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Original Article

Analysis of Solar-Assisted Cooling and Heating Technologies in Residential Buildings

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Abstract *- Solar-assisted ventilation and heating technologies in residential buildings not only represent an additional means to diminish global energy consumption and greenhouse gas emissions but also constitute an effective approach, given that the building sector accounts for a significant portion of worldwide energy utilization. The paper reviews major solar-assisted systems such as active and passive solar water heaters, thermosiphon systems and batch systems, and the main components of these systems, such as collectors, storage tanks, and heat transfer fluids. It also draws attention to solar-assisted cooling methods, especially to desiccant-based systems and thermally driven chillers, which can completely or lightly replace conventional electrically driven cooling systems. The role of the international initiatives IEA-SHC Task 25 and Task 38 in terms of system design, performance assessment, and market development is pointed out. There is no doubt that a lot of work has been done, yet there are still issues to be tackled such as dependency on environmental conditions, high upfront costs, need for maintenance, and limited applicability.*

Keywords *- Solar-Assisted Cooling, Residential Buildings, Solar Water Heating Systems, Renewable Energy, Building Energy.*

1. Introduction

The residential buildings play a crucial part in creating a healthy and pleasant interior living space [1]. Climate change symptoms, such as overheating, might reduce resident productivity and increase the risk of heat-related diseases [2]. The increased peak cooling and heating needs could also put a strain on electricity generation, which could lead to more frequent power disruptions. Adaptive thermal comfort research has not yet produced a comprehensive assessment of its potential to reduce energy consumption in residential buildings. In addition to contributing significantly to global warming and the urban heat island effect, the construction and building industry is the single largest consumer of primary energy and a major source of greenhouse gas (GHG) emissions [3].

BEMS allow for the optimization of energy usage throughout construction and renovation, leading to increased energy efficiency. The issue of energy sustainability is pressing in the 21st century [4]. There has been a disturbing increase in the emission of greenhouse gases (GHG) due to the present energy production and consumption systems, which has generated major climatic problems on a global scale. The emissions have triggered alarming problems, such as global warming which is a direct threat to human well-being and health.

Renewable energy sources are being pursued by researchers and governments as potential replacements to traditional power generation methods, with the hopes of improving efficiency and decreasing costs. There must be no compromise on safety, cost, or environmental impact when choosing an energy source [5]. Solar power is generally considered to be among the best options for meeting energy needs because of its widespread availability, positive environmental impact, and reduced reliance on fossil fuels. It has become more important to develop technologies that utilize renewable energy sources, as there has been a shift toward sustainable energy in recent years. This holds true in the realms of science and industry in addition to homes and businesses [6]. One of the most encouraging energy solutions to meet the problems of the new millennium and ensure sustainability is the utilization of solar energy, whether it be thermal energy or photovoltaic energy.

Energy is the engine that propels society forward because it powers everything from growing food and water to transporting people and goods, running businesses, constructing and maintaining infrastructure, and, of course, heating and cooling buildings [7]. Most of these things happen in or around urban areas. Consequently, interaction and GDP are both boosted by the concentration of activity at specific locations. Constant energy supply is essential because cities typically generate 75% of a country's GDP. Globally, urban areas account for three-quarters of all energy use and between fifty and one hundred sixty percent of all GHG emissions. This likelihood rises to 80% if city dwellers are indirect [8]. One way to estimate the quantity of heat that will escape from a building is to calculate its heating load, which is the amount of heat that will be required to maintain a comfortable temperature within. Some of the variables considered by this load include ambient temperature, insulation level, air leakage, and building type. To keep the inside of a building at a reasonable temperature during hot weather, a certain quantity of heat energy must be removed from the structure. This amount is called the cooling load.

Multiple internal and external elements contribute to this amount of heat gain: weather, solar radiation, air penetration, and people, appliances, and lights [9]. Additionally, building design plays a role in this load.

1.1. Structure of the paper

The organization of the paper is as follows: The technologies for solar-assisted heating and their major parts are described in Section II. The different methods of solar-assisted cooling are the topic of Section III. Section IV talks about the main issues that these systems face. Section V gives an overview of the recent literature and the technological progress made. Section VI wraps up the study and indicates areas for future research.

2. Solar Assisted Heating Technolgies in Buildings

The heating, cooling, and hot water systems in buildings use a lot of energy and release a lot of greenhouse gases into the air. Buildings are extremely energy-intensive, accounting for 20% and 40% of total energy use in developing nations and wealthy countries, respectively [10]. Energy consumption is projected to continue rising at a rapid pace due to rising living standards and building service levels.

2.1. Solar Water Heating Systems in Residentials

Water heating is a prevalent application of solar energy, and solar water heaters play a crucial role in this process [11]. To heat water, solar water heaters typically use nothing more complicated than the sun's rays. Interactions between working fluids and dark surfaces exposed to sunlight cause the fluids' temperatures to rise. Water is the fluid in question in direct systems, while a glycol/water mixture is an example of a heat transfer fluid that could be used in indirect systems, conveyed via a heat exchanger. The main categories that these systems belong to are these:

2.1.1. Active Systems

The electric pumps, valves, and control systems that make up the active systems are responsible for actually moving the water or other heat-transfer fluids through the collectors. Active systems can be either direct or indirect. Forced circulation systems are another name for the former. Within the active system, two subsets exist:

2.1.1.1. Open-Loop (Direct) Active Systems

System dynamics (open-loop) to transfer water from one container to another, pumps are utilized. This design can reduce operational expenses and is efficient in soft or acidic water, but it quickly becomes ineffective owing to corrosion and scale. Many locations that don't experience extreme cold commonly utilize these open-loop systems. Active flow via the open-loop system is seen in Fig. 1.

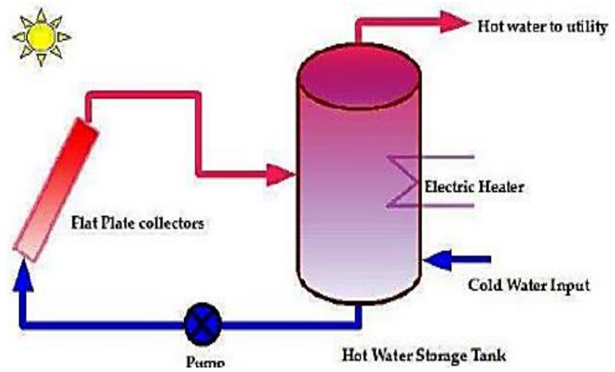

Fig 1: Open-Loop Active Systems

2.1.1.2. Closed-Loop (Indirect) Active Systems

This type of system uses collectors to pump heat transfer fluids, which are a mixture of glycol and water antifreeze. The fluid's heat is transferred to the water in the tanks through heat exchangers. When prolonged exposure to freezing temperatures is a common occurrence, many turn to closed-loop glycol systems for their superior freeze protection. The active closed-loop systems are illustrated in Fig. 2.

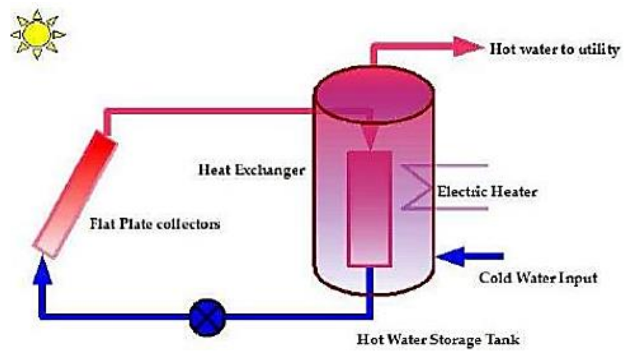

Fig 2: Closed-Loop Active Systems

2.1.2. Passive Systems

The fundamental principle of a passive system is to transport heat from a lower storage tank to a higher one by means of natural convection, as facilitated by water or another heat transfer fluid. A fluid's density drops as its temperature rises; this is a basic fundamental. The fluid is drawn to the storage tank as it floats to the collector's upper level as its density decreases. The fluid returns to the collector after refrigerating at the base of the storage tank. While passive methods may be more cost-effective, their effectiveness is debatable. Passive systems are exemplified by the thermosiphon system.

2.1.2.1. Thermosiphon Systems

The thermosiphon mechanism transfers water from the upper tank to the base of the solar collector. As a result, water flows from the collector to the storage tank whenever the temperature of the water in the absorber rises. The insulated hot water storage tank is forced to retain the replenished hot water after the cold water at the base of the tank flows into the collector (Fig. 3). The circulation process comes to a halt when the collector is no longer exposed to solar energy. Due to the lack of controls and instrumentation, the thermosiphon system is simple and requires little maintenance. The collector's efficiency is directly related to two factors: the temperature differential between the collecting area and the surrounding air, and the strength of the sun's radiation.

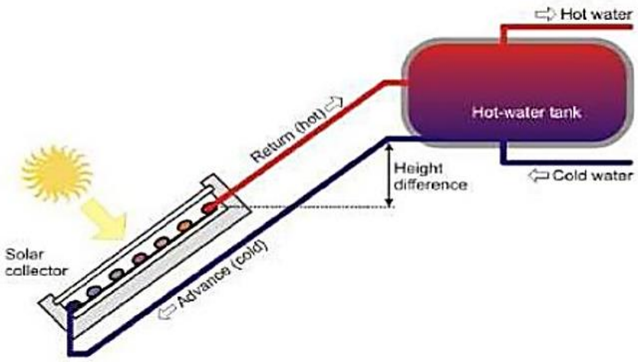

Fig 3: Thermosiphon Systems

2.1.2.2. Batch Systems

A simple passive system, an integral collector storage system (or batch system) consists of a sun-facing glass side and an insulated box that houses one or more storage tanks. As seen in Fig. 4, batch systems integrate collecting and storing processes. The lack of pumps and other moving parts in these systems makes them cheap, simple, low-maintenance, and reliable.

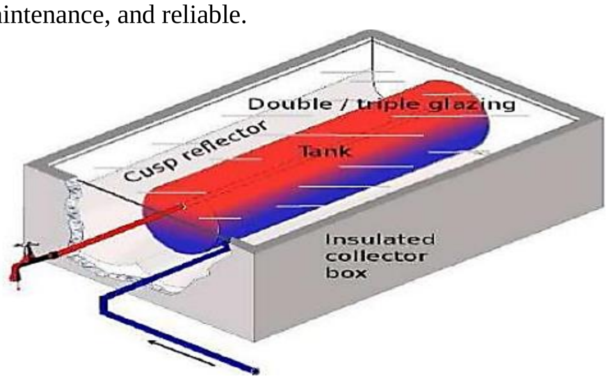

Fig 4: Batch System

2.2. Components of Solar Water Heating Systems

Solar water heaters typically consist of water storage, a pump, a heat exchanger, pipelines, an auxiliary heater, water-absorbing panels and a reservoir. The following sections provide an overview of some of the most important components.

- **Solar Collectors:** A number of environmental considerations and heating demands must be considered before settling on a collector. Concentrated solar collectors, flat plate collectors, and evacuated tubes are the three main categories of solar energy harvesting equipment.
- **Storage Tank:** A well-insulated storage tank is required by the vast majority of current solar water heater models. A thermal storage tank is constructed with an insulated fiber and aluminum foil surrounding a core of stainless steel that can withstand high pressures [12]. Pumps are an integral part of alternative solar water heater systems, transferring water between storage tanks, collectors, and open pipelines. This is usually done when the outdoor temperature dips low enough to prevent the pipes from freezing.
- **Heat Transfer Fluid:** A heat exchanger or heat transfer fluid moves the heat from the collector to the holding tank. A low-cost anti-corrosive fluid with good thermal conductivity, specific heat capacity, viscosity, and thermal expansion coefficient would be ideal for an efficient SHW design [13]. Water is the most effective heat transfer fluid, when compared to glycol, hydrocarbon oils, silicon oils, and water. Water is the most economically viable, easily accessible, and thermally efficient fluid; nevertheless, it freezes and can induce corrosion.

3. Solar Assisted Cooling Technologies in Residential

Solar cooling is a method of cooling and dehumidifying a place by utilizing thermal energy that is collected from the sun. This takes the place of the current electrical power input that is normally needed in a refrigeration cycle that uses vapour compression [14]. One advantage of this technology is that it can help lower electricity use (and carbon dioxide emissions) during the hot summer months, when power grid demand is highest. The entire solar cooling system is made up of numerous separate components, all of which combine together to offer cooling, yet each component has its purpose in the entire system. Common components of solar cooling systems include heat rejection loops, thermal energy storage, and sun collectors.

3.1. Methods of Solar Cooling

There are two main approaches that have been widely used for sun cooling applications. There are two main approaches to air conditioning. A desiccant cycle conditions the air directly, whereas a thermally driven chiller produces cooled water in the other. This water is subsequently utilized in a conventional air handler unit. A description of both approaches follows.

3.1.1. Desiccant Based Systems

A desiccant solar cooling system employs direct ventilation as one way of air conditioning incoming air. There are three main parts to the process: (1) removing moisture from the air entering the system by using a desiccant, which can be solid or liquid; (2) reusing the sensible heat from the exhaust air; and (3) bringing the air temperature down to the appropriate level through evaporative cooling. Solar thermal energy is then used to reactivate the desiccant, which successfully removes any residual water. Because desiccant systems remove enough water vapour from the air to enable evaporative cooling, they are most effective in temperate regions.

Additionally, systems that rely on desiccant technology can be efficient when their sole purpose is to remove moisture from entering ventilation air before it is cooled to the required temperature by a conventional air conditioning system. These devices work by contacting a concentrated liquid desiccant solution with the air that is drawn in through the ventilation system. In order for these systems to work, a liquid desiccant solution is introduced to the incoming ventilation air. The latent loads from dehumidification are three to eight times more than the sensible loads from ventilation air, making this method ideal for North American structures with high ventilation rates. It is becoming increasingly clear that ventilation air is bearing a greater share of the cooling load in modern residential buildings. If this trend continues, dehumidification using liquid desiccant may become a more appealing option for residential applications.

3.1.1.1. Thermally Driven Chiller

Solar thermal energy is the main component of thermally powered chillers, which generate cold water by absorbing or adsorbing gases. Absorption chillers use two distinct chemical components, the absorbent and the refrigerant, to do their job. The absorption refrigeration cycle involves pumping the refrigerant to the generator after it has been absorbed into an absorbent. The refrigerant is no longer compressed between the evaporator and condenser, but rather evaporates from the solution as a vapour thanks to the addition of heat to the processes in this revised vapour refrigeration cycle [15]. The chemical reaction that occurs in the operation determines the difference between adsorption and absorption chillers; the working fluids that are selected determine this difference. The most frequent working fluids for absorption chillers include water and lithium chloride or ammonia, although adsorption chillers often employ water and silica or zeolite or activated carbon with methanol or ammonia as their working fluid. Because they can generate cold water that can be utilized in the majority of conventional air handling devices with no adjustments, thermally powered chillers find widespread use.

A common feature of continuous thermodynamic running chillers is the continuous flow of working fluids between various components, which is often powered by heat. An intermittent absorption cooling cycle is an alternate setup that can be used instead of this one. There are just two components used in this cycle, and they are piped together. The generator and absorber functions are performed by the first component, while the condenser and evaporator are performed by the second. There are two distinct phases to these systems' operation, and they cannot coexist. Condensation of the desorbed refrigerant and heat input into the generator are being handled by the absorbent and regenerator, respectively, at this stage of the process. Disposal of the heat produced by the condensed refrigerant is necessary (for instance, using a cooling tower). The absorbed refrigerant is then delivered to the evaporator, marking the start of the second phase. By converting atmospheric heat into vapour, the condenser lowers the temperature of the surrounding air, acting as an evaporator in this stage. Once again, the absorbent is used to collect the vaporized refrigerant from the regenerator, which is now also the absorber. It is necessary to dissipate the heat generated by the exothermic absorption of the gas.

3.2. International Energy Agency and the Solar Cooling Programme

The Solar Heating and Cooling (SHC) Programme, run by the International Energy Agency, has been the focal point of solar cooling research. In 1974, the IEA was formed as an autonomous entity inside the OECD. In order to implement a thorough energy cooperation program, the European Community Commission and twenty-five member states established the International Energy Agency (IEA) [16]. The Solar Heating and Cooling Programme was one of the first projects launched by the IEA in 1977. Its stated goal was "to facilitate an environmentally sustainable future through the greater use of solar design and technology." Solar photovoltaic, active, and passive technology advancement was its principal aim.

3.2.1. Task 25

The IEA-SHC Task 25 Solar Assisted Air Conditioning of Buildings program was an endeavor from June 1999 to May 2004 that involved specialists from over ten different nations. The goal of this assignment was to fix the three main issues with conventional air conditioners. They are characterized by high energy consumption, high power peak loads, and, in most cases, the usage of refrigerants that are harmful to the environment. Encouraging solar-assisted cooling solutions to enter the market and reducing primary energy usage and peak electrical loads were the key goals of Task 25. Facility owners and managers, as well as planners and architects, were the intended recipients of the Task's findings.

3.2.2. Task 38

Solar aided cooling is also the subject of a second, more current Task, which is part of the IEA-SHC. Methods for producing cooled water or air conditioning by means of solar thermal energy were investigated in Task 38 - Solar Air-Conditioning and Refrigeration from 2006 to 2010. One of the many objectives of Task 38 was to design and test refrigeration equipment with the intention of quickly commercializing solar-assisted cooling systems for households and small enterprises. The primary focus of Task 38 was the development of simulation tools for the purpose of testing and assessing pre-engineered systems for medium- and small-sized applications.

4. Problems in Solar Heating and Cooling Systems

Solar power is up against formidable obstacles that can slow its meteoric rise. There are four ways to characterize these challenges: technological, political, economic, and reliability-related. Water cooled by solar radiation is known as a solar cooling system. Solar thermal energy conversion, photovoltaic conversion, or simply converting sunlight into electricity, is what is used for this purpose. Fig. 5 depicts a solar cooling plant's typical layout.

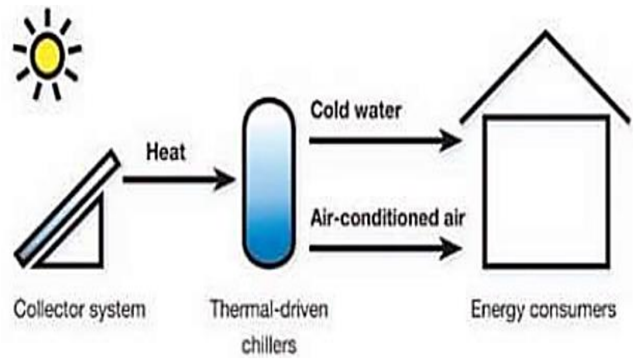

Fig 5: Solar Cooling Plant

4.1. Problems related to Solar Cooling Systems

The standard solar thermal system for solar cooling consists of solar panels or collectors, a reservoir for collected energy, a control unit, plumbing, pumps, and a cooling device that runs on thermal energy. This section addresses many issues that could arise with solar cooling systems:

- **Weather Dependent:** Thermal solar screens need one thing in particular: the sun. When the weather isn't ideal for solar panels to absorb sunlight, and find that solar cooling system isn't working as well as expected [17]. It all comes down to whether it's bad weather, a bad weather season, or a bad weather location. Solar powered cooling system is simply not effective in areas that do not have many hours of strong sunlight.
- **Tracking the Sun:** To achieve its maximum efficiency, the solar energy panels must always face the sun. It is preferable to adjust panels to the season, though with most people having solar panels they tend to fix them in one location based on the latitude of the area they are located and thus they are not set at the best location to use all year round.
- **Cleaning:** Solar panels should be washed and directed towards the sun. Cloudy weather condition is not suitable for the system. Solar energy systems are normally set up at high on a roof, but with snow and sleet, it becomes tricky and hard to clean.
- **Limited Power Supply:** Solar panels do not kill too much power. If a panel the average size can provide about 200 watts. Limited power output solar panels need to consider sq.ft. of home and electric usage.
- **Expensive Batteries:** Batteries are costly, costly to maintain and less durable. Power storage issue is side of the system, require maintenance. Batteries are expensive, high to maintain, and less durable.

4.2. Problems related to Solar Heating Systems

Solar energy optimization, when done well, can lessen production unpredictability. Continuous attempts are being made to improve the efficiency and use of solar heater power technology through research and development [18]. Certain problems that lie in solar heating systems are as follows:

- **Extra Investment:** Storage batteries, inverters, and solar cells are all offered separately. Inverters change DC current into AC current so that it can be fed into the power grid. For on-grid connections to provide constant electric power, storage batteries are crucial [19]. However, this increased expenditure may resolve the sporadic issues with the PV cells.
- **Issues with Intermittency:** All renewable energy sources, including solar heaters and photovoltaic cells, are susceptible to interruptions. It suggests that there are times when it is unavailable for converting energy, like at night or in overcast or rainy conditions. Because of this, PV cells probably won't be able to supply all of the electricity that a grid needs.
- **Easily broken:** As it is, many families just cannot afford the astronomical prices of solar heating systems on the market. An extra layer of insurance can shield investment from potential harm.
- **Expensive:** The prices of solar heating systems in the market are still out of control and unaffordable by most households. The increased production prices of nonconventional energy, coupled with the cheapness of fossil fuels, present an attraction to the customers and create a market competition for non-renewable technology.
- **Low productivity level in future:** The disposal of the panels installed during the initial phases of the energy boom presents a new and substantial challenge to technology shortly after their expected lifespan has passed [20]. Although these panels are expected to last for around 25 years, according to the manufacturer, their output begins to decline after that point.

5. Literature Review

Based on the literature, novel solar-assisted cooling and heating systems increase the efficiency and sustainability of the entire system, but there are still obstacles to overcome in the areas of configuration optimization, integration improvement, and performance verification in various climates and real-world situations. Abid et al. (2025) examined and contrasted the exergy and energy of solar-assisted single effect, series flow double effect, and parallel flow double effect absorption cooling cycles employing LiBr-H2O and LiCl-H2O working pairs. In order to determine how nanofluids impact the exergetic efficiency and coefficient of performance (COP) of the integrated systems, researchers are studying these systems. built and simulated absorption cooling systems using EES software, including single effect, series flow double effect, and parallel flow double effect configurations. The cooling capacity of each system could be reduced to 1000 kW. It is possible to examine the system's overall performance by adjusting the nanoparticle concentration [21].

Feng et al. (2025) SOFC can directly and efficiently convert chemical energy into electricity without additional pollutants, which is a very promising power generation technology. A gas turbine (GT) is often used together with it in an SOFC-GT combined cycle to realize more efficiency. The exhaust from the SOFC-GT combined cycle still contains a significant amount of waste heat, though. As a result, the bottoming cycle frequently employs the ORC and the sCO2 Brayton cycle to recover exhaust waste heat even more efficiently. One possible method of capturing solar energy is the utilization of solar power towers (SPTs), which are often coupled with sCO2 Brayton cycles to generate electrical power [22].

Celik-Toker and Kizilkan (2025) offered the thermodynamic analysis of a multigenerational system that simultaneously generates electricity, refrigeration, and hydrogen through the use of solar energy. This comprises of a solar tower, partial cooling-reheating sCO2 Brayton cycle, ORC integrated with a VCRC, proton exchange membrane (PEM) electrolyzer, and thermoelectric generators (TEG). The system's performance is determined regarding energy and exergy efficiency in relation to varying levels of solar radiation [23].

Zhao et al. (2025) utilized the mass transfer factor and heat transfer factor to demonstrate the mass transfer and heat transfer performance of the coupled cooling system, respectively, in an experimental system that was set up with a heat pipe and an evaporator linked for cooling. examined the impact of incoming air relative humidity and dry bulb temperature on the efficiency of heat pipes and evaporators, and then created equations for the correlation of mass transfer factors [24].

Liu (2024) with the rapid development of electronic technology and micro-assembly capabilities, the development of electronic equipment shows a trend of high integration, miniaturization and high-frequency, followed by the increase in the heat flux of electronic equipment, which poses a great challenge to the stability and service life of the equipment [25].

Abdullah and Polus (2022) study aims to evaluate the efficiency of a thermal solar flat plate collector system in conjunction with an absorption chiller during the summer months in Erbil, a city in Iraq's Kurdistan region. To make sure the TRNSYS 16 model was accurate, the researchers from Erbil Polytechnic University's Research Center of Solar Energy initially connected it to their solar thermal heating system. There are currently ten 2-square-meter collectors, one 1-meter-volume storage tank, heat exchangers, three fan coils, and pumps that make up the solar heating equipment. A water-based lithium bromide absorption chiller with 4.7 kW of output is powered by the linear plate collector system [26].

Yaïci et al. (2021) the cooling and heating processes consume a significant amount of energy in most countries, making it imperative to have cost-effective and efficient systems for producing power, as well as for cooling and heating. An ORC system that incorporates a SAHP and FPCs is the subject of this study, which delves into its practical implications. A dynamic simulation model has been developed using the TRNSYS software to analyze the performance of the micro-trigeneration system. Take a look at its potential uses in homes and compare it to a PV/T-SAHP, a hybrid power system [27].

Key studies on Solar-assisted Cooling and Heating Technologies are summarized in Table I, which gives the details of the technologies, methods, solar components and environmental conditions examined. Even though the integration of solar energy improves system efficiency and sustainability, there are still problems in optimizing configurations, adapting systems, and validating performance over different climates that need to be solved.

Table 1: Summary of Recent Studies on Solar-Assissted Heating and Cooling Technologies

Reference	Technology	Method / System Studied	Solar Component	Environmental Conditions	Compliance / Notes
Abid et al., (2025)	Solar aided absorption cooling.	Evaluation of exergy and energy in LiBr-H_2O and LiCl-H_2O nanofluid absorption cycles including single-effect, series-flow double-effect, and parallel-flow double-effect.	Absorption system (Simulation EES solar heat input).	Change in the nanoparticle concentration; Cooling capacity 1000 kW.	Simulation-based; No explicit compliance reported.
Feng et al., (2025)	Solar-assisted SOFC–GT power system with waste heat recovery.	SOFC-GT merged cycle and sCO2 Brayton cycle and ORC to generate more power.	Solar Power Tower (SPT) integrated with sCO_2 Brayton cycle.	Waste heat availability; High-temperature SOFC exhaust.	Thermodynamic performance analysis; Compliance not specified.
Celik-Toker & Kizilkan (2025)	Solar-assisted multigeneration (electricity, refrigeration, hydrogen).	Solar tower + sCO_2 Brayton cycle + ORC + VCRC + PEM electrolyzer + TEG.	Solar tower (primary energy source).	Variable solar radiation levels.	Thermodynamic modelling; No specific compliance stated.
Zhao et al., (2025)	Solar-relevant cooling/heat pipe technology.	Experimental analysis of heat pipe–evaporator coupled cooling system using heat/mass transfer factors.	Indirect solar relevance (heat pipe systems used in solar cooling).	Inlet air RH and dry bulb temperature.	Laboratory correlations developed; Compliance not reported.
Liu (2024)	High-flux	Study on heat dissipation	None (no solar	High heat flux,	Not applicable;

	electronic cooling (not solar-specific).	challenges in high-power electronic systems.	component mentioned).	miniaturized electronics.	Not directly solar-assisted.
Abdullah & Polus (2022)	An absorption chiller that uses solar energy.	TRNSYS simulation of flat plate collector system powering 4.7 kW LiBr-H_2O absorption chiller.	Flat plate collectors (10 collectors × 2 m^2) + 1 m^3 storage tank.	Summer conditions in Erbil; Real system validation.	Verified with existing installation; TRNSYS-based.
Yaïci et al., (2021) [23]	Solar-assisted heat pump + ORC micro-trigeneration.	TRNSYS model of SAHP + ORC; compared with PV/T-SAHP for residential heating/cooling/power.	Flat plate collectors (FPC) and PV/T system.	Residential energy demand scenarios.	Feasibility evaluation; No compliance standards given.

6. Conclusion and Future Work

Solar-assisted cooling and heating technologies aim to reduce energy consumption and greenhouse gas emissions in the residential sector, where these three essential services are still in high demand. The present study gives an insight into the various systems that use solar-assisted technologies starting with active and passive solar water heaters, then continuing with desiccant-based cooling and thermally driven chillers and also indicating their critical components that make their operation possible. A number of worldwide initiatives, including IEA-SHC Tasks 25 and 38, have helped bring solar-assisted refrigeration systems to fruition, including their comprehensive design, performance evaluation, and market readiness. On the other hand, these systems still face some challenges like dependence on the environment, large capital outlay, serviceability, and small supply range. To perform the whole process of removing the barriers and other challenges, it will be through the progressive system optimization, integration, and long-term performance enhancement that innovation can be the factor required. Future research and development into solar-assisted HVAC systems should account for the fact that these technologies have a ways to go before they are fully scalable, reliable, and efficient. New materials, better integration, smart control, and hybrid designs can help to a big extent. Massive demonstrations and prolonged field studies will be very important in speeding adoption and making sustainable energy used in dwellings the norm.

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