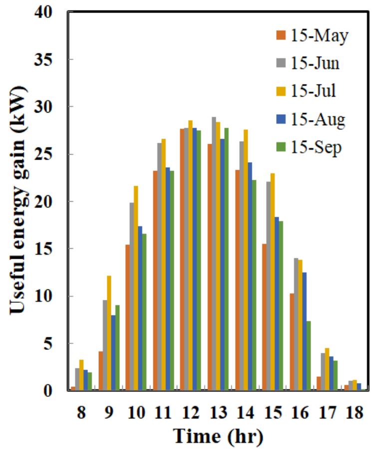
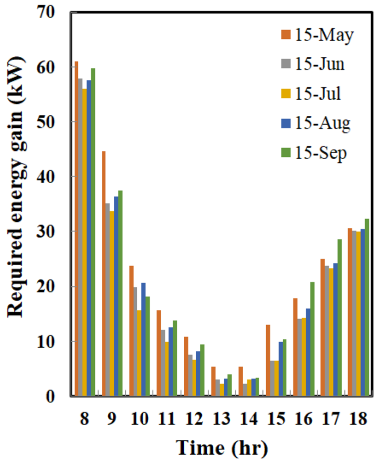



**FIGURE 9.** Chiller water temperature's effect on cooling capacity and COP.



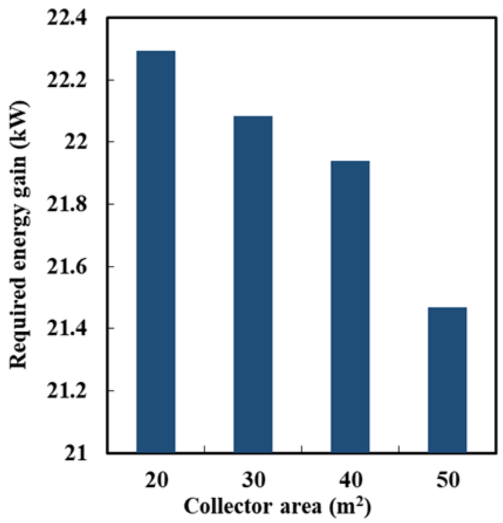

(a) The daily rate of useful energy.



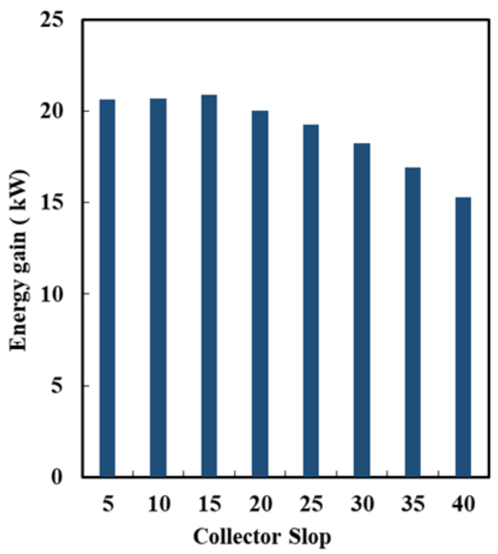

(b) The daily rate of the energy used by the heater.

**FIGURE 10.** The useful energy and required energy gain.

Figure 11a shows how the solar collecting area affects the amount of supplemental heating required. the solar collector area increases from 20 to 50 $m^2$, resulting in a decrease in the amount of energy required from the auxiliary heater. Figure 11b shows the average variations in solar gain under different angles of solar collector inclination. The solar collector with a 15-degree inclination angle had the best absorption of solar energy, according to the optimization results.




**(a)** The required energy gain with different collector areas.




**(b)** The Solar energy gain with different tilt angles.

**FIGURE 11.** Energy indicators for the suggested solar system.

## 7. CONCLUSION

This study provides a systematic approach for the summertime component selection of solar-assisted cooling systems. To achieve the goals of this study, simulation software was used to optimize the solar collectors' area, slope, and the exit water temperature from the auxiliary heater. Using TRNSYS software, the dynamic system was modeled. Its validity was verified by comparing the model with measurement data. From the analysis, the following results were drawn:

1. The operating conditions have a big impact on how well the system performs. The cooling capacity increased as the inlet hot water temperature increased from 70 to 95 °C, peaking at 95 °C. This also led to an increase in COP until it reached 0.52. An appropriate value of 1.19 kg/s was found for the average flow rate of heated water in the case examined.
2. When the temperature of the chilled water increased from 10 to 15, the cooling capacity increased. It was discovered that the suggested value for the case analyzed was 1.262 kg/s for the chilled water's flow rate. Moreover, the performance factor improved until it reached 0.48.
3. Solar absorption-induced cooling was significantly influenced by the features of the solar collector. 50 $m^2$ of the collector area with a 15-degree inclination angle had Cairo's maximum cooling capacity and COP.
4. Adding an auxiliary heater ensures that the solar water air conditioning unit reaches the required performance without disruption during the summer period.

## ACKNOWLEDGMENTS

This work is the outcome of a master’s thesis in the Department of Mechanical Power Engineering - Faculty of Engineering, Shubra, Benha University. The researcher would also like to thank and appreciate the master’s thesis supervisors, Dr. Ashraf Mimi Elsaid (Helwan University), Dr. Ashraf Lashin (Benha University), and Dr. Ahmed Attia (Benha University) for the psychological, academic, and moral support to reach this stage of the road.

## REFERENCES

[1] Ashraf Mimi Elsaid, Fathia A. Hashem, Hany A. Mohamed, M. Salem Ahmed, Improving summer cooling in the Egypt hot/dry arid region utilizing a Trombe wall system: A field investigation, Solar Energy 267 (2024) 112235.

[2] Ashraf Mimi Elsaid, Ali M. Abdelhady, Gamal B. Abdelaziz, M.A. Halim, Performance improvement for chilled water air conditioning cooling coils with various dimple fin geometries, International Journal of Thermal Sciences 193 (2023) 108441.

[3] S. Mehmood, J. Lizana, and D. Friedrich, “Solar-driven absorption cooling system with latent heat storage for extremely hot climates,” Energy Convers. Manag., vol. 297, no. October, p. 117737, 2023.

[4] Ashraf Mimi Elsaid, Fathia A. Hashem, Hany A. Mohamed, M. Salem Ahmed, The energy savings achieved by various Trombe solar wall enhancement techniques for heating and cooling applications: A detailed review, Solar Energy Materials & Solar Cells 254 (2023) 112228.

[5] Ashraf Mimi Elsaid, A novel Design, Implementation and Performance Evaluation of the First Electronic Expansion Ejector for Energy Saving of a Mini Split Air Conditioner Controlled by Inverter, Energy Conversion and Management 260 (2022) 115603.

[6] W. N. A. Wan Roshdan, H. Jarimi, A. H. A. Al-Waeli, O. Ramadan, and K. Sopian, “Performance enhancement of double pass photovoltaic/thermal solar collector using asymmetric compound parabolic concentrator (PV/T-ACPC) for façade application in different climates,” Case Stud. Therm. Eng., vol. 34, no. April, p. 101998, 2022.

[7] Abdalla Gomaa, Eldesuki I Eid, Wael IA Aly and Ashraf Mimi Elsaid, Thermal performance of the chilled water spirally coiled finned tube in cross flow for air conditioning applications, Ain Shams Engineering Journal-Mechanical Engineering 3 (2012) 49–59.

[8] E. Chen, J. Chen, T. Jia, Y. Zhao, and Y. Dai, “A solar-assisted hybrid air-cooled adiabatic absorption and vapor compression air conditioning system,” Energy Convers. Manag., vol. 250, no. November, p. 114926, 2021.

[9] D. Ali and W. Ratismith, “A semicircular trough solar collector for air-conditioning system using a single effect NH3–H2O absorption chiller,” Energy, vol. 215, p. 119073, 2021.

[10] W. M. Duarte, S. N. Rabelo, T. F. Paulino, J. J. G. Pabón, and L. Machado, “Experimental performance analysis of a CO2 direct-expansion solar assisted heat pump water heater,” Int. J. Refrig., vol. 125, pp. 52–63, 2021.

[11] A. Alahmer, X. Wang, R. Al-Rbaihat, K. C. Amanul Alam, and B. B. Saha, “Performance evaluation of a solar adsorption chiller under different climatic conditions,” Appl. Energy, vol. 175, pp. 293–304, 2016.

[12] D. B. Jani, M. Mishra, and P. K. Sahoo, “Performance analysis of a solid desiccant assisted hybrid space cooling system using TRNSYS,” J. Build. Eng., vol. 19, no. December 2017, pp. 26–35, 2018.

[13] B. Buonomo, F. Cascetta, L. Cirillo, and S. Nardini, “Application of nanofluids in solar cooling system: Dynamic simulation by means of TRNSYS software, Model. Meas. Control B, vol. 87, no. 3, pp. 143–150, 2018.

[14] A. M. Reda, A. H. H. Ali, M. G. Morsy, and I. S. Taha, Design optimization of a residential scale solar driven adsorption cooling system in upper Egypt based, Energy Build., vol. 130, pp. 843–856, 2016, doi: 10.1016/j.enbuild.2016.09.011.

[15] L. Chen, W. Deng, and Y. Chu, “Experimental study on desiccant evaporative combined chilled air/chilled water air conditioning systems, Appl. Therm. Eng., vol. 199, no. September, p. 117534, 2021.