Optimization Efficiency of Solar-Powered Air Conditioning Systems: A "Comprehensive Review

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Abstract

This review investigates the use of solar energy for air conditioning, highlighting the advantages and limitations of using photovoltaic (PV) panels to power cooling systems. With the global increase in energy demands and the depletion of fossil fuels, renewable energy sources have become crucial. The review covers various solar-powered cooling technologies, including PV systems, solar thermal cooling, and adsorption/absorption chillers, demonstrating notable energy savings and reduced environmental impact. Optimizing system designs and utilizing intelligent control technologies can significantly enhance efficiency. The paper suggests that future research should aim at improving these systems' performance and sustainability.

Keywords: optimization efficiency, solar-power, air conditioning systems

1. Introduction

Renewable power, additionally referred to as opportunity, sustainable, or non-conventional electricity, is derived from obviously replenishing resources inclusive of wind, solar, hydroelectric, geothermal, bioenergy, and ocean strength. As global demand for electricity and electricity rises and fossil fuel reserves diminish, renewable electricity sources are gaining popularity (IRENA, 2020) Furthermore, many far off and rural regions remain with out electricity, making renewable strength a possible choice wherein extending transmission traces is economically unfeasible. Renewable energy is also recognized for its environmental benefits, being easy and eco-friendly. However, its adoption faces several demanding situations. One fundamental undertaking is its reliance on climatic conditions, which vary by means of area and might result in inconsistent electricity availability—which include the absence of solar power at night time or on cloudy days. Although hybrid systems and electricity storage answers have partially addressed this issue, it remains a challenge. Another project is the high cost of technology, with renewable sources typically being greater steeply-priced in comparison to standard methods, specifically inside the case of geothermal electricity. Lastly, improvements in era and marketing are essential to overcoming these barriers and improving the performance and affordability of renewable energy. (Tröster & Schmidt, 2012).

Photovoltaic panels are a generation for converting solar energy into electrical strength the usage of sun cells. Historically, photovoltaic panels have been used normally to generate energy for home and industrial use. However, in current years, people have all started to look at the usage of photovoltaic panels to electricity air conditioning systems. Using photovoltaic panels to power air conditioning systems is a sustainable and environmentally friendly option to meet the developing cooling wishes of groups. When the use of photovoltaic panels to power an air conditioner, solar power is converted into power to run the air conditioner, as opposed to relying on traditional strength sources inclusive of fossil fuels. When the usage of photovoltaic panels to electricity an air conditioner, the sun panels are established on a rooftop or an open area with plenty of daylight. The sun panels are linked to the air conditioner to offer the power needed to operate it. Solar tracking structures also can be used to ensure that the solar panels are always aligned with the sun to seize the most amount of solar energy. Air conditioners powered through photovoltaic panels provide numerous blessings. As a smooth and renewable energy supply, they produce no harmful emissions, making them environmentally pleasant. Moreover, with the aid of reducing reliance at the traditional electricity grid, those systems make a contribution to lower power payments and decreased power consumption.

2. WORLD ENERGY

The escalating worldwide electricity demand, driven by means of fast population boom and business growth, poses a massive mission. A surge of billion people within a unmarried generation underscores the urgency of addressing the strength crisis as a paramount issue of the 21st century (Jäger-Waldau, 2017). To sustain a developing population, strength deliver should unexpectedly boom. However, the current energy blend is inadequate due to a confluence of factors inclusive of populace boom, economic fluctuations, technological advancements, and the environmental effects of fossil gas intake (Schaber, Steinke & Hamacher, 2012). Developing countries, in particular, grapple with balancing economic development and environmental stewardship at the same time as increasing power get right of entry to to a burgeoning populace. Despite technological advancements in energy production, many people in growing countries nonetheless lack dependable strength. Furthermore, the finite nature of non-renewable resources exacerbates the energy deficit, as illustrated in Fig. 2.1. (Schaber, Steinke & Hamacher, 2012). Proper resource management is crucial to ensure that power may be regenerated and to create a sustainable surroundings for destiny generations. Unfortunately, many countries continue to rely upon depleting strength resources, which contributes to climate change and poses risks of severe herbal screw ups which can damage ecosystems. Therefore, it's far crucial to discover and invest in environmentally pleasant energy resources to enhance sustainability (IRENA, 2016).

Power technology the usage of fossil fuels is the primary contributor to greenhouse gas emissions, at the same time as sun cells are an option to lessen carbon emissions (Malvoni, Leggieri, et al. 2017). Solar energy resources are spread all around the world and are abundant, so the strength they generate cannot be captured via a single u . S .. Interestingly, not like traditional electricity sources, only sun cells and other renewable electricity assets offer the opportunity of decreasing charges inside the destiny rather than growing them (Jäger-Waldau 2017; Schaber, Steinke et al. 2012). Solar cell systems can be deployed almost everywhere on our planet because they're collectible. Furthermore, increasingly international locations inside the global (through their renewable energy independent energy purchase programmers) have established smooth strength production goals for several reasons, which includes diversification of the electricity blend, accomplishing low carbon emissions, and, specifically, to dispose of the current issues associated with strength vegetation. Conventional strength generation, including greenhouse gas emissions. Most of the smooth energy sources, like solar mobile strength plant life, wind power flora, and bioenergy, to mention a few, are freely to be had in nature and are considered environmentally pleasant all over the international. Due to the global force for easy electricity that has seen many countries get involved in renewable energy and due to the increase of the solar mobile market globally, mainly in the last few years, it has end up increasingly essential to analyses and evaluate the overall performance of solar cellular modules running, in particular beneath environmental situations. Solar power resources. Monitoring the overall performance of various technology, distinct sun mobile wavelengths, and special orientations of sun cellular systems is rare, resulting in few reports based totally on field consequences for hooked up and operated solar cellular systems. The decline in prices of solar mobile systems through approximately seventy five% in much less than 10 years has made sun cells a cost-competitive, reliable, and sustainable opportunity for power technology in many components of the sector (Schaber, Steinke et al. 2012; IRENA 2016). It is envisioned that strength era by way of sun mobile flowers that commenced working in early 2017 can be about 375 terawatt hours in 2022. For international energy intake wishes, that is equivalent to about 1.8% of the strength deliver (IRENA 2020. The sun mobile enterprise has had an annual cumulative price of boom of round forty% over the past sixteen years, making sun cells one of the most unexpectedly developing industries currently. This boom became supported by way of a giant discount in capital costs for solar power plant additives and projects (Malvoni, Leggieri, et al).

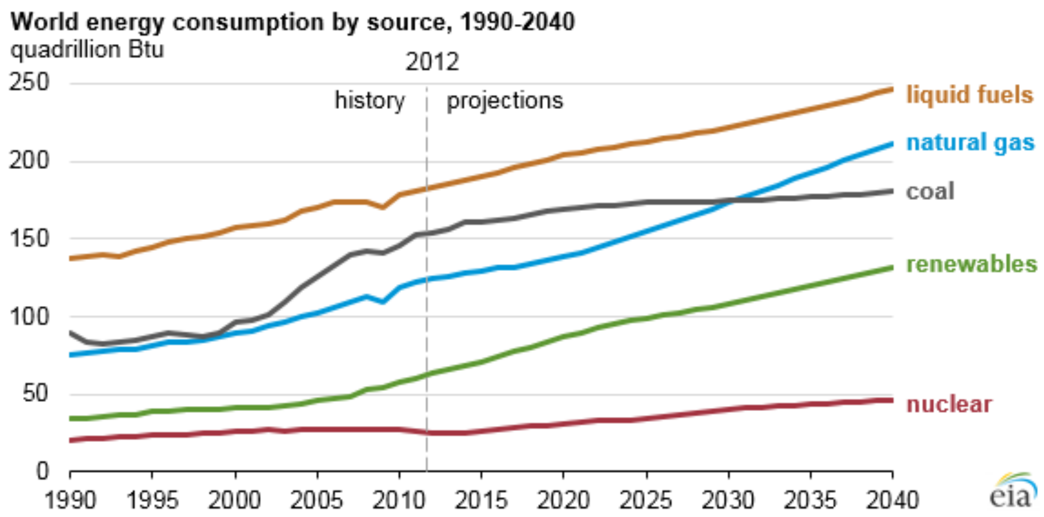

Fig. 1 The rate of energy consumption in the world from different sources. Khan et al. (2018).

Currently, the capital cost (CAPEX) of a solar energy system makes up less than 40% of the system cost, with the remaining percentage going towards operation and maintenance (O&M) costs, permits, administration, fees, and taxes, as well as financing costs. Optimization of solar power plants related to the design and daily operation of the system is associated with costs associated with operation and maintenance. Therefore, it is clear that greater attention should be paid to operation and maintenance during design and any subsequent phase of the solar power plant's life cycle. This affects the financial economics associated with the installation and operation of the solar power plant. In order to accommodate more solar energy and improve the electrical output of a PV system, installers typically Fig. the systems by adjusting the orientation and tilt of the system or by using mechanisms to track the sun across the sky. Generally, in the Southern Hemisphere, such as South Africa, the annual power production of a fixed system can be optimized by orienting the unit towards the north and tilting at an angle equal to the local latitude. Many studies have been conducted to explore the effect of orientation and tilt on the performance of solar energy systems in many parts of the world. To the best of our knowledge, no study has been reported in South Africa describing a comparison of the performance of solar energy systems consisting of different module technologies and installation designs operating side by side on the same site. At the system level, the integration of solar energy into the electric grid faces many challenges, one of which is matching demand and supply, especially when the level of solar penetration is high. A variation between the optimal tilt and azimuth angles of PV modules (e.g., east-west orientation instead of north orientation) can be useful in this regard. Tröster and Schmidt (2012) studied the impact of solar module routing on electrical grid operation by evaluating several installation configurations for the city of Aachen, Germany. They determined that east- and west-orientated structures have capability factors not a great deal decrease than south-orientated systems, in addition to significantly decrease top energy and output gradients, offering blessings for electrical grid and sun integration. According to these research, top-quality orientation is related to climate situations at website places.

3. PREVIOUS STUDIES OF SOLAR AIR CONDITIONING SYSTEMS

Chen et al. (2017) In their study titled 'Simulation and Optimization of Photovoltaic-Powered Air Conditioning Systems for Commercial Buildings' determined that powering air con systems with photovoltaic panels can lessen energy intake through up to 30% and substantially decorate power performance. The study emphasizes the importance of choosing high-performance photovoltaic panels and optimizing power control to maximize the machine's blessings.

Fig. 2 Simulation and Optimization of Photovoltaic-Powered Air Conditioning Systems for Commercial Buildings.MaxRoi Solar. (2024).

Li et al. (2018) Performed a study titled 'Performance Analysis of a Photovoltaic-Powered Air Conditioning System Using Dynamic Simulation,' which discovered that dynamic manage era and ongoing optimization of settings for PV panel-based totally air con structures can decorate strength efficiency by up to 25% and reduce reliance at the outside electrical grid. The look at also advises using clever manage technologies to higher balance energy intake with consumer comfort.

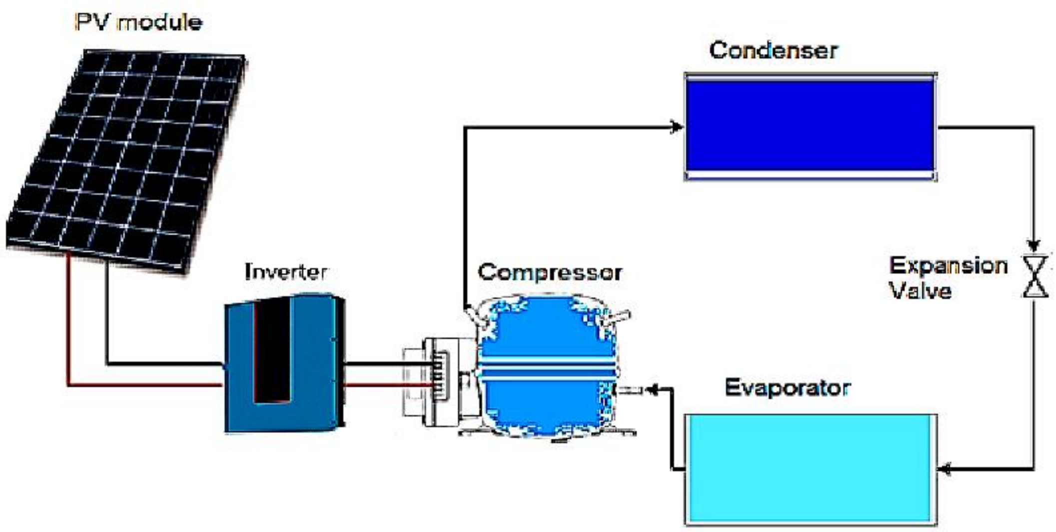

Fig. 3 Performance Analysis of a Photovoltaic-Powered Air Conditioning System Using Dynamic Simulation. Albatayneh et al. (2021).

Zhang et al. (2019) In their take a look at 'Simulation and Optimization of Photovoltaic-Powered Air Conditioning Systems for Off-Grid Applications' located that standalone photovoltaic systems can provide a sustainable and cost-powerful answer for powering air con systems in regions without get entry to to an electrical grid. To enhance gadget performance and sustainability, the study recommends improving system layout, choosing suitable photovoltaic panels, and utilizing advanced control strategies.

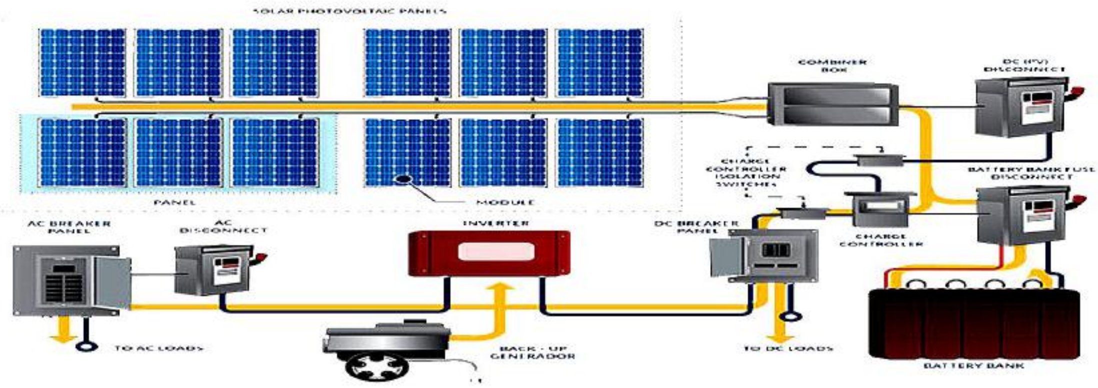

Fig. 4 Using standalone PV systems to power air conditioning systems Solar Chief (2023).

The research conducted by Zhao et al. (2019) In quot "Optimal Design and Performance Analysis of Photovoltaic-Powered Air Conditioning Systems" quot demonstrates that enhancing the scale, layout, and manage mechanisms of air con systems powered through photovoltaic panels can considerably boost energy efficiency and reduce expenses. The examine emphasizes the significance of optimizing machine design, deciding on excessive-efficiency additives, and employing clever control strategies to attain the first-rate performance and value financial savings.

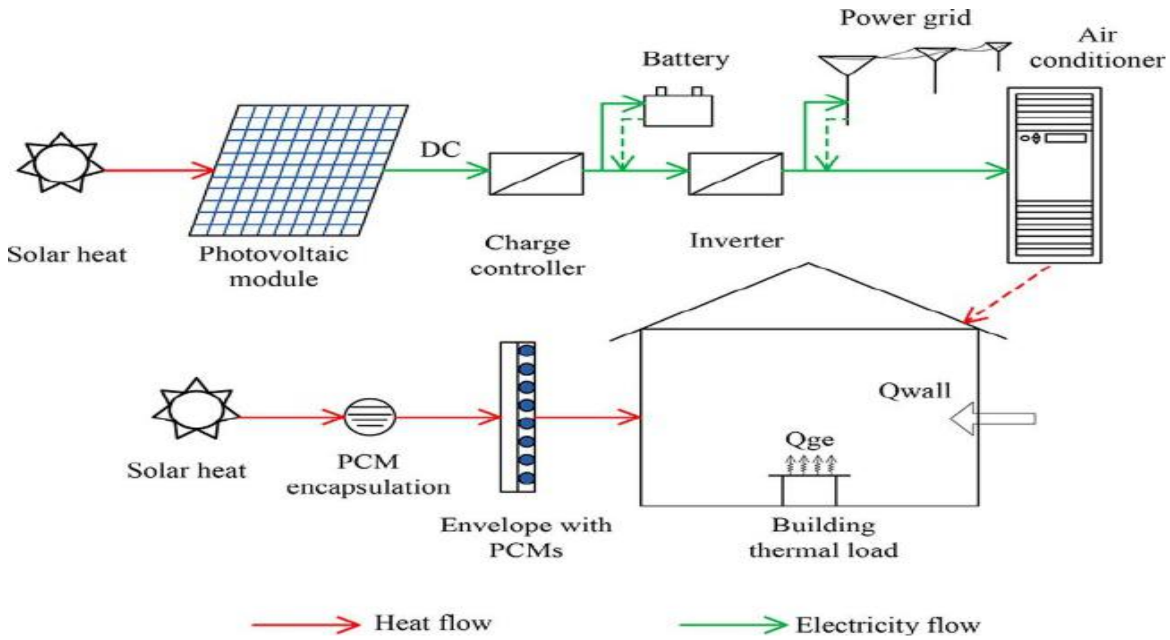

Fig. 5 Performance Analysis of Photovoltaic-Powered Air Conditioning Systems.Sun et al. (2021).

Song et al. In their 2017 study, quot "Performance Analysis of a Solar-Assisted Air Conditioning System with PV/T Collectors," tested the effectiveness of an air con system that integrates photovoltaic panels with solar heating structures, as shown in Fig. 2.6. The research discovered that the incorporation of PV/T panels can enhance strength performance and reduce the overall charges of the air con gadget.

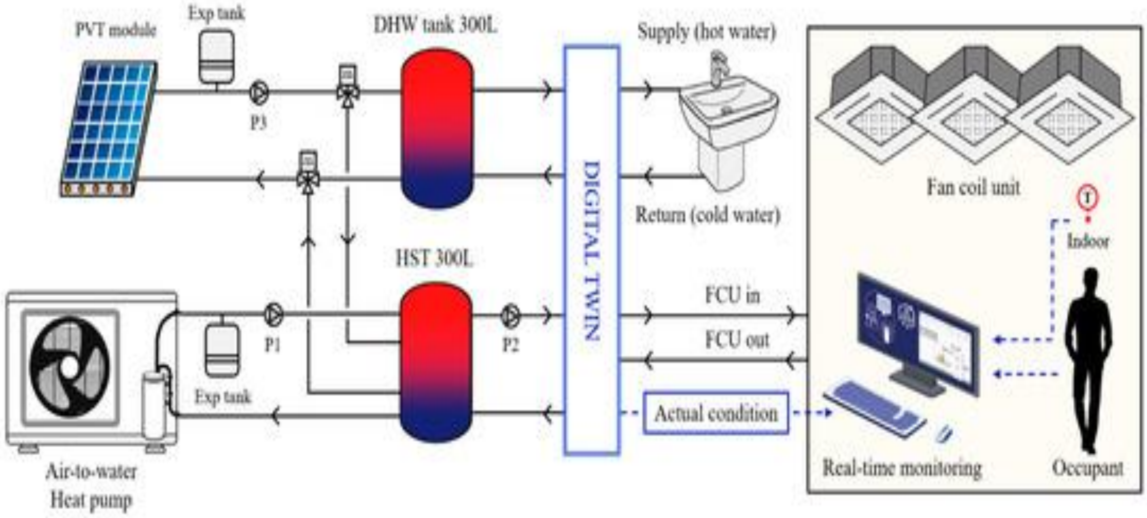

Fig. 6 Performance evaluation of an air conditioning system based on photovoltaic panels integrated with solar heating systems. Bae et al. (2022).

In 2018, Hong et al. Done a feasibility observe on a sun-powered aircon gadget that employs photovoltaic/thermal creditors. The findings indicated that this system is efficient in strength use and might extensively decrease dependence on conventional energy resources.

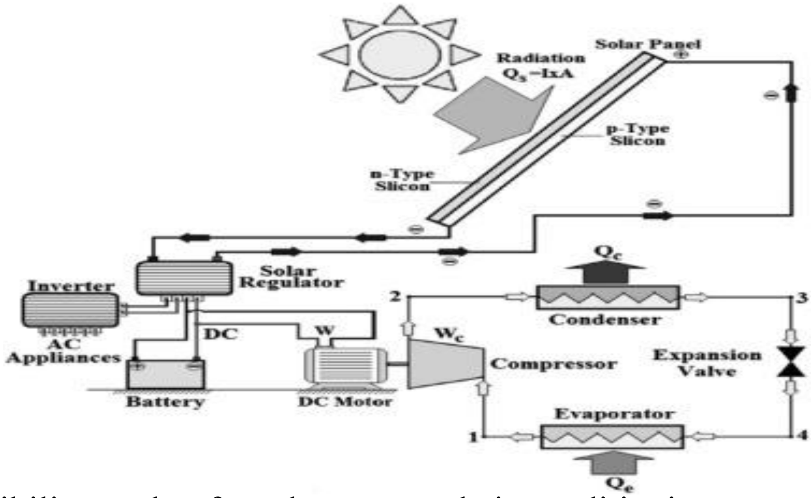

Fig. 7 Feasibility study of a solar-powered air conditioning system using photovoltaic/thermal collectors. Al-Yasiri et al. (2022).

Chen et al.(2019) Carried out an analysis named' Energy and Exergy Analysis of a Solar- supported Air Conditioning System with Flat Plate and Concentrating Photovoltaic/ Thermal Collectors.' The look at evaluates the overall performance of an air exertion machine using both flat plate and concentrating solar panels included with photovoltaic and sun heating systems. The findings suggest that employing concentrating solar panels can beautify energy effectiveness and usual machine performance

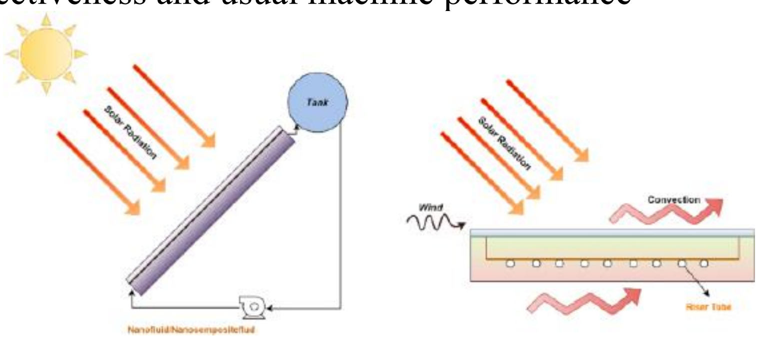

Fig.8 Energy and exergy analysis of a solar-assisted air conditioning system with flat plate and concentrating photovoltaic/thermal collectors. Khan & Amirtham (2023).

Li et al. (2020) Accomplished an experimental examine on a sun-assisted aircon gadget that employs hybrid photovoltaic/thermal (PV/T) creditors. Their research, grounded in realistic experiments, discovered that the device strikes an powerful stability between thermal and electrical overall performance, resulting in more advantageous strength performance.

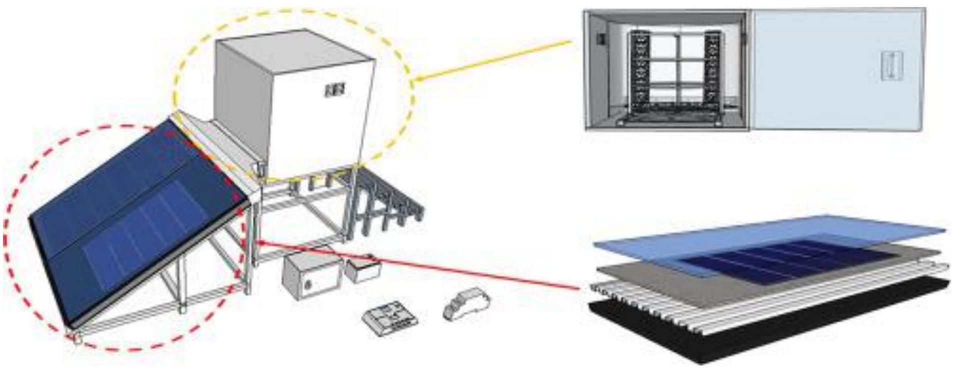

Fig. 9 Experimental investigation of a solar-assisted air-conditioning system based on hybrid photovoltaic/thermal collectors. Kong et al. (2020).

Elgendy et al. (2016) Investigated the design and performance of a solar-powered aircon device supposed for residential use. Their findings indicated that the machine efficiently keeps a stability between energy consumption and user comfort while additionally assisting to lower typical energy prices.

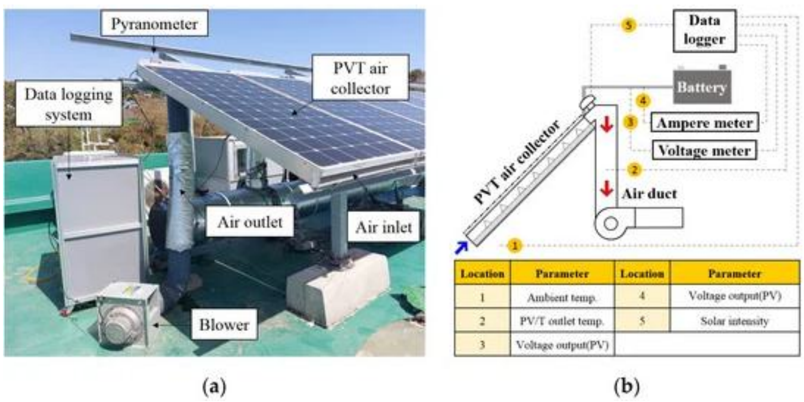

Fig. 10 Design and performance evaluation of a solar-powered air conditioning system for residential buildings. Choi & Choi (2022).

Wang et al. (2017) Assessed the effectiveness of an air con system powered via photovoltaic panels in office homes. Their studies discovered that the implementation of photovoltaic panels can lessen energy utilization and improve the power performance of air conditioning systems in workplace environments.

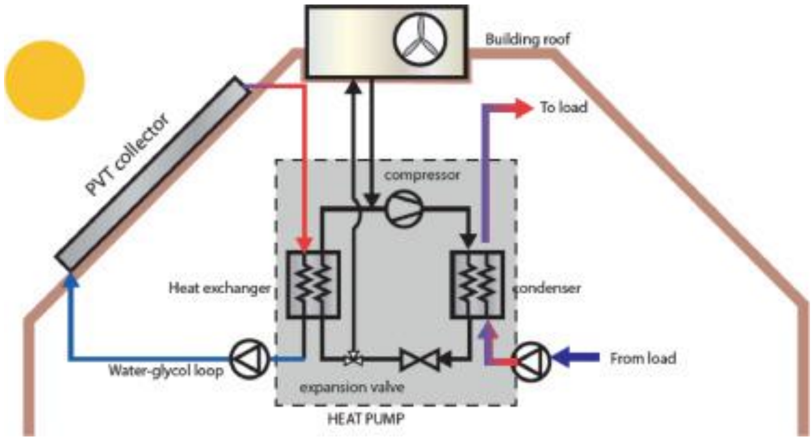

Fig. 11 Performance evaluation of solar-assisted air conditioning systems for office buildings. Miglioli et al. (2023).

The research paper "Economic Analysis of a Solar-Powered Air Conditioning System for Commercial Buildings" by Zhang et al. (2018) explores the monetary feasibility of using photovoltaic panels to strength aircon structures in business environments. The effects advise that making an investment on this kind of gadget is economically possible and might bring about sizeable long-time period savings on power charges.

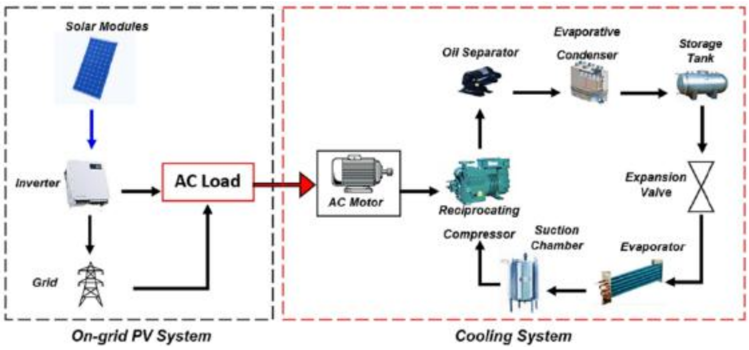

Fig. 12 Economic analysis of a solar-powered air conditioning system for commercial buildings. Setiawan et al. (2021).

The study titled "Techno-economic analysis of a hybrid solar air conditioning system for industrial applications" by Chen et al. (2019) Offers a complete technological and monetary assessment of an air conditioning gadget powered by way of photovoltaic panels for business use, The findings indicate that the hybrid machine correctly balances the demands for cooling even as concurrently reducing energy consumption and operational prices within the industrial quarter.

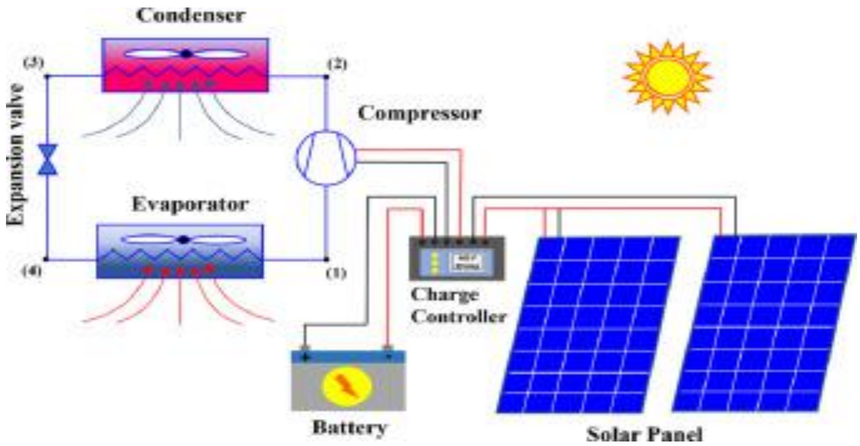

Fig. 13 This study deals with a technological and economic analysis of an air conditioning system based on photovoltaic panels in industrial applications.

Solar immersion air exertion A comprehensive review of systems and performance ” by Sharma et al.(2016) This observe objectives to review solar immersion cooling technologies and dissect the overall performance of these structures. The observe concluded that solar immersion cooling systems are able of furnishing effective and sustainable cooling the usage of sun power. Systems used on this surroundings include solar dryers, warmth exchangers, and immersion bias. The specialised and worthwhile challenges associated with this generation had been bandied, comparable as perfecting the effectiveness of immersion and heat storehouse and perfecting the distribution of cooled air.

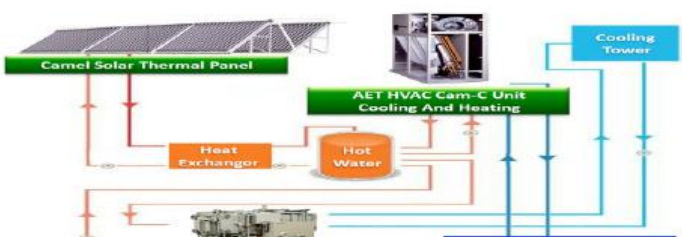

Fig. 14 Solar absorption air conditioning: A comprehensive review of systems and performance. Rahadiyanti (2017).

The article "Solar Desiccant Cooling Systems: A Review" by Wang et al. (2017) Offers an outline of sun dryer cooling structures and evaluates their overall performance. The studies indicates that sun dryers can enhance cooling performance and make a contribution to energy savings. It explores diverse standards and techniques related to sun dryer cooling, which include moisture extraction from the air and the usage of sun warmth for dryer regeneration. Additionally, the study addresses demanding situations in machine layout and operation, which includes optimizing manage mechanisms and deciding on effective absorbent materials.

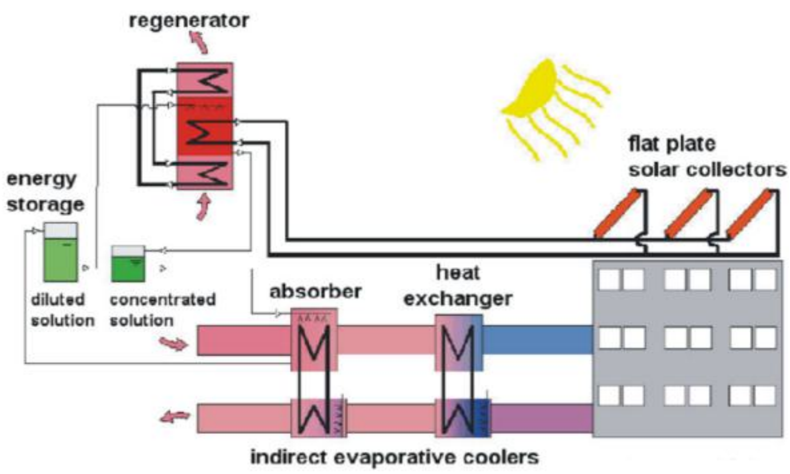

Fig. 15 Solar desiccant cooling systems. Batukray (2019).

Solar-Powered Desiccant Evaporative Cooling Systems: A Review" by Li et al. (2018) Provides an overview of sun dryer evaporative cooling structures and evaluates their performance. The findings imply that these structures can supply green and sustainable cooling thru sun strength. The paper explores the ideas and strategies of sun dryer evaporative cooling, which includes the usage of dryers and evaporative processes for cooling and the regeneration of sun dryers. It additionally addresses the thermal and humidity overall performance, power efficiency, and destiny challenges related to the design and operation of these structures.

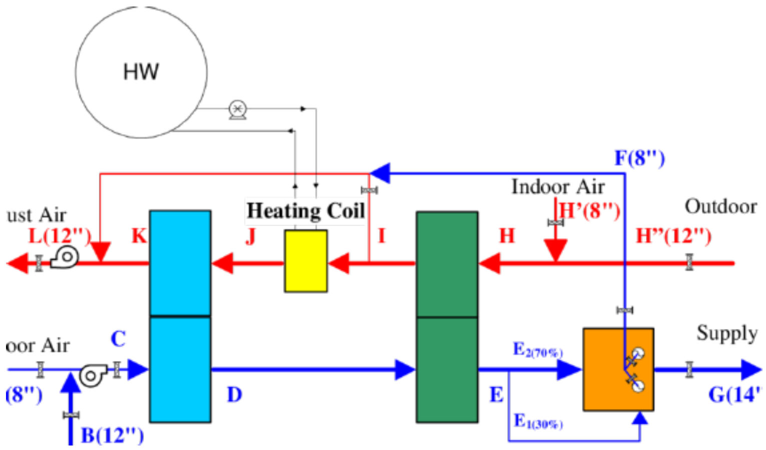

Fig.16 Solar-powered desiccant evaporative cooling systems. Ouazia et al. (2009).

The study titled "Solar-assisted Radiant Cooling Systems: A Review" by Hong et al. (2019) Makes a speciality of comparing radiant cooling structures powered by solar power and assessing their performance. The findings imply that sun radiant cooling can substantially enhance electricity efficiency and thermal consolation in homes, as illustrated in Fig. 2.17. The authors discover the principles and techniques of sun radiant cooling, which include the usage of solar radiation to chill surfaces and gadgets even as directing heat far from the building. The assessment covers the thermal performance, power efficiency, and comfort degrees of those structures, in conjunction with the challenges and opportunities related to their implementation in constructing designs.

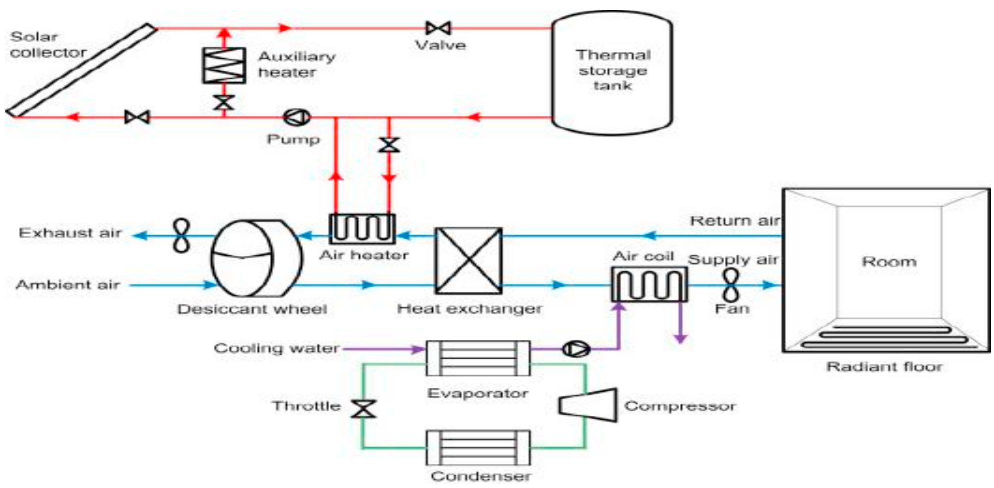

Fig.17 The principles and techniques of solar radiant cooling. Wang et al. (2022).

4. SOLAR ELECTRIC COOLING

Solar electric powered cooling is an effective method to utilizing solar electricity for cooling structures (Chwieduk, 2014, p. 339). This approach involves linking a standard vapor compression refrigeration unit to a photovoltaic (PV) power deliver device, as illustrated in Fig. 4. The refrigeration unit can characteristic on both direct contemporary (DC) or alternating cutting-edge (AC). A DC device necessitates a battery, which limits the device's length and potential, making it primarily suitable for small-scale applications, inclusive of portable gadgets for storing meals or drug treatments in tropical climates. In evaluation, AC-powered refrigeration devices require an inverter to convert the DC electricity produced by the photovoltaic cells into AC energy. Furthermore, an AC machine related to the electric grid can offer energy during instances of inadequate solar radiation. Solar PV cooling technology is usually employed for small-scale residential and business needs that require much less than 5 kW of cooling (Baniyounes et al., 2013b, p. 795), owing to the benefit of machine installation.

Numerous research have investigated the era of PV solar cooling. Kotak et al. (2014) Tested the effects of roof-hooked up sun panels on cooling masses in five wonderful climates throughout India. Their research revealed that a rooftop PV gadget ought to decrease cooling strength desires by way of seventy three% to ninety%, with a potential annual electricity technology of eleven. Nine MWh from a 90-square-meter rooftop. Hartmann et al. (2011) Performed a assessment of solar thermal cooling and solar PV cooling for a small workplace in Freiburg and Madrid the usage of TRNSYS software. Their results indicated that grid-linked photovoltaic solar cooling structures are more economically and power efficient than thermal sun cooling structures. In a comparable vein, Beccali et al. (2014) Evaluated the lifestyles cycle overall performance of a small sun thermal absorption cooling machine against a grid-connected PV evaporative compression cooling machine. Their findings confirmed that the PV-powered vapor compression refrigeration system outperformed the thermal system in terms of world power intake, worldwide warming impact, and economic payback length.

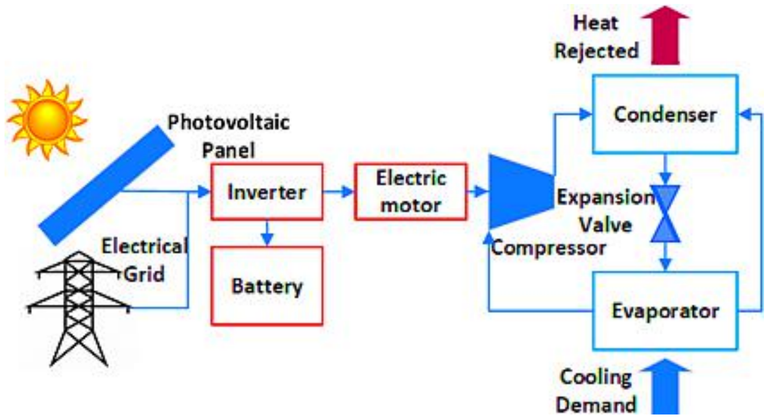

Fig. 18 Solar electric cooling technology. Guercio et al. (2024).

5. SOLAR THERMAL COOLING TECHNOLOGY

Solar thermal cooling era makes use of sun thermal collectors to capture sun electricity and convert it into cooling via a thermally pushed mechanism. According to Hwang et al. (2008), This era can be classified into 3 primary kinds: thermo-mechanical cooling, closed-cycle cooling, and open-cycle cooling. Closed-Cycle Cooling Process: In this approach, solar thermal collectors soak up solar heat, that's transformed into thermal strength. This strength heats a running fluid, including a refrigerant, which then undergoes a cycle of compression and enlargement to generate cooling. The running fluid extracts warmth from the surroundings and releases it out of doors, resulting in a cooling effect. This era is typically employed in smaller-scale programs, along with residential and commercial air con structures. - Open-Cycle Cooling

Process: Also called desiccant cooling, this technique leverages sun thermal power to regenerate a desiccant fabric that dehumidifies the air. Solar thermal creditors warmth the desiccant, allowing it to absorb moisture from the air. The resulting dry air is then cooled the usage of traditional techniques, which includes evaporative cooling or mechanical refrigeration, to obtain the preferred temperature. This approach is specially effective in hot and humid climates, in which dehumidification is important for comfort. Fig. 2.19 presents a visible illustration of the diverse levels concerned in these solar thermal cooling technologies. Each class gives unique strategies for harnessing solar warmth for cooling, catering to one-of-a-kind utility necessities and environmental conditions.

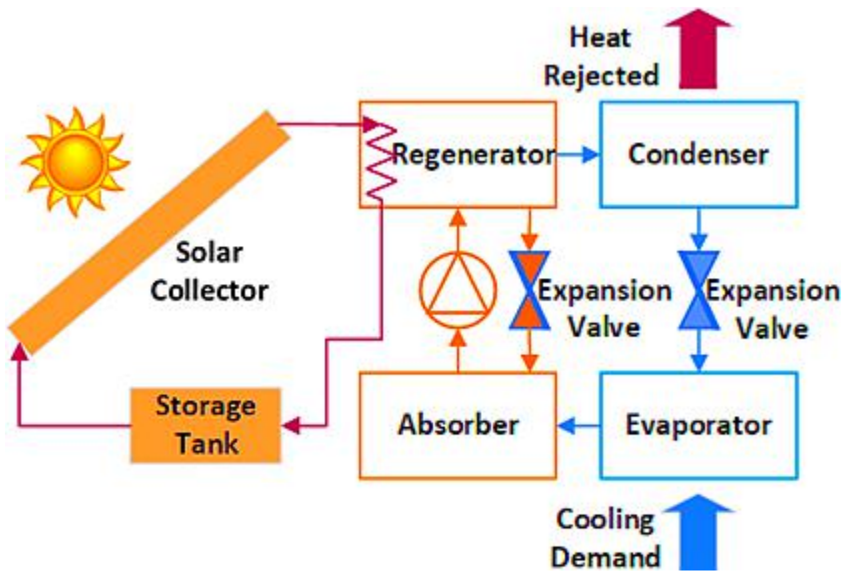

Fig. 19 Shows the solar thermal cooling stage. Guercio *et al.* (2024).

The Rankine cycle sun cooling gadget is recognized for its stunning coefficient of overall performance (COP), which could rival that of vapor compression cycles. This performance can be in addition advanced via making use of high-performance sun collectors (Baniyounes et al., 2013b, pp. 795-796). However, the device's strength generation efficiency is commonly decrease, and there are environmental worries concerning the working fluids hired. Recent research have concentrated on enhancing and advancing Rankine cycle sun cooling structures. For instance, Hu et al. (2014) Carried out a thermodynamic analysis of a solar-driven organic Rankine-vapor compression icemaker. Zandian and Ashjaee (2013) Delivered a hybrid layout combining a cooling tower and solar chimney to enhance the thermal performance of a steam Rankine cycle. Li and Zhang (2013) Investigated a transcritical CO2 warmth pump device powered via a solar-driven CO2 Rankine cycle for both heating and cooling purposes. Wang et al. (2011) Assessed the performance of a blended organic Rankine cycle and vapor compression cycle for heat-activated cooling. Additionally, Grosu et al. (2015) Completed an exergy analysis of a mixed solar organic Rankine cycle and absorption cooling device implemented in an academic building.

These studies recognition on enhancing the overall performance and performance of Rankine cycle solar cooling structures by means of examining numerous factors, together with gadget layout, selection of operating fluids, and integration with other cooling technologies .

The steam ejector cooling method represents a form of sun cooling gadget that operates in addition to standard vapor compression systems, but it utilizes a thermally driven ejector for refrigerant compression rather than an electric compressor, thereby doing away with transferring components (AIRAH, 2015, para. 4). This gadget capabilities on a warmth-pump refrigeration cycle, with the steam ejector managing the compression. A schematic representation of this device can be discovered in Fig. 2.9 (Hwang et al., 2008, p. 520). Steam ejector-based totally solar cooling systems are favored for his or her simplicity, reliability, low operational and installation expenses, flexibility in refrigerant selection, and capability to generate cooling using renewable energy resources (ANU, 2015, paras. 9 and 18However, these structures commonly show off a decrease coefficient of overall performance (COP), usually falling below 0.4 (Baniyounes et al., 2013b, p. 796).

Recent studies have targeting enhancing and optimizing sun ejector cooling technology. Huang et al. (1998) Evaluated a unmarried-level solar ejector cooling gadget utilising R141b as the operating fluid. In Athens, Alexis and Karayiannis (2004) Tested a sun-driven ejector cooling device that employed R134a. Ersoy et al. (2007) Assessed a sun-powered ejector cooling system providing evacuated-tube collectors and R123, mainly in Turkish climates. Varga et al. (2009) performed a theoretical evaluation of a sun-assisted ejector cooling device the usage of water because the running fluid for small-scale air conditioning in Mediterranean areas. Huang et al. (2001) in comparison the overall performance of a sun ejector cooling device with 3 exclusive forms of solar collectors. Furthermore, Tashtoush et al. (2015) performed a dynamic simulation of a sun ejector cooling gadget the usage of R134a refrigerant underneath Jordanian situations, employing TRNSYS-EES software program. These investigations purpose to decorate the overall performance and performance of solar ejector cooling structures by using inspecting different factors, inclusive of the selection of operating fluids, system design, and optimization of sun collectors.

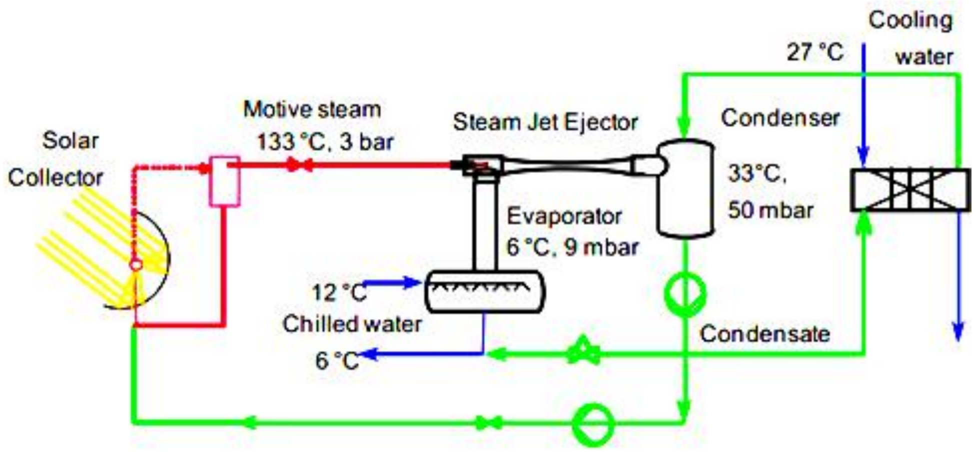

Fig. 20 A schematic diagram of a steam ejector solar cooling system. Carbonare (2016).

Closed cycle refrigeration systems regularly appoint convection chillers to generate chilled water for air coping with gadgets, making them a favored option for aircon in business homes. The market functions diverse alternatives, inclusive of absorption and adsorption chillers (Baniyounes et al., 2013b, p. 797Absorption chillers operate the use of a liquid absorbent, while adsorption chillers rely upon a stable absorbent (AIRAH, 2015, para. 4). Additionally, solar cooling systems, which utilize properly-established generation, present vast opportunities to decrease strength intake and reduce greenhouse gas emissions in each new and current systems (Baniyounes et al., 2013b, p. 797).

The absorption refrigeration cycle features similarly to a conventional vapor compression cycle, however it substitutes the mechanical compressor with a thermal compressor that consists of an absorption tool, condenser, generator, evaporator, answer pump, and move pump (Huang et al., 2008, p. 513). In this device, the refrigerant evaporates inside the evaporator at low strain, which cools the chilled water. The vapor is then absorbed by a liquid absorbent, lowering the partial strain inside the evaporator and facilitating continuous refrigerant evaporation. This aggregate of absorbent and refrigerant is ultimately pumped to the generator, where it's far heated the usage of sun energy and a backup heater, main to the evaporation of the refrigerant. The resulting excessive-stress refrigerant fuel condenses into a liquid within the condenser, flows via the growth valve, and returns to the evaporator to copy the cycle (Baniyounes et al., 2013c, p. 422). Fig. 2.21 depicts the solar absorption refrigeration cycle (Hwang et al., 2008, p. 514). Solar absorption cooling systems correctly harness renewable electricity and had been the challenge of sizable research geared toward enhancing their performance and performance, making them nice for reducing energy consumption in buildings and lowering greenhouse fuel emissions.

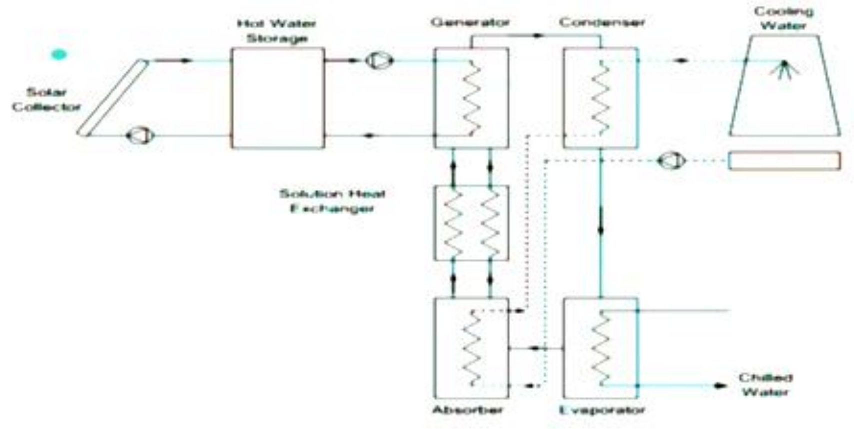

Fig. 21 Shows a schematic diagram of the solar absorption refrigeration cycle. Jani (2019).

Absorption chillers generally utilize pairs of running fluids: LiBr/H2O (lithium bromide/water) and H2O/NH3 (water/ammonia). The LiBr/H2O combination employs lithium bromide as the absorbent and water because the refrigerant, generating chilled water at temperatures ranging from 5 to 8°C. On the alternative hand, the H2O/NH3 pair uses water because the absorbent and ammonia as the refrigerant, making it suitable for commercial applications that require chilled water temperatures under five°C (Baniyounes et al., 2013b, p. 797). Each fluid pair has its own advantages and disadvantages, as outlined by Baniyounes et al. (2013b, p. 797).

There are three number one sorts of sun absorption cooling technology primarily based on the absorption chillers and sun collectors hired: unmarried-effect, double-effect, and triple-impact structures. Single-effect structures are the maximum widely used due to their high efficiency, fee-effectiveness, and lower temperature necessities for the heat supply. In contrast, multi-effect systems, which encompass double and triple-effect configurations, provide greater performance however necessitate considerably better temperatures from the warmth supply (Hwang et al., 2008, p. 514).

Recent studies have concentrated on enhancing solar absorption cooling technologies. Li and Sumathy (2000) Performed a overview of earlier studies on LiBr-H2O systems and simulated performance improvements by way of partitioning the storage tank into sections (Li & Sumathy, 2001). Assilzadeh et al. (2005) Optimized and completed an monetary analysis of a LiBr-H2O machine using evacuated tube collectors in Malaysia, suggesting a warm water storage tank of zero.8 m³ and 35 m² of creditors inclined at 20°. Eicker and Pietruschka (2009) Assessed the effectiveness of a sun absorption gadget for office homes across Europe. Tsoutsos et al. (2010) Evaluated the technical and financial viability of a LiBr-H2O gadget for a medical institution in Greece the use of TRNSYS software application. Additionally, Mateus and Oliveira (2009) Examined the electricity and economic elements of such structures for residential, office, and hotel settings in Berlin, Lisbon, and Rome.El May et al. (2009) Explored the viability of a single-impact, air-cooled LiBr-H2O absorption solar air con machine in hot, arid climates. Their studies indicated that a coefficient of performance (COP) of zero.Sixty six could be carried out for a ten kW chiller, operating at an evaporation temperature of 11°C and a generator inlet temperature of ninety°C, with a cooling medium temperature of 35°C. In a separate study, Baniyounes et al. (2013a) Applied TRNSYS software to assess sun absorption cooling for an workplace constructing in three subtropical regions of Australia. Their findings found out that using 50 m² of sun creditors in conjunction with a 1.Eight m³ hot water garage tank should result in about eighty% financial savings in number one electricity as compared to a conventional vapor compression machine, which had a COP of 2.5.

In adsorption cycle cooling systems, a stable adsorbent captures moisture from the air, leading to cooling via the evaporation system (Zhai et al., 2008, p. 299). Commercially to be had adsorption chillers commonly make use of pairs of water and silica gel, with water serving because the refrigerant and silica gel as the adsorbent (Al-Zubaydi, 2011, p. 28). A regular adsorption chiller consists of two sorption chambers (adsorbed and desorbed), together with an evaporator and a condenser (Hwang et al., 2008, p. 516). The cycle initiates within the evaporator, wherein the water refrigerant vaporizes at low temperature and strain, cooling an outside water circuit to generate chilled water. The ensuing water vapor is then adsorbed by using the silica gel within the adsorbed chamber. In the desorbed chamber, the water vapor is launched by means of regenerating the adsorbent using hot water from a solar warmness supply. The vapor is finally condensed within the condenser with cooling water sourced from a cooling tower. The condensed liquid refrigerant is then sprayed lower back into the evaporator through a throttling valve, finishing the cycle (Baniyounes et al., 2013b, p. 798If the cooling capacity diminishes because of adsorbent saturation, the operation of the two chambers can be reversed by adjusting the drift of heating and cooling water and enhancing the settings of the throttling valve (Hwang et al., 2008, p. 517).

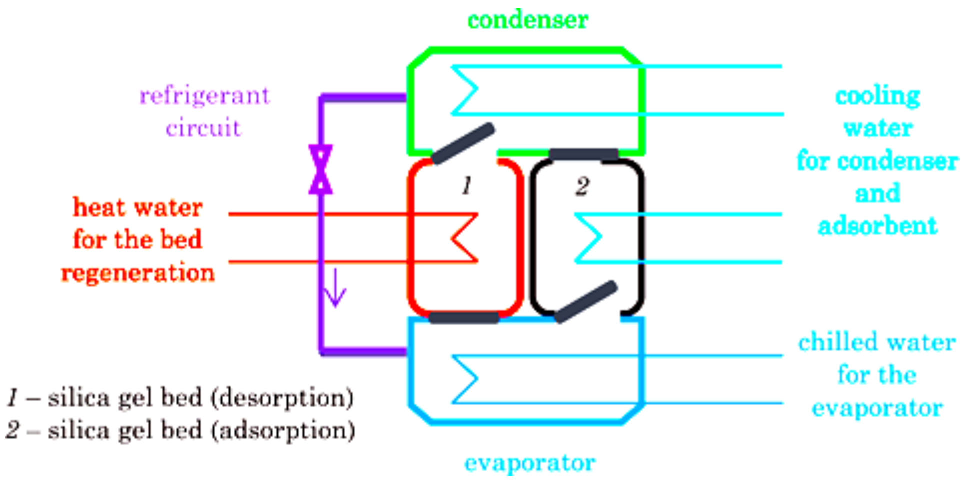

Fig. 22 Adsorption chiller. Krzywański et al. (2016).

The adsorption cycle starts offevolved in the evaporator, wherein the water refrigerant evaporates at low temperature and strain, cooling the external water circuit and producing chilled water. The ensuing water vapor is then absorbed by way of the silica gel adsorbent inside the adsorption chamber. In the desorption chamber, the solid adsorbent is regenerated the use of warm water from a solar warmness supply, which releases the water vapor. This vapor is sooner or later condensed within the condenser with cooling water sourced from a cooling tower. Finally, the condensed refrigerant is sprayed lower back into the evaporator thru a regulating valve, completing the cycle (Baniyounes et al., 2013b, p. 798). If the cooling capability diminishes due to adsorbent saturation, the operation of the two chambers can be reversed through switching the waft of warm and bloodless water and adjusting the regulating valve (Al-Zubaydi, 2011, p. 29; Hwang et al., 2008, p. 517).

Currently to be had adsorption refrigeration devices provide cooling capacities among 50 and 500 kW (Al-Zubaydi, 2011, p. 29) and exhibit a coefficient of overall performance (COP) starting from zero.Three to 0.7, depending on the working temperature, which falls among 60°C and 95°C (Hwang et al., 2008, p. 517). This technology is attractive as it typically functions at lower temperatures as compared to absorption refrigeration cycles, has no moving elements, and may be designed compactly for applications in industrial air con, system cooling, and business settings (Baniyounes et al., 2013b, p. 798). Furthermore, corrosion troubles which might be frequently present in absorption systems are not a challenge with adsorption cycles (Zhai et al., 2008, p. 299). However, adsorption chillers do have some risks, which include decrease performance (COP), increased weight, and better installation charges (Baniyounes et al., 2013b, p. 798).

Recently, numerous studies have investigated sun adsorption cooling technology. Zhai et al. (2008) finished a layout and optimization evaluation of a solar-assisted adsorption cooling device for an institutional building in Shanghai. In a observe-up have a look at, Zhai and Wang (2009) compared sun absorption and adsorption refrigeration technologies in China, concluding that solar absorption refrigeration is extra suitable for large buildings, while sun adsorption refrigeration is better proper for smaller programs. Hassan et al. (2011) utilized AC software program to simulate a ducted sun adsorption cooling device, reporting a solar module coefficient of overall performance (COP) of zero.211 and a selected cooling potential of two.326. Lu et al. (2013) examined a novel solar adsorption cooling gadget alongside a sun absorption cooling system using composite parabolic collectors, watching that the adsorption chiller operated with hot water at 55°C and completed a mean machine performance coefficient of 0.16. El-Sharkawy et al. (2014) assessed the viability of a sun-powered silica gel/water adsorption cooling machine for climates in the Middle East. Additionally, a sun adsorption cooling machine has been mounted at a café milk manufacturing facility in Wyong, New South Wales, Australia, offering a cooling potential of 10 kW, 34.Eight m² of vacuum tube collectors, a 1,500-litre hot water garage tank, and a 500-litre cooling water garage tank.

An open-cycle refrigeration gadget is a form of dry cooling machine that utilizes water because the refrigerant, allowing it to interact directly with the encompassing air. Unlike closed-cycle structures that produce chilled water, open-cycle systems create fresh, dried, and cooled air directly (Henning et al., 2013, p. 117). After the air is dried, it turns into sufficiently dehumidified to facilitate evaporative cooling. This processed air is then in addition cooled earlier than being provided directly to the conditioned place (AIRAH, 2015, para. 4). Dehydration refrigeration structures are categorised into two types primarily based on the substances used for dehydration: liquid dehydration refrigeration and solid dehydration refrigeration.

Solar liquid dehydration cooling structures hire a liquid desiccant to control moisture tiers in conditioned air. As illustrated in Fig. 2.23 (Al-Zubaydi, 2011, p. 33), the gadget capabilities by using circulating a desiccant answer between an air dryer and a regenerator. In the air dryer, the desiccant solution is sprayed onto a cooling coil in a path opposite to the airflow, allowing it to absorb moisture from the air, thereby drying and cooling it. The now diluted solution is then pumped to the regenerator, where it's far sprayed onto a heating coil in opposition to the airflow to launch the absorbed water and repair the desiccant's drying capability. The heat required for this process levels from 40°C to eighty°C and may be furnished by way of a sun thermal collector (Buker & Riffat, 2015).

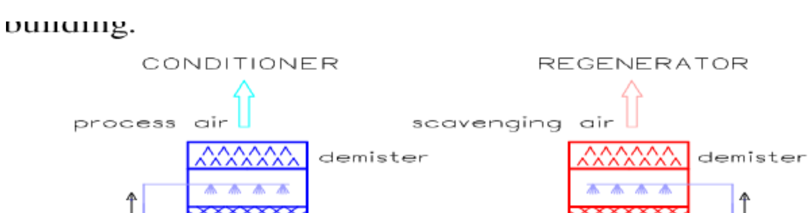

Fig. 23 The detailed diagram of the solar liquid dehydration cooling system. Lowenstein *et al.* (2006).

Liquid desiccants are characterized via their odorless, non-toxic, and non-flammable residences, making them a cost-powerful choice. Commonly utilized beverages include lithium chloride, lithium bromide, and triethylene glycol (Baniyounes et al., 2013b, p. 799). The number one blessings of liquid dehydration cooling structures encompass:

-Low fluid pressure, leading to a discounted recovery temperature.

-High warmth transfer performance whilst paired with a liquid-liquid warmth exchanger.

-Compact unit sizes, facilitated by the capacity to pump beverages.

However, there are some dangers to don't forget:

-Increased fan strength consumption due to the substantial stress drop of system air passing via submerged liquid drying beds.

-The requirement for a separate warmth exchanger to chill the desiccant.

- The hazard of system damage from droplets inside the process air and capacity corrosion of the desiccant materials.

Recent research have thoroughly investigated solar liquid dehydration cooling technology. Li and Yang (2008) along side Li, Lu, and Yang (2010) evaluated the energy performance and monetary viability of a solar liquid dehydration air conditioning gadget in Hong Kong the usage of EnergyPlus. Their findings indicated that combining a sun liquid dehydration dryer with a traditional evaporative compression system could result in annual energy financial savings starting from 25% to 50%, with a payback period of around seven years.

In a similar vein, Abdel-Salam, Ge, and Simonson (2014) performed a thermo-economic overall performance evaluation of a solar film liquid dehydration cooling device using TRNSYS. They assessed 8 wonderful gadget configurations, which covered 4 heating systems, and as compared their effectiveness. The research underscored both the benefits and demanding situations related to the usage of non-poisonous, non-flammable, and fee-effective dry liquids like lithium chloride, lithium bromide, and triethylene glycol in these structures (Baniyounes et al., 2013b, p. 799).

Table 1. Summary of Research on Solar-Powered Air Conditioning Systems

Author	Year	Title of Research	Type of System	Main Findings	Recommendations
Chen et al.	2017	Simulation and Optimization of Photovoltaic-Powered Air Conditioning Systems for Commercial Buildings	Solar-powered air conditioning system	Reduction in electricity consumption by up to 30%	Select high-efficiency solar panels
Li et al.	2018	Pecrformance Analysis of a Photovoltaic-Powered Air Conditioning System Using Dynamic Simulation	Solar-powered air conditioning system	Improved energy efficiency by up to 25%	Employ smart control technologies
Zhang et al.	2019	Simulation and Optimization of Photovoltaic-Powered Air Conditioning Systems for Off-Grid Applications	Off-grid solar air conditioning system	Sustainable and cost-effective alternative for areas without grid power	Improve system design and select appropriate solar panels
Zhao et al.	2019	Optimal Design and Performance Analysis of	Solar-powered air conditioning	Optimal sizing and configuration	Apply intelligent control and design improvements

		Photovoltaic-Powered Air Conditioning Systems	system	improve energy efficiency and reduce costs	
Song et al.	2017	Performance analysis of a solar-assisted air conditioning system with PV/T collectors	Integrated solar-PV/T air conditioning system	Enhanced energy efficiency and cost reduction	Use integrated PV/T solar panels
Hong et al.	2018	Feasibility study of a solar-powered air conditioning system using photovoltaic/thermal collectors	Solar thermal air conditioning system	Effective in reducing energy consumption and dependency on traditional sources	Improve system design for future applications
Chen et al.	2019	Energy and exergy analysis of a solar-assisted air conditioning system with flat plate and concentrating photovoltaic/thermal collectors	Solar-assisted air conditioning system with flat plate and concentrating PV/T collectors	Increased energy efficiency and system performance	Utilize concentrated solar panels for improved efficiency
Li et al.	2020	Experimental investigation of a solar-assisted air conditioning system based on hybrid photovoltaic/thermal collectors	Hybrid PV/T solar-assisted air conditioning system	Achieves a good balance between thermal and electrical performance	Optimize hybrid PV/T design for better efficiency
Elgendy et al.	2016	Design and performance evaluation of a solar-powered air conditioning system for residential buildings	Solar-powered air conditioning system for residential buildings	Balance between energy consumption and user comfort	Implement in residential buildings for overall energy savings
Wang et al.	2017	Performance evaluation of solar-assisted air conditioning systems for office buildings	Solar-assisted air conditioning system for office buildings	Reduced electricity consumption and improved energy efficiency	Implement in office buildings for enhanced energy performance
Zhang et al.	2018	Economic analysis of a solar-powered air conditioning system for	Solar-powered air conditioning system for	Economically sustainable with long-term cost	Invest in solar-powered systems for long-term benefits

		commercial buildings	commercial buildings	savings	
Chen et al.	2019	Techno-economic analysis of a hybrid solar air conditioning system for industrial applications	Hybrid solar air conditioning system for industrial applications	Balance between cooling needs and reduced energy consumption	Apply hybrid systems in industrial applications for optimal performance
Sharma et al.	2016	Solar absorption air conditioning: A comprehensive review of systems and performance	Solar absorption air conditioning system	Capable of providing effective and sustainable cooling	Improve absorption and heat storage efficiency
Wang et al.	2017	Solar desiccant cooling systems: A review	Solar desiccant cooling system	Improved cooling efficiency and energy savings	Optimize design and use effective absorbent materials
Li et al.	2018	Solar-powered desiccant evaporative cooling systems: A review	Solar desiccant evaporative cooling system	Effective and sustainable cooling using solar energy	Enhance thermal and humidity performance
Hong et al.	2019	Solar-assisted radiant cooling systems: A review	Solar radiant cooling system	Effective for improving energy efficiency and thermal comfort	Apply in buildings to enhance energy efficiency and comfort

6. Conclusion

This comprehensive review has analyzed the optimization efficiency of solar-powered air conditioning systems, emphasizing the significant potential of such systems to address global energy demands and environmental concerns. The studies reviewed consistently highlight that solar-powered air conditioning systems, whether powered by photovoltaic (PV) panels or integrated with solar thermal technologies, offer substantial energy savings and reduced environmental impacts. Key findings from the review indicate that the efficiency of solar-powered air conditioning systems can be greatly enhanced through optimized system designs, the use of high-efficiency PV panels, and the implementation of intelligent control technologies. The integration of these systems not only reduces reliance on fossil fuels but also contributes to lower electricity bills and a decrease in greenhouse gas emissions. Moreover, the economic analyses suggest that investing in solar-powered air conditioning systems is a sustainable and cost-effective alternative in the long run, particularly in areas with high solar irradiance. The future of solar-powered cooling systems looks promising, with ongoing research focusing on improving performance, sustainability, and integration with existing energy infrastructures.

Term	**Definition**
PV	**Photovoltaic**: Technology for converting solar energy into electrical energy using solar cells.
AC	**Alternating Current**: A type of electric current in which the flow of electric charge periodically reverses direction.
DC	**Direct Current**: A type of electric current that flows in a single direction steadily.
PCM	**Phase Change Material**: Materials capable of storing and releasing large amounts of thermal energy during their phase transitions (e.g., solid to liquid).
Qge	**Heat Generation**: The amount of heat produced in a system, affecting its thermal performance.
PVT	**Photovoltaic Thermal**: Systems that combine the generation of electricity from PV panels with the capture of thermal energy.
COP	**Coefficient of Performance**: A ratio that measures the efficiency of a cooling or heating system, calculated as the amount of cooling or heating provided per unit of energy consumed.
O&M	**Operation and Maintenance**: Costs associated with running and maintaining a system after its installation.
CAPEX	**Capital Expenditure**: The upfront costs for the installation and commissioning of a system.
LiBr/H2O	**Lithium Bromide/Water**: A common working fluid pair used in absorption chillers, where LiBr is the absorbent and water is the refrigerant.
H2O/NH3	**Water/Ammonia**: Another working fluid pair used in absorption chillers, where water is the absorbent and ammonia is the refrigerant, suitable for low-temperature applications.

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