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PERFORMANCE AND ENERGY SAVING EVALUATION OF SOLAR ABSORPTION REFRIGERATION SYSTEMS IN NORTHEASTERN ALGERIA

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ABSTRACT

The global energy demand and environmental concerns rise, solar absorption refrigeration systems present a sustainable alternative to conventional cooling technologies. This study aims to evaluate the performance of a solar absorption refrigeration machine in Constantine (North-East Algeria), focusing on its efficiency and suitability for the region's climate. This region, known for its high temperatures and abundant solar radiation, offers an ideal setting to study these systems.
The Aspen software is employed to simulate the absorption refrigeration system without solar collectors. Empirical equations were developed, and a Python code was used to integrate a solar thermal collector and calculate overall Coefficients of Performance (COPs) for the air conditioning mode. The system utilized water and lithium bromide as working fluids. Setting an indoor temperature at 25°C, hourly outdoor temperatures and solar radiation data for Constantine from May to October are provided by Meteonorm software (version 7).
The present investigation revealed that Constantine's summer monthly solar irradiation reaches up to 220 KWh/m2, making the region highly suitable for solar-powered cooling. The system demonstrated promising performance and energy saving, with COP ranging from 0.75 to 0.89 and COPs between 0.57 and 0.63. Likewise, it also confirms the feasibility of solar absorption refrigeration systems in high-temperature, high-solar-radiation regions like Constantine, Algeria. The observed performance metrics suggest significant potential for sustainable cooling solutions in similar climates and will influence how cities are designed and built, especially in hot climates. This type of system mitigates climate change. Future research should focus on integrating advanced solar collectors and optimizing system design to enhance efficiency and cost-effectiveness.

KEYWORDS

Absorption, Energy Saving, Solar Irradiation, Climate Change, Refrigeration, COP

CITATION

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1. Introduction

Air conditioning and refrigeration systems represent a large percentage of global electricity consumption, approximately 30% of the building global consumption energy and 26% of global energy-related emissions *(*Buildings - Energy System - IEA*, n.d.)* especially in recent years where the purchasing power of a certain population is increasing, as well as the consequences of climate change *(Clarke et al., 2018)* and rising global population. In Algeria 23% of primary used in buildings *(Ministry of Energy and Mines, 2022)*, This sector is responsible for consuming up to 40% of the total energy consumption in some developed countries *(Berardi, 2015)*. The depletion of energy sources has become a major problem for developed and developing countries *(Pang et al., 2024)*, especially since traditional air conditioning machines are high energy-consuming systems, Currently, a majority of our existing domestic air-conditioning needs are met using a relatively mature and well-understood technology called vapor compression cycle (VCC) *(Park et al., 2015)* . Not to mention their influence on the environment because most refrigeration systems are mechanical compression systems that use electricity as an energy source *(McLinden et al., 2020)*, in Algeria, most of this energy being generated through thermal power plants that use fuel (gas or fuel oil) for their operation. We can also add the influence of old refrigerants or transition fluids on global warming and the ozone layer, especially CFCs and HFCs. Already in the urban areas, the people with cars and air-conditioners emit 4.5 mt of carbon dioxide/greenhouse gases per year, while the low-income people without car and air-conditioners emit an average of 1.1 mt of CO_2 /GH gases *(Jain, 2023)*. In Algeria, 97% for electricity produced throw a thermal power station *(*Ministère de l'Énergie | Algérie*, n.d.)*

To remedy these two problems, we need an economical system that uses non-harmful refrigerants for the environment, consumes less energy and above all uses clean energy sources. Thermal refrigeration systems that use thermal energy for their operation represent an effective alternative to old mechanical compression refrigeration systems. Among thermal refrigeration systems, absorption meets the characteristics of an economical, environmentally friendly system that can be powered by clean energy such as solar energy

Solar absorption refrigeration is an innovative technology that harnesses the power of the sun to provide cooling and refrigeration, offering a sustainable and environmentally-friendly alternative to traditional vapor-compression systems. Refrigerants with low global warming potential (GWP), including those exhibiting mild to high flammability, offer substantial reductions in greenhouse gas emissions, thereby contributing to international climate and sustainability objectives. However, the utilization of such refrigerants necessitates a comprehensive assessment of potential safety hazards and environmental consequences associated with their end-of-life management (Cheekatamarla & Sharma, 2024).

This section presents a concise overview of existing research on solar absorption refrigeration, highlighting its advantages, challenges, and potential applications.

The operating principles of solar absorption refrigeration systems are well-documented in the literature. These systems utilize the thermal energy from the sun to drive an absorption cycle, typically involving a refrigerant and an absorbent, such as water and lithium bromide. The solar energy heats the absorbent, causing the refrigerant to vaporize and be absorbed by the absorbent, creating a cooling effect through the evaporation and condensation process (Aliane et al., 2016)

One of the key advantages of solar absorption refrigeration is its ability to operate in remote areas where reliable electricity is scarce. This is particularly beneficial for applications such as vaccine storage, where maintaining a consistent and reliable temperature is crucial for preserving the integrity of heat-sensitive medical supplies (McCarney et al., 2013).

Recent studies have explored various solutions to improve the performance and efficiency of solar absorption refrigeration systems. For instance, researchers have investigated the feasibility of combining solar cooling with other cooling modes, such as integrating it with traditional vapor-compression systems or incorporating it into hybrid systems that utilize multiple energy sources (Aridhi et al., 2016). Yeung et al (Yeung et al., 1992) discusses the performance of a solar-powered air conditioning system in university of Hong Kong designed with flat plate collector temperature reaching approximately 80°C, absorption chillers, and a direct cooling water tower. The power gain of the system is above 400 W/m^2 for most of the day on a typical sunny day. The authors provide system design parameters and describe the data acquisition and processing system used to collect performance data. The paper concludes that the performance of the solar-powered air conditioning system is promising, the system could be an efficient alternative to conventional energy-intensive air conditioning systems. The results exhibits optimal performance in arid, high-temperature environments characterized by significant daily fluctuations in both humidity levels and air temperature. The work of Syed et al (Syed et al., 2005) is an experimental investigation of a solar cooling system in Madrid. This system was installed on the roof of UC3M Legane´s Campus and it uses a flat-plate collector array. The paper presents the experimental setup, data collection methods, and data analysis techniques. One of the important results is the daily energy balance for the solar cooling system for typical Spanish houses in Madrid during the summer period of July - August 2003, which includes values of daily global insulation, daily heat produced, and the input and output temperatures of different equipment of the system. daily average and period average COP were 0.60 (at maximum capacity), 0.42 and 0.34, respectively. The paper also highlights that the presented data can be used as benchmark figures for comparative purposes. The results clearly demonstrate that the technology works best in dry and hot climatic conditions where large daily variations in relative humidity and dry bulb temperature prevail. Assilzadeh et al (Assilzadeh et al., 2005) discusses the design and optimization of a solar-assisted cooling and heating system for a commercial building in Kuala Lumpur, Malaysia. The system is designed to cover 100% of the cooling load, while the heating load is covered by a natural gas fired boiler. The paper presents hourly and monthly variations of the solar collector outlet temperature, collector energy gain, dry bulb temperature, and solar radiation on a horizontal surface. The system is optimized through simulation runs, and the results show that the system has a solar fraction of 0.81 and a coefficient of performance of 0.59. The paper concludes that the solar-assisted cooling and heating system is viable for use in commercial buildings in Malaysia. Li et al(Li et al., 2014) presents a parametric analysis of a solar-powered air-cooled double effect absorption chiller. The study aims to investigate the effects of key parameters on chiller performance and optimize the system design. Simulation results show that the COP, total efficiency, and solar fraction (SF) can be maximized with specific parameter settings. The optimal parameter values are found to be an absorber and condenser temperature of 338 K, an evaporator temperature of 273 K, and a cooling water inlet temperature of 296 K. Unexpectedly, the study found that increasing the concentration of the LiBr/H2O solution does not necessarily improve chiller performance. The authors employed a simulation-based approach, with a thermodynamic property model and a lumped parameter method for the storage tank. The study concludes that the proposed parametric model can be used to optimize the chiller design process and improve overall performance. The results contribute to the field by providing insights into system performance and design for solar-powered absorption chillers.

2. Method and Samples.

A key benefit of absorption refrigeration is its ability to extract cooling from sources with relatively low temperatures. The refrigeration system utilizes a lithium bromide absorption cycle which can utilize thermal energy source, as illustrated in Figure 1.

An absorption refrigeration system consists of five primary components: the absorber, evaporator, condenser, generator, and the expansion valve. Additionally, there are auxiliary components such as an economizer (a heat exchanger between the generator and absorber) and the pump. The generator provides thermal energy to heat the binary fluid, typically a lithium bromide-water or ammonia-water solution, increasing the temperature and pressure of the refrigerant (the more volatile component) to facilitate heat rejection at the condenser. The absorbent, in liquid form after separation, returns to the absorber. The pump assists in transferring the binary mixture from the absorber to the generator. The heart of this machine is the generator. To improve system efficiency and sustainability, it is essential to utilize clean and renewable thermal energy sources such as solar, geothermal, and industrial waste heat.

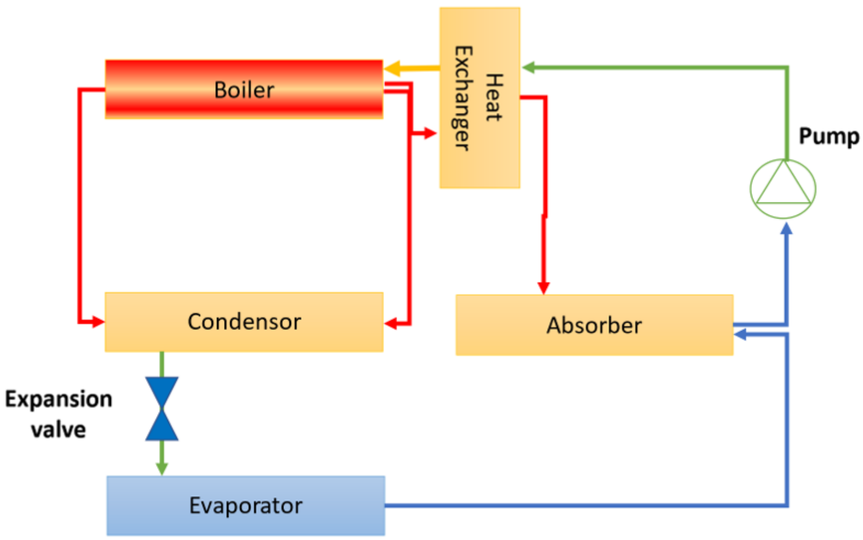

Fig. 1. Basic principle of the absorption refrigeration system (Talpada & Ramana, 2019)

The solar absorption refrigeration system comprises five primary components: two heat exchangers (the evaporator and the condenser), an expansion valve, an absorber, and a boiler. Also, the system incorporates auxiliary equipment, including a pump and an intermediary heat exchanger. The thermodynamic behavior of the system can be characterized by analyzing the heat balance for each component.

The thermodynamic parameters at various points within the system were calculated using Aspen software. A single-effect model was selected for this analysis. Based on the specified parameters and system configuration, energy balance equations were formulated and solved. The primary objective of this thermodynamic analysis was to determine the coefficient of performance (COP) of the refrigeration cycle. This key performance indicator was subsequently utilized to evaluate the overall system efficiency, encompassing both the refrigeration unit and the auxiliary subsystem. The latter comprises multiple thermal collectors and a storage component.

The COP, defined as the ratio of cooling output to energy input, serves as a crucial metric for assessing the thermodynamic efficiency of the refrigeration cycle. Furthermore, it provides a foundation for analyzing the performance of the integrated system, allowing for a comprehensive evaluation of the synergy between the solar thermal collection, energy storage, and refrigeration processes.

This approach enables a thorough investigation of system behavior under various operating conditions and facilitates the optimization of design parameters to maximize overall energy efficiency.

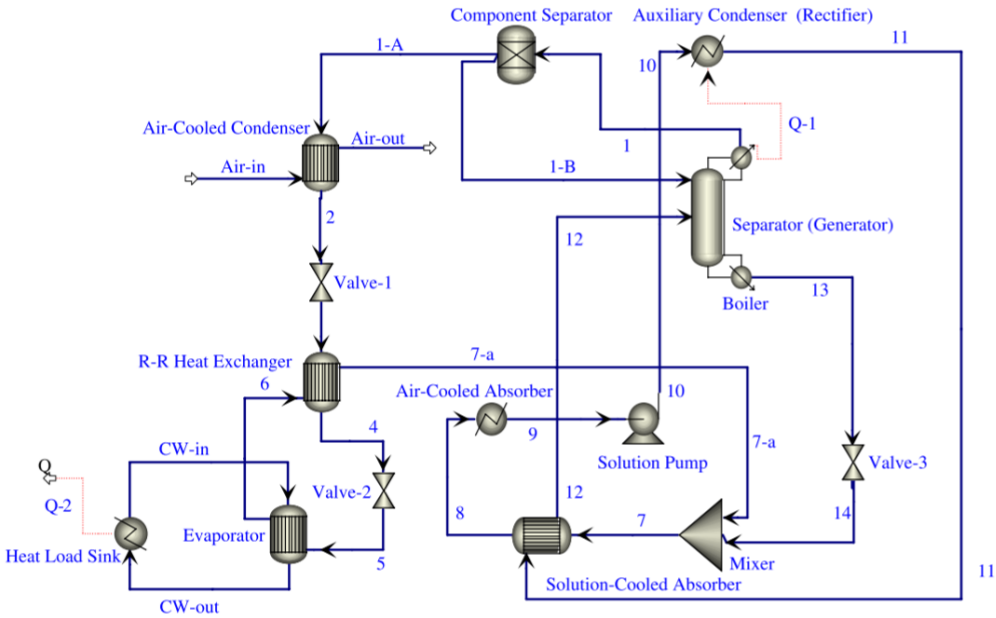

Fig. 2. Aspen flowsheet for simple absroption refrigeration system (Darwish et al., 2008)

The absorption refrigeration system without a solar collector subsystem is optimized using the same model of Darwish (Darwish et al., 2008) et al. The results of the work mentioned above were validated by Horuz and Callander's experimental work (Horuz, I., 2004), which was used to support their outcomes.

$$COP = \frac{\text{Chilling capacity}}{\text{heating capacity}} = \frac{Qe}{(Qg + Wp)} \tag{1}$$

The COP reversible is given by

$$COP = (\frac{T1-T4}{(T1)})(\frac{T10}{(T8-T10)}) \tag{2}$$

Non dimensional efficiency ratio defined as the ratio of coefficient of performance to maximum reversible coefficient of VAR system.)

$$\eta = \frac{COP}{COP_{rev}} \text{ (Patel et al., 2016)} \tag{3}$$

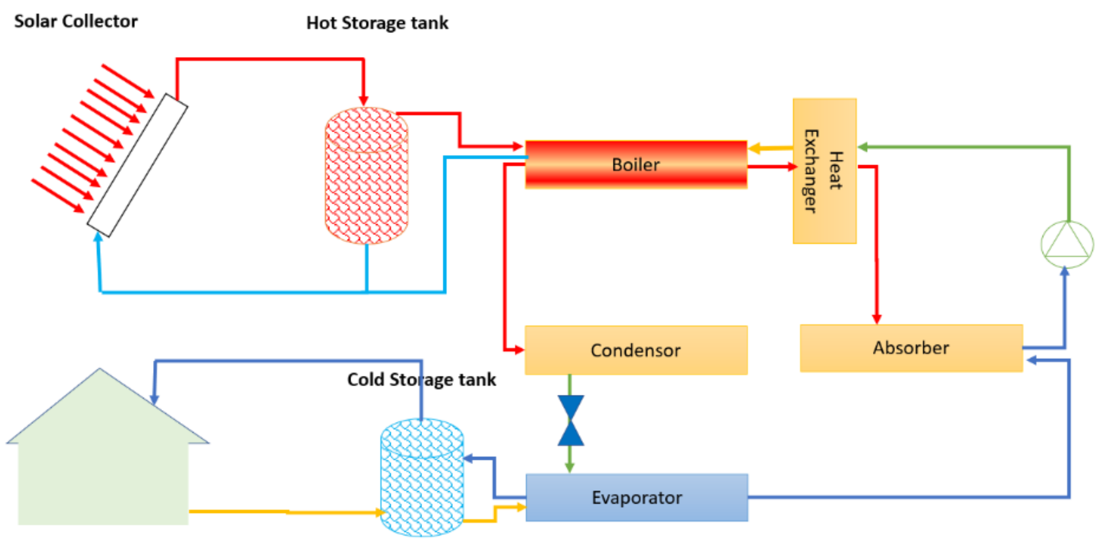

Fig. 3. Principle of the solar absorption refrigeration system

Many research using different equation for calculation solar thermal collector efficiency like
A solar thermal collector type under vacuum is chosen for its high efficiency compared to the other types. The performance equation of the collector considered is given by

$$\eta_{SC} = 0.82 - 7.884\,\frac{Ti-Ta}{I_T} \text{ (Assilzadeh et al., 2005)} \tag{4}$$

Where:
T_i inlet temperature of fluid to collector (ºC)
T_a ambient temperature (ºC)
I_T total incident radiation on a flat surface per unit area (kJ/h m^2)
A Python code is written to calculate the global coefficient of performance for the whole system.

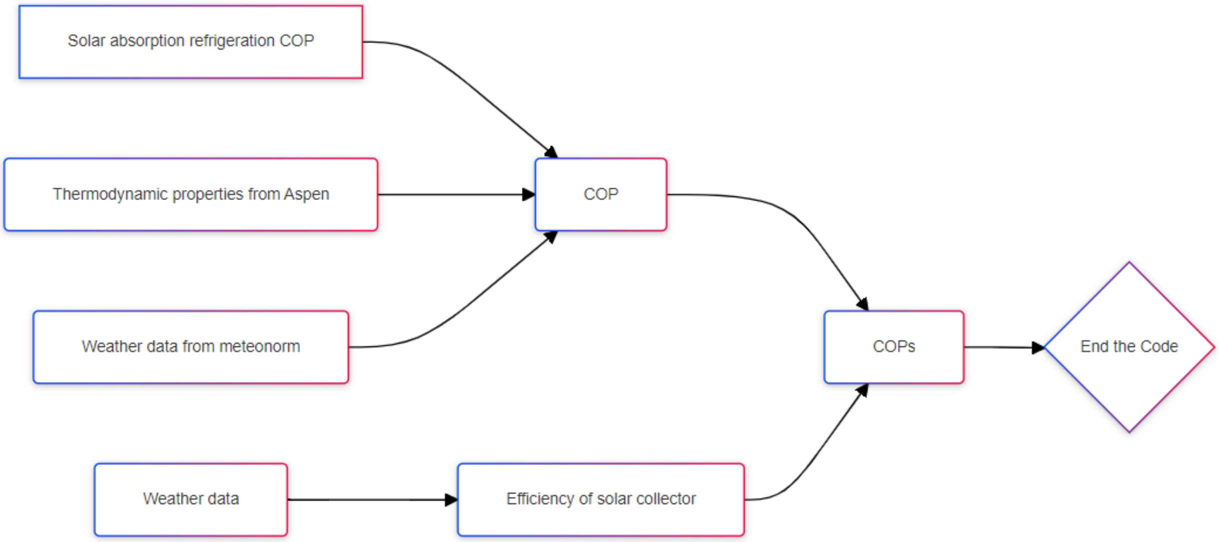

Fig. 4. Flowchart for calculating solar absorption refrigeration system performance

3. Results and Discussions

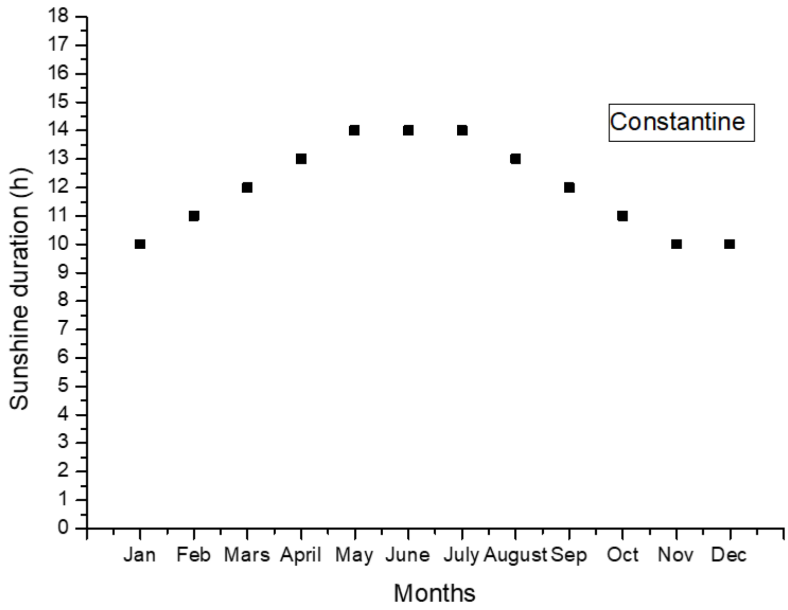

Fig. 5. Monthly astronomic sunshine duration

The graph below depicts the duration of sunshine in Constantine over the course of a year. The values fluctuate between 10 hours and a peak of 14 hours, which is characteristic of the months of May, June, and July from the software metronom, this database collect a data from many weather stations around the world. These conditions give rise to increased thermal loads on the one hand, while also presenting significant potential for solar heat generation to drive absorption refrigeration systems. Consequently, a balance must be struck to develop an air conditioning system that is both efficient, cost-effective, and environmentally friendly.

Constantine receives high levels of global solar irradiation (direct and diffuse), consistently exceeding 150 kWh/m² between May and October. This abundant solar energy offers a promising avenue for driving absorption refrigeration systems. Although the region's warm climate provides ample solar energy, optimizing system performance necessitates considering factors such as ambient temperature, humidity, and solar irradiance variations.

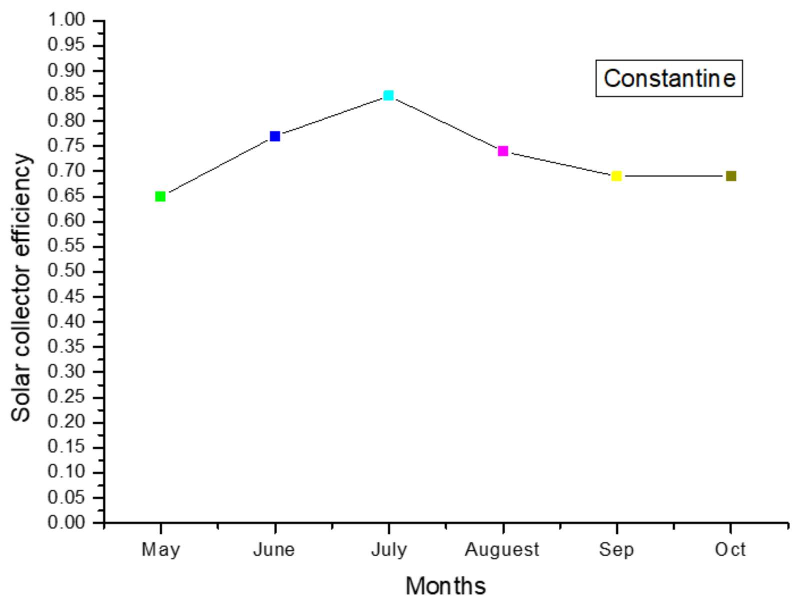

Fig. 6. Monthly solar collector efficiency in Constantine

The figure illustrates the monthly variation in thermal solar collector efficiency during Constantine's peak air conditioning months, the weather data from meteonorm software are used and python code is written for the calculation for the efficiency solar collector. Efficiency peaks in July, coinciding with the highest solar irradiation and also a high temperature is registered. While the minimum efficiency in May is 0.65, overall performance is comparable to previous studies (Florides et al., 2002) (Assilzadeh et al., 2005)and supports the potential for a high-performing, sustainable, and cost-effective air conditioning system.

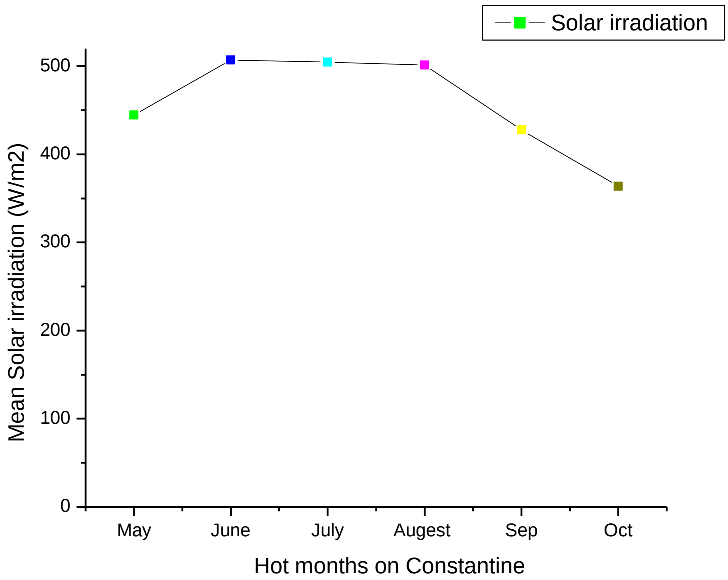

Fig. 7. Monthly mean global solar irradiation in Constantine

The graph illustrates the average monthly ambient temperatures in Constantine. Although June, July, and August represent the peak cooling load period, extreme heat events can extend into May and September. To ensure optimal system design and performance, thermal calculations are typically conducted for these three principal summer months to guarantee adequate indoor thermal comfort.

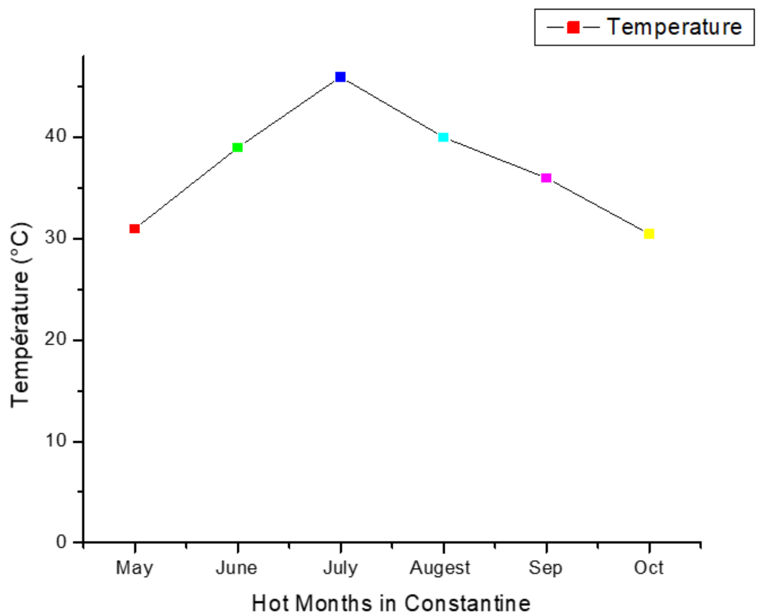

Fig. 8. Mean monthly summer temperature variation in Constantine

The previous graph highlights that the region experiences a substantial temperature range during the cooling season, with temperatures varying between 30°C (May and October) and reaching a maximum of 45°C in July. To mitigate the adverse effects of such extreme heat and ensure occupant comfort, an advanced and energy-efficient cooling system is imperative.

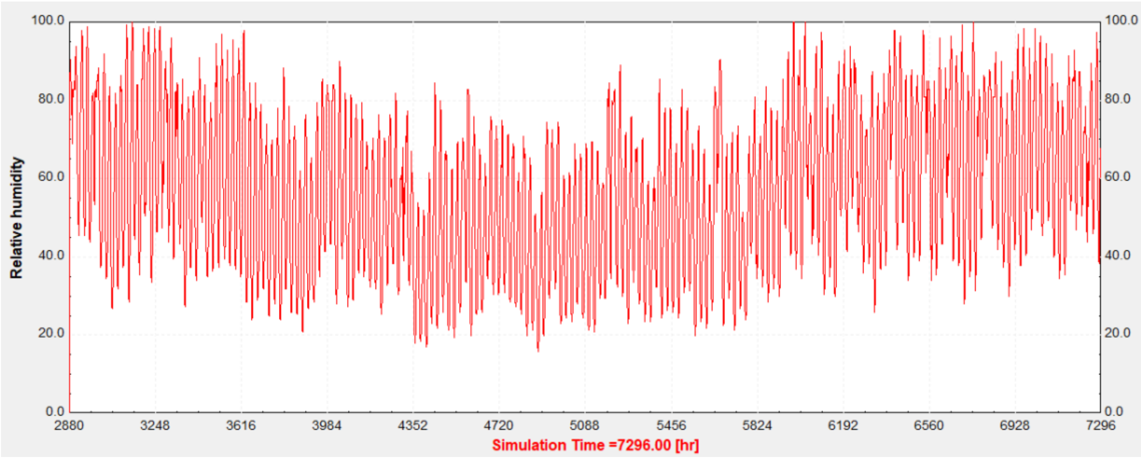

Fig. 9. Relative humidity in Constantine for summer months

Relative humidity levels in Constantine during summer months were analyzed using TRNsys version 17.0 software. The results indicate that ambient humidity closely aligns with the optimal range for human thermal comfort in indoor environments (middle of the graph). This natural alignment eliminates the need for supplementary humidification or dehumidification processes to maintain comfort conditions during summer. Such favorable atmospheric characteristics significantly enhance building energy performance, potentially leading to substantial energy savings in air conditioning system operations. This finding underscores the importance of considering local climatic conditions in the design and implementation of energy-efficient HVAC systems.

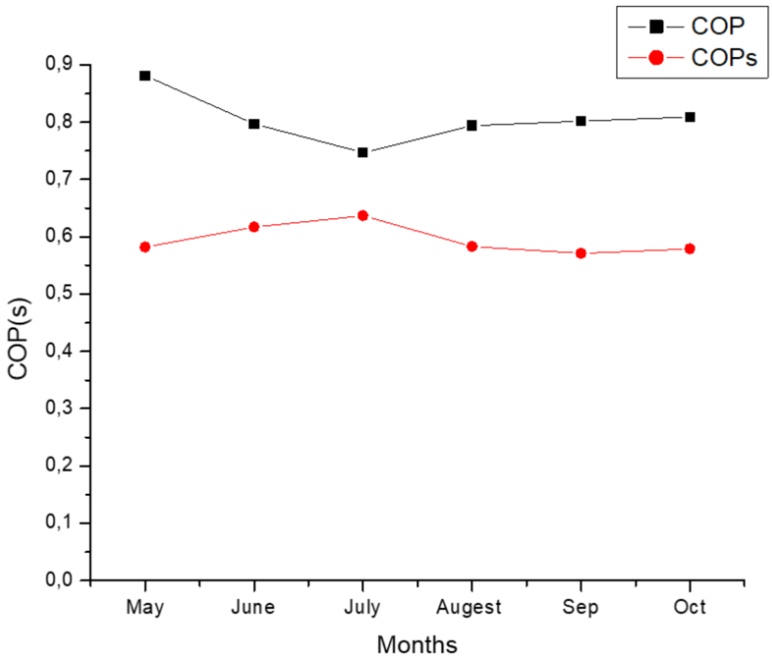

Fig. 10. Comparison between COP and COPs

The temperature of the generator, the fixed evaporator, and the condenser (based on weather data for Constantine city from May to October) must be indicated in accordance with the meteorological data used to compute the solar collector subsystem. The COP and overall COP (which includes the solar heat generation system) for an absorption chiller utilized for air conditioning from May to October are shown in the figure. The warmest month of the year with the highest solar radiation is July, when the COP and COPs values are most closely linked. In terms of COP, the absorption refrigeration system performs better than other thermal machine refrigeration methods, including ejection refrigeration, indicating that solar energy may operate the air conditioning system during the summer (Derghout & Rouabah, 2022). The values of the coefficient of performance of this system in Constantine is acceptable and is higher than other performance of solar absorption refrigeration machine in other Mediterranean cities (Florides et al., 2002), in addition, summertime solar radiation provides us with a significant potential to generate massive cooling capacity.

4. Conclusions.

The Mediterranean climate of Constantine, northeastern Algeria, is characterized by hot temperatures, particularly during summer months when peaks can reach 45°C. This climate necessitates efficient, energy-saving cooling solutions. Our study demonstrates that absorption refrigeration systems, with a coefficient of performance (COP) between 0.75 and 0.9, offer a feasible alternative to conventional cooling methods. By integrating solar energy into these systems, we achieved an overall COP of 0.58 to 0.62, creating a sustainable and economical cooling solution.

These solar-powered absorption air conditioning systems are particularly well-suited to northeastern Algeria's climate and energy landscape. Their implementation could significantly reduce reliance on mechanical compression systems, which currently dominate the Algerian market. This shift would not only decrease electricity consumption but also substantially reduce greenhouse gas emissions, especially CO_2, given Algeria's current dependence on fossil fuel-based thermal power stations.

Our findings suggest that widespread adoption of solar-powered absorption cooling systems could play a crucial role in Algeria's transition towards more sustainable energy practices and saving energy, aligning with global efforts to mitigate climate change while meeting increasing cooling demands in hot climates and will shape the design and construction of cities.

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