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A review on solar air conditioning systems

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ABSTRACT

In order to meet the growing need for cooling in buildings, solar air conditioning systems are a creative and environmentally friendly alternative. Solar energy is the primary energy source for producing chilled air, which can be used to maintain comforting inside temperatures. The working theories and components of several solar air conditioning systems, including hybrid, adsorption, and absorption systems, are thoroughly reviewed in this research. It also discusses the performance, efficiency, and economic feasibility of these systems and their environmental impact. The review highlights the potential benefits of solar air conditioning, such as plummeting greenhouse gas emissions, reducing energy usage, and enhancing indoor air quality. However, the paper also recognizes the limitations and challenges that need to be addressed to increase the widespread adoption of solar air conditioning systems. During our analysis, we found that solar air conditioning systems require consideration in terms of design and technological aspects. Ensuring these systems perform optimally in different climates and are economically viable is crucial. While there are challenges involved such as addressing the variations in resources and the initial setup costs. However, we are witnessing progress through advancements in materials, components, and control strategies. This continuous improvement inspires and reinforces the belief that solar air conditioning can become an accessible cooling solution for applications. This review provides a valuable resource for researchers, engineers, and policymakers interested in promoting sustainable and energy-efficient cooling technologies.

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1. Introduction

With the growing concerns over energy consumption, environmental impact, and the need for sustainable solutions, the quest for efficient and eco-friendly air conditioning technologies has become a top priority. Traditional air conditioning systems heavily rely on electricity generated from fossil fuels, contributing to greenhouse gas emissions and exacerbating the global energy calamity. Incorporating solar energy into air conditioning systems has emerged as a promising solution, offering a sustainable and renewable alternative [1]. Concerning the problems caused by conventional air conditioning systems, scientists have been looking to design sustainable and modern air conditioning systems using renewable energy resources, especially solar energy, which is abundant, endless, and clean [2]. Solar cooling can potentially significantly reduce climate change and environmental deterioration [3–5]. Solar air conditioning technology can considerably decrease CO_2 emission into the air, protecting the ozone layer, and is an environmentally friendly principle for indoor air temperature control [6]. It has been demonstrated that solar cooling is technically feasible. Since peak cooling loads and the existing solar power almost coincide, it is a particularly desirable application for solar energy [7].

Analyses reveal that desiccant, adsorption, and absorption systems all provided energy savings of up to 80, 50, and 52 percent, respectively [1]. This paper aims to provide a comprehensive review of the advancements in solar air conditioning systems, covering various technological approaches, system designs, and performance characteristics. The study covers multiple technologies, including absorption chillers, desiccant cooling, and photovoltaic-driven systems, with a focus on energy efficiency and environmental impact.

By harnessing the abundant solar energy, these systems can significantly reduce electricity consumption and mitigate environmental impacts, ultimately leading to a more sustainable future. The evaluation of solar air conditioning systems will be examined in this review, focusing on important assessment factors such as cooling capacity, energy efficiency ratio (EER), coefficient of performance (COP), and overall system performance across various weather conditions. Comparative analysis with conventional air conditioning systems will also be included to highlight the advantages and limitations of solar technologies.

In conclusion, this comprehensive review will provide a detailed overview of solar air conditioning systems, offering insights into their technological advancements, performance characteristics, challenges, and potential for widespread adoption. By shedding light on the progress made in this field, this review aims to inspire further research and development efforts toward a sustainable and energy-efficient future in air conditioning.

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2. History of solar air conditioning systems

This section presents a thorough summary of the historical progression of solar air conditioning, highlighting significant advancements, pioneering investigations, and technological breakthroughs that have shaped the development of this sustainable cooling technology. The report traces the major milestones and pivotal moments in the evolution of solar air conditioning systems, starting from early experiments to their present-day commercialization. In 1856, scientist Eunice Foote conducted groundbreaking research on solar energy, observing the "greenhouse effect" phenomenon and identifying certain gases that can trap heat from the sun. Foote's experiments contributed to the comprehension of solar thermal principles, which later found application in solar air conditioning systems [8,9].

During the 1880s, inventors Augustin Mouchot and John Ericsson made significant advancements in the development of solar thermal collectors [10]. Their innovative designs involved using mirrors to concentrate sunlight onto a receiver, generating steam for various mechanical applications. These early solar collectors provided important insights into utilizing solar energy for heating and cooling purposes. In the 1940s and 1950s, notable progress was made in absorption refrigeration, a cooling technology driven by heat.

In 1947, Swiss scientists Fridolin Stahly and Jürg Waser developed the first solar-powered absorption cooling system, which combined a solar collector with an absorption chiller to provide cooling capabilities. This pioneering work laid the foundation for integrating solar energy into air conditioning systems. From the 1960s to the 1970s, various research institutions and organizations conducted experiments and demonstrations to showcase the potential of solar air conditioning. An example of such progress took place in 1965 when the University of Florida successfully installed a solar air conditioning system on a building, demonstrating its practicality and viability [11]. In 1979, the Solar Energy Research Institute achieved a significant milestone by developing a solar-powered absorption chiller for the White House, providing further validation of the practicality of solar air conditioning [12].

Additionally, the advancements in solar thermal and photovoltaic technologies during the 1980s and 1990s played a crucial role in improving the efficiency and performance of solar air conditioning systems. Researchers directed their efforts towards enhancing solar collectors, improving thermal storage systems, and ensuring the overall reliability of the systems [13]. The years from the 2000s to the present have marked a pivotal moment in the commercialization and widespread availability of solar air conditioning systems. Manufacturers and companies worldwide have introduced solar air conditioning products tailored for both residential and commercial applications [14–17]. Integration with grid-connected systems and building management systems has become more common, allowing for optimized energy usage and improved control. Recently, there have been advancements in solar air conditioning systems with a key focus on enhancing their efficiency and reliability. These advancements involve the utilization of collectors that are equipped with improved materials and designs. These collectors effectively capture sunlight and convert it into thermal energy [18]. Also, energy storage solutions like high capacity batteries are being integrated to ensure uninterrupted cooling even during periods of low solar radiation. Hybrid systems that combine power with renewable sources are also being employed to enhance both reliability and efficiency [19,20].

To optimize energy consumption and adapt cooling settings based on real-time weather conditions and demand patterns, smart control and optimization technologies are being employed [21]. Additionally, thermochemical processes such as solid-state cooling and advanced sorption materials enable the development of efficient cooling systems [22]. Continuous research and development endeavors aim to further enhance solar air conditioning technologies' efficiency, affordability, and scalability.

3. Methodology

The methodology for this research involved a systematic and comprehensive approach to reviewing solar air conditioning systems. A thorough literature search was conducted using Web of Science, Google Scholar, Science Direct, Academia, Scopus, IEEE Explore, Research Gate, etc. The search employed keywords such as "solar air conditioning," "solar cooling," "absorption cooling," "adsorption cooling," and "hybrid systems." The selected articles were screened based on relevance to the topic and inclusion criteria, including peer-reviewed publications, conference papers, and authoritative reports published within the last decade. The selected articles were then analyzed to extract key information, such as working principles, system configurations, components, performance metrics, energy efficiency, environmental impact, economic considerations, and notable advancements or challenges in the field.

The collected data were synthesized to provide a comprehensive overview of solar air conditioning systems, including categorization and comparison of different technologies based on their working principles, performance metrics, advantages, and limitations. The literature was further reviewed to evaluate the economic feasibility and environmental impact of solar air conditioning systems, considering factors such as initial investment costs, payback period, operating and maintenance costs, energy savings potential, greenhouse gas emissions, energy consumption, and resource utilization. Limitations of the reviewed literature and research gaps were identified and discussed, and future research directions and potential improvements in solar air conditioning systems were proposed based on the identified gaps and emerging trends. The findings from the review were compiled following the appropriate structure for a review paper, presenting the methodology, results, analysis, and discussion in a coherent manner supported by relevant citations and references. This methodology provided a systematic and comprehensive approach to reviewing solar air conditioning systems, ensuring that a wide range of literature was considered and analyzed to gain insights into the working principles, components, performance, economic feasibility, environmental impact, limitations, and future research directions in the field.

4. Literature review

An air conditioning system is a series of devices and parts used to deliver heating, cooling, humidification, dehumidification, air circulation, air cleaning, air purifying, transportation of the conditioned air, recirculation of the indoor air, and control and maintenance of indoor air quality by using an optimum amount of energy [23]. Solar air conditioning systems utilize two techniques: solar thermal collector air conditioning systems and Photovoltaic Module Air Conditioning Systems.

These systems have gained significant attention as promising solutions for sustainable cooling. Numerous solar air conditioning methods, such as desiccant-based, adsorption, and absorption systems, have been thoroughly researched. Researchers have concentrated on assessing the coefficient of performance (COP), these systems' cooling capacity, and energy efficiency. To evaluate the efficiency of a solar cooling system, a theoretical and experimental study was carried out in the United Arab Emirates [24]. The study offered conceptual models and recommended areas for development.

The outcomes presented that the COP varied between 0.60 and 0.80, with an average COP of 0.70. The performance of the system, particularly the absorption chiller, is affected by incoming cooling and hot water temperatures, as was also noted in the study. COP and the energy-saving potential of a Solar Desiccant Evaporative Cooling system were the subject of another study carried out in southern Europe [25]; the experimental results showed effective temperature and humidity regulation of the supplied air, with 75% of the energy consumption derived from renewable sources. The study also identified a correlation between higher outdoor temperatures and increased instantaneous COP values.

These findings suggest that implementing Solar Desiccant Evaporative Cooling systems, particularly in hot climates like southern Europe, could contribute significantly to achieving the energy objectives of Nearly Zero Energy Buildings in the European Union.

In addition to performance evaluation, control strategies, and optimization techniques have been explored to improve solar air conditioning systems' operation and energy management. Case studies have demonstrated successful solar air conditioning implementations in residential and commercial settings, energy savings, economic viability, and environmental benefits [26]. A notable case study involves a solar thermal-assisted cooling system with a 100-ton refrigeration capacity installed in a rural hospital in Vadodara, India, in 2008. The system has been functioning well and has replaced the previous biomass-fired boiler for space cooling, resulting in significant wood mass savings [27]. Another study by Omgba presents a new solar-assisted air conditioning system integrating a parabolic trough concentrator and eco-friendly refrigerants. It achieves significant energy savings of 25.3% to 43.8% under solar irradiation of up to 1000 W/m^2, compared to conventional compression refrigeration, and R123 is identified as the best-performing fluid for the system [28].

However, challenges such as cost, system integration, and seasonal variations still exist, highlighting the need for further research and innovation to address these limitations and fully unleash the potential of solar air conditioning technology. Overall, the literature underscores the energy-efficient and environmentally friendly nature of solar air conditioning while emphasizing the importance of continuous research and development in this field.

5. Solar thermal air conditioning system

A solar thermal system transforms solar energy into heat energy through various fluid circulation methods. The solar collector, a key system component, absorbs solar energy and transfers it to the circulating fluid that carries the heat to heat exchangers or thermal storage units [29]. Typically, the solar thermal system operates using several thermal processes in the area of solar air conditioning, such as the absorption cycle, adsorption cycle, desiccant cycle, and ejector cycle.

5.1. Absorption cycle

The absorption cycle is one of the favorable cooling systems for to use of solar heat energy in domestic and industrial applications. Absorption systems are comparable in some ways to vapor compression systems but differ in the pressurization parts of the system. During the vapor compression cycle, the compressor obtains the pressurization phase of the refrigerant. But at the absorption cycle, the pressurization phase is attained by liquefying the refrigerant into an absorbent material using heat energy; the absorption cycle uses a chemical absorption process and a generator with a pump for circulation and pressure changes. There are two basic absorption cycles, the first one is water-lithium bromide (H_2O/LiBr) which produces positive cold, and the second is ammonia-water (NH_3/H_2O), which produces negative cold and is used in industrial cooling systems.

Due to the low-temperature operation method, the H_2O/LiBr cycle is more attractive and widely in use than the NH_3/H_2O cycle [30]. The COP for the H_2O/LiBr cycle is higher than the NH_3/H_2O; the generator inlet temperature for H_2O/LiBr cycle is about 70-88°C and for the NH_3/H_2O is 90-180°C [31]. In H_2O/LiBr cycle water acts as the refrigerant and in NH_3/H_2O cycle ammonia is the refrigerant

[29]. Figure 1 shows the main components of the absorption cycle. Heat is provided to the generator from the out-heat sources, sources such as a solar thermal collector, gas, fuel, etc.

The heat source causes the H_2O/LiBr to boil and the pressure of the solution increases. The vapor refrigerant flows to the condenser and condensation of the vapor occurs at high pressure and temperature at this point, the temperature difference between the vapor refrigerant and the environment causes heat to be rejected to the surroundings. The high-pressure liquid then passes through an expansion valve, causing its pressure and temperature to drop. As it passes through the evaporator, the liquid absorbs heat from the conditioned space, cooling the air which is then supplied to the room by a fan behind the evaporator.

The vapor is subsequently guided to the absorber, where it transforms into a liquid solution of lithium bromide. The solution is then pumped into the generator, where the absorbent is separated from the water by applying heat. The water vapor is directed to the condenser while the absorbent returns to the absorber chamber. This cyclic process continues uninterrupted, supplying cooling to the intended area [32]. There are also some other types of solutions used in absorption cooling systems, but due to the low level of performance, they are not widely in use.

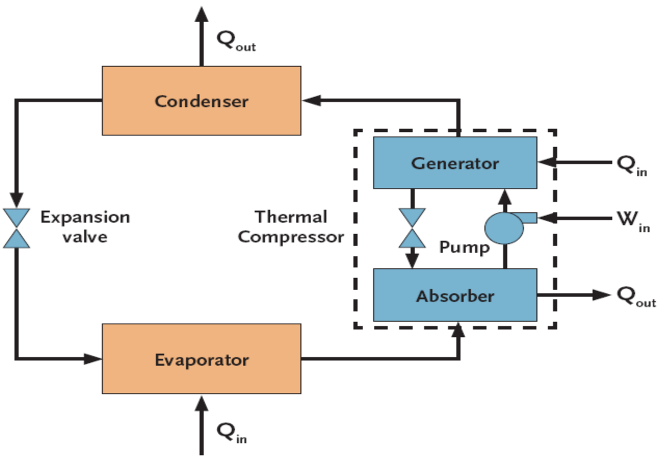

Figure 1. Absorption cooling cycle main components [33].

Typically, the coefficient of performance (COP) for the single-stage absorption cycle is between 0.6 and 0.8, and in double-effect machines that operate at high temperatures (above 140°C), the COP is increased up to 1.2 [34], and for triple – effect machine the COP reaches about 1.7 [29]. Solar collector type and performance are the primary keys to choosing an absorption cooling machine [35].

A feasibility study results for solar absorption air conditioning in Tunisia for a 150m² room is applied; the system consists of an 11-kW absorption chiller with water-lithium bromide as working fluid and 0.8 m³ hot water storage tank capacity. When the cooling load reaches 16.5 kW, the COP reaches 0.725 [36]. In Algeria absorption, the solar cooling system is analyzed using TRNSYS software [37]. Solar energy is harnessed to cover the cooling demand of 120 m² houses. A flat plate collector with 28 m² of the area at an inclination angle of 35° and an 800-liter hot water storage tank is used. The annual solar fraction was calculated at 80%, thermal performance coefficient COP of 0.73 was achieved.

5.2. Adsorption cycle

Similar to the absorption cycle, the adsorption cycle is a thermally driven process. The only difference is that in the absorption cycle, refrigerant is dissolved into a liquid, but in the adsorption chiller system, the refrigerant is adsorbed onto a porous solid material. Currently, due to the high cost, large size and volume, and lower specific cooling power [38], the adsorption cycled solar air conditioners are less in use than the absorption type. But they are comparable in terms of the maximum coefficient of performance with the absorption chillers.

There are two types of adsorption systems; physical and chemical. Zeolite, silica gel, activated carbon, and alumina are used as the physical adsorbents in the physical adsorption cycle. And in the chemical adsorption process. The most frequently utilized chemical adsorbent in solar cooling systems is calcium chloride (CaCl2). Calcium chloride absorbs ammonia to form CaCl2·8NH3 and can also absorb water to form CaCl2·6H2O. However, due to poor heat transfer properties and limited adsorbent capacity, adsorption chillers tend to be larger in size than absorption chillers. The average coefficient of performance for this type of system is around 0.5 to 0.7 [38].

5.3. Desiccant air conditioning system

Desiccant cooling systems offer an economical alternative to traditional air conditioning systems as they operate based on heat. These systems utilize a desiccant wheel that dehumidifies the air and transports it to a heat exchanger, where the air's temperature decreases. Subsequently, the air is directed to an evaporative cooler for further cooling, and the resulting cooled air is then supplied to the space for cooling purposes [39]. Desiccant cooling systems follow an open-cycle design, where water is employed as a refrigerant in direct contact with the air. The fundamental principle of a thermally-driven desiccant cooling cycle involves a combination of evaporative cooling and air dehumidification facilitated by a desiccant material. The thermally-driven desiccant cooling system can utilize either liquid or solid materials.

A liquid desiccant cooling system is more appealing and has more benefits than a solid one. A system using a water-lithium chloride solution as the sorption material has better air dehumidification capabilities compared to a solid system within the same temperature range, and the concentrated solution also has a high potential for energy storage [40]. A solid desiccant system can also function as a heating source for buildings with minimal heating requirements. This type of system incorporates flat-plate solar thermal collectors.

Figure 2 illustrates the key components of this system. The incoming warm and moist air first passes through a slowly rotating desiccant wheel, where it undergoes dehumidification through water adsorption (1-2). The absorption of heat then heats the air before passing through a heat recovery wheel (2–3), which causes the air supply to pre-cool significantly. Based on the appropriate temperature and humidity settings for the supplied air, the air is then further chilled and humidified by a controlled humidifier (3–4). To enhance cooling potential and enable efficient heat recovery, the exhaust air leaving the rooms gets humidified close to saturation point (6-7). Finally, to ensure that the dehumidification process runs continuously, the sorption wheel required to be heated to a temperature between 50°C and 75°C [41].

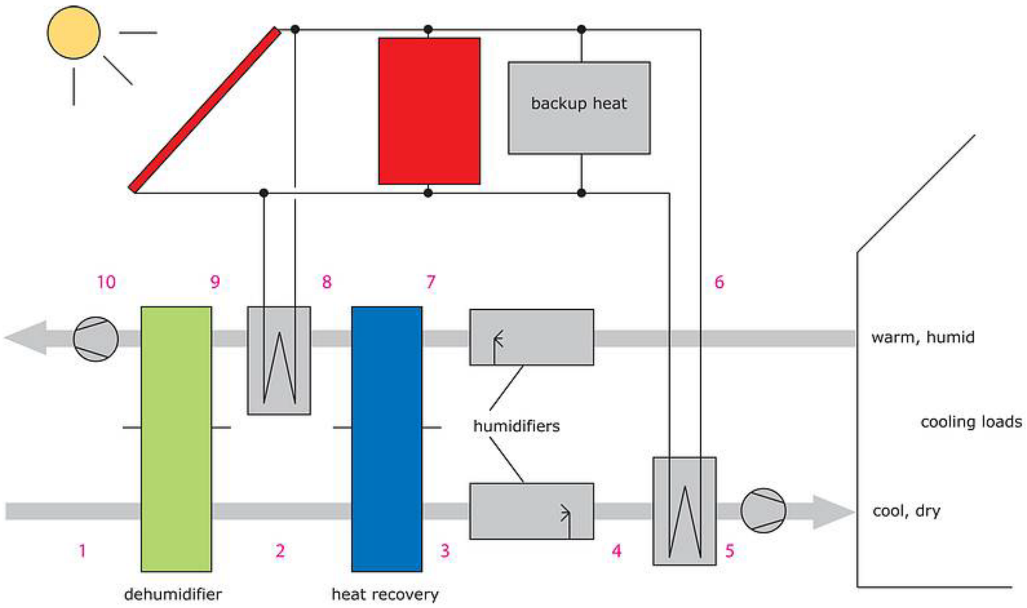

Figure 2. Desiccant cooling system schematic diagram [40].

5.4. Ejector cycle air conditioning system

In a heat pump refrigeration system, the ejector serves as a thermal compressor, replacing the need for an electrical one. It utilizes heat energy to compress the refrigerant. Because of its simplicity and initial low cost than other thermal-driven systems, it is one of the most promising technologies [41]. The advanced ejector chillers and air conditions operating at 100 – 200 kilowatts are suitable alternatives to the water–lithium bromide absorption system [41]. The ejector cycle is made up of key parts, including the condenser, evaporator, liquid receiver, vapor generator, refrigerant, pump, and expansion valve [42]. Figure. 3 shows a solar-powered ejector system [43].

The ejector system works through the use of high-pressure vapor from a solar vapor generator (SVG). The primary vapor is sent through an ejector nozzle, causing a reduction in pressure and an increase in speed due to a change in the nozzle's cross-section. This creates low pressure in the suction chamber, which pulls in secondary vapor from an evaporator. The two vapor streams are mixed in a constant-cross-section mixing chamber. The mixed streams are then slowed down and their pressure increases in a diffuser before being released as a compressed refrigerant vapor stream that goes to the condenser. There, the vapor is condensed into liquid and partially returned to the SVG through a pump, with the rest flowing to an evaporator where an expansion valve reduces its pressure for cooling.

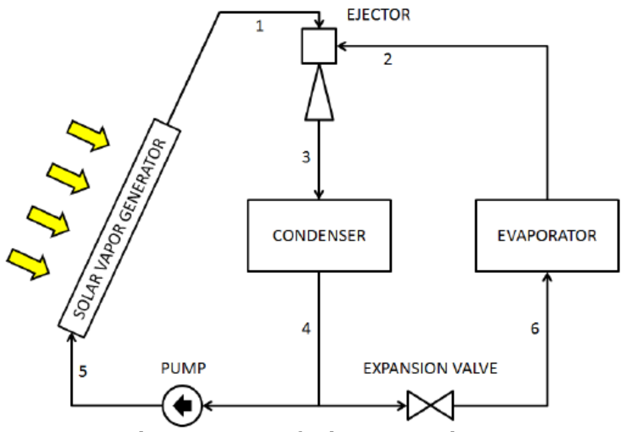

Figure 3. Schematic view of solar-powered ejector system [43].

6. Solar-powered air conditioning systems

Using a charge controller, this method converts sunlight into electricity so that the air conditioner can run straight from a solar panel. This arrangement can power both conventional air conditioners and solar-powered air conditioners. Direct current (DC) power is used to operate the solar-powered air conditioner, which is directly connected to the solar panel. Backup batteries are not required if air conditioning is only required during the day [35]. Alternating current (AC) and mechanical vapor compression cycles are used in typical air conditioners to cool buildings. A solar inverter is needed to convert the direct current (DC) from the solar energy source to alternating current to run a conventional air conditioner (AC). In this instance, the conversion process causes the supplied power's efficiency to decline [44]. Solar-powered compression air conditioning system schematic diagram is shown in Figure 4.

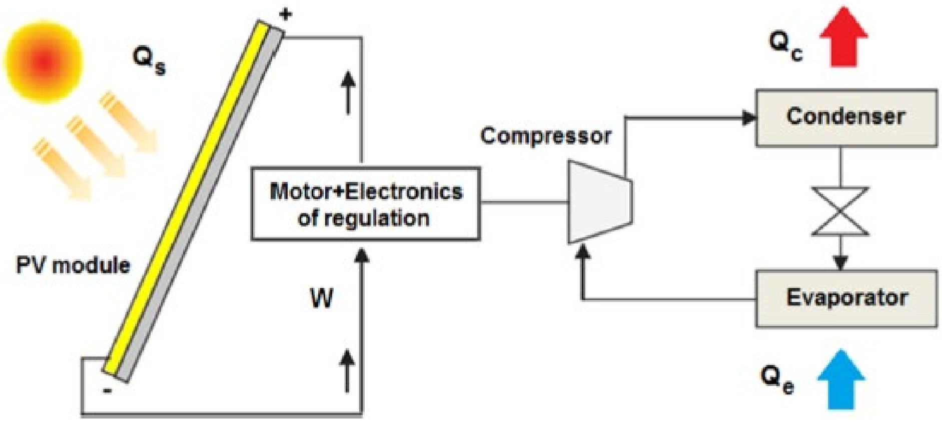

Figure 4. Solar Powered Compression Air Conditioning System Schematic Diagram [44].

7. Comparison of vapor compression and sorption refrigeration systems

Sorption and vapor compression refrigeration systems function similarly by extracting heat at low pressure through refrigerant evaporation and releasing heat at high pressure through refrigerant condensation [36]. The main distinction between vapor compression and sorption refrigeration systems is the circulation process, which establishes the necessary pressure difference for refrigerant movement. In the sorption cycle, a heat source is employed without the need for mechanical work input, whereas the vapor compression cycle relies on a mechanical compressor to generate the required pressure differential for refrigerant circulation. These differences make the sorption method highly appealing and frequently adopted in areas where energy sources, such as solar energy or other heat energy sources, can be efficiently converted into heat [45].

8. Potential benefits

Solar air conditioning systems offer several potential benefits that contribute to sustainable and efficient cooling solutions. The following benefits are associated with the use of solar air conditioning systems:

- Include the accessible and most relevant study to the topic (published).
- Reduced energy consumption: Solar air conditioning systems utilize renewable energy from the sun to power cooling processes. These systems significantly reduce reliance on traditional electricity sources by harnessing solar energy, resulting in lower energy consumption and reduced utility costs [46–48]. This contributes to energy conservation and promotes a more sustainable approach to cooling. A research project assessed the feasibility of solar-powered absorption cooling technology in Tunisia using TRNSYS and EES simulations with meteorological data from Tunis. The optimized system for a typical 150 m^2 building includes an 11-kW water lithium bromide absorption chiller, a 30 m^2 solar collector, and an 800-liter hot water storage tank. This offers benefits like reduced fossil fuel usage and electricity demand, especially during peak periods [36].
- Lower greenhouse gas emissions: Solar air conditioning systems operate without the use of fossil fuels, which are major contributors to greenhouse gas emissions. By relying on clean and renewable solar energy, these systems help mitigate climate change by reducing carbon dioxide and other harmful emissions [49]. This environmental advantage makes solar air conditioning an eco-friendly choice for cooling needs. A study by Ali Akyüz demonstrates that heating the compressor entry in AC systems using solar energy reduces energy consumption by 8% to 28%. This leads to a significant decrease in indirect emissions, which are primarily caused by energy consumption in air conditioning. The author also mentioned that, solar-powered AC systems contribute to a sustainable environment by lowering emissions and conserving natural resources. The use of renewable energy sources, like solar energy, in AC systems presents a promising solution to combat the increasing energy load and emission values associated with global warming [50].
- Improved indoor air quality: Solar air conditioning systems often incorporate advanced filtration and ventilation technologies to enhance indoor air quality. These systems promote a healthier and more comfortable indoor environment by effectively removing pollutants, allergens, and contaminants from the air

[51,52]. This is particularly beneficial for individuals with respiratory conditions or allergies, as it helps to reduce the presence of airborne particles and improve overall air quality.

- Enhanced energy independence: Solar air conditioning systems offer the advantage of energy independence by reducing dependence on the electrical grid. This becomes especially valuable in areas with unreliable or limited access to electricity. By utilizing solar power, individuals and businesses can become self-sufficient in their cooling needs, reducing their vulnerability to power outages and fluctuations in electricity supply [26,53–55].
- Long-term cost savings: While the initial investment costs of solar air conditioning systems may be higher compared to conventional cooling systems, they offer long-term cost savings. By utilizing free solar energy, users can significantly reduce their electricity bills over the system's lifespan [26,56,57]. Additionally, with technological advancements and increasing market adoption, the cost of solar air conditioning systems is expected to decrease, making them more financially viable in the long run.

9. Impediments

Solar air conditioning systems face several impediments to widespread adoption. The high initial cost of installation, limited efficiency compared to traditional units, and the need for energy storage solutions like batteries pose significant challenges. Additionally, the space requirements for solar panels, climate variability affecting energy generation, system complexity for integration with existing HVAC infrastructure, and public awareness and perception issues hinder their acceptance. Despite these obstacles, ongoing research and development aim to improve energy storage, efficiency, and system design, which could help overcome these impediments and make solar air conditioning more accessible and viable in the future. Some of the potential obstacles are listed below.

- Solar air conditioning systems' initial and installation expenses are considerably higher than traditional systems that rely on electric power, such as those utilizing vapor compression cycles [47,58–60].
- One of the technical factors to consider is that conventional air conditioning systems have a significantly superior coefficient of performance (COP) compared to solar air conditioning systems [60].
- Solar air conditioning systems, both the chiller and solar system components, are complex and require the expertise of professionals for routine maintenance and unexpected operations [61].
- The competitiveness of solar air conditioning systems with traditional systems is hindered by the limited number of manufacturers and traders available [61].
- The intermittent availability of solar energy on a daily and yearly basis necessitates the use of additional storage devices and supplementary energy systems [62].

10. Discussion

This comprehensive review of solar air conditioning systems yielded several key findings. The analysis revealed a variety of working principles and system configurations, including absorption, adsorption, and hybrid systems, each with its own advantages and limitations. Performance metrics such as the coefficient of performance (COP) and cooling capacity varied depending on the technology and operating conditions. Economic feasibility assessment showed that while initial investment costs may be higher, solar air conditioning systems offer long-term cost savings through reduced energy consumption.

Environmental impact evaluation indicated their potential to reduce greenhouse gas emissions significantly. Previous research on air conditioning systems has provided insights but has some limitations and drawbacks. One common limitation is the absence of long-term performance data since many studies focus on short-term experiments or simulations. This makes it challenging to assess the reliability and durability of these systems over extended periods.

Additionally, variations in design parameters, types of collectors, and system configurations across studies lead to inconsistent findings and difficulties in directly comparing results. Another issue is that some research only focuses on components or aspects of the system while neglecting its performance and integration challenges. Moreover, real-world complexities like fluctuating weather patterns, dynamic energy demands, and the impact of maintenance over time are not always considered. Economic evaluations might also overlook costs such as system maintenance expenses and energy storage costs resulting in financial assessments. Furthermore, limited field studies conducted in locations and climates restrict the generalizability of findings. Therefore, it is crucial to conduct real-world evaluations to understand regional variations and performance implications better. It is crucial to overcome these limitations and bridge the existing gaps in research by making progress in air conditioning systems and encouraging their widespread use as an eco-friendly cooling solution. This will help to establish a foundation for their advancement. Overall, the review provides valuable insights into solar air conditioning systems' performance, economic feasibility, environmental impact, and future prospects. It underscores the need for ongoing research and collaborative efforts to unlock their full potential as a sustainable cooling solution.

11. Conclusion

Solar air conditioning systems represent a sustainable and energy-efficient solution for cooling applications. These systems offer numerous advantages by utilizing solar energy, including reduced energy consumption, environmental benefits, and potential cost savings. Solar-powered air conditioning systems contribute to conserving energy and promoting friendly cooling methods. They offer an opportunity to achieve energy independence in areas with limited electricity access. However, some obstacles hinder the adoption of these systems. These include costs for installation, lower efficiency compared to traditional systems, the need for effective energy storage solutions, space requirements for solar panels, the impact of climate variations, system complexity for integration with existing HVAC infrastructure, and public awareness. While challenges exist, ongoing research and development efforts address these issues, driving innovation and paving the way for the widespread adoption of solar air conditioning systems.

As the world seeks cleaner and more sustainable cooling solutions, solar air conditioning stands at the forefront of the energy transition, offering a promising path toward a greener future. One of the most coveted uses of solar thermal energy has always been cold production through absorption cycles. Presently, absorption systems stand out as the most advanced solar cooling technology. Ultimately, the complete system's investment cost, the refrigerant's performance coefficient, and the accessibility of solar energy resources are the key factors used to determine the most economically efficient solar air conditioning system. Further research and development are essential to overcome these limitations and improve the effectiveness and affordability of air conditioning technology. Progress in energy storage, system design and market availability are anticipated to promote acceptance and increase the practicality of air conditioning systems in the future.

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