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Overview of Solar Assisted Cooling Technologies

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Abstract

Traditional air conditioning devices or vapor compression devices are the major consumers of power in epochal buildings. Public environment problems arise from the vapor compression device, like greenhouse gases emissions and also heat waste. The adaptation of solar energy elements to the vapor compression device will reduce these problems. The buildings sectors account for 30-40 % of the consumption of energy of world and the manufacturing sector is the most energy-intensive sector. Solar energy is the most appropriate clean energy source which is utilized in cooling, heating and electricity generation in the building sector. Solar refrigeration is a cleaner and price-effective technology, solar chilling provides environmental advantages, including decreasing major grid request and shifting load during maximum usage and reducing the emissions of greenhouse gases. The paper discusses the various solar technologies of refrigeration that can be used to provide the necessary cooling and cooling effect of solar energy.

Keywords: absorption system; solar cooling; solar absorption; solar absorption refrigeration; solar collector**.**

ABBREVIATIONS

A.C.: Activated Carbon

AHP: Absorption Heat Pump

CNG: Compressed Natural Gas

COP: Coefficient of Performance

CPC: Compound Parabolic Concentrator

DCS: Desiccant Cooling System

DFA: Direct Flow Absorber

DNI: Direct Normal Insolation

DOAS: Dedicated Outdoor Air System

ECOS: Evaporatively Cooled Sorptive Dehumidification System

EHS: Enerworks Heat Safe

ETC: Evacuated Tube Solar Collectors

ETHPA: Evacuated Tube Heat Pipe Array

EUAC: Equivalent Uniform Annual Cost

EV: Expansion Valve

FPC: Flat Plate Collector

G. A.: Genetic Algorithm

GAX: Generator Absorption Exchange

GHI: Global Horizontal Irradiance

HGAX: Hybrid Generator Absorption Exchange

HGETSC: Water-In-Glass Evacuated-Tube Solar Collector

HPA: Heat Pipe Array

HPG: High Pressure Generator

HX: Heat Exchangers

IFPC: Improved Flat-Plate Collector

IRR: Internal Rate of Return

LCOR: Levelized Cost of Refrigeration

LFR: Linear Fresnel Reflector

LPG: Low Pressure Generator

MAC: Mechanical Chiller Capacity

NCPSC: Nanofluid-Based Concentrating Parabolic Solar Collectors

NPV: Net Present Value

OWHE: Oil/Water Heat Exchanger System

PB: Payback Period

PTSC: Parabolic Trough Solar Collector

PVT: Photovoltaic Thermal System

RE: Root Mean Square Error

SAC: Solar Absorption Cooling

SDEC: Solar Desiccant Evaporative Cooling

SD: Solar Dish Collector

HDCC: Hybrid Solar Desiccant-Compression Cooling

SEER: Seasonal Energy Efficiency Ratio

SF: Solar Fraction

SHC: Solar Heating and Cooling

SOFC: Solid Oxide Fuel Cell

SWH: Solar Water Heater

TPTC: Solar Transparent Parabolic Through Collector

TSS: Transient System Simulator

UPETSC: U-Pipe Evacuated-Tube Solar Collector

VARS: Vapor Absorption Refrigeration Systems

1. INTRODUCTION

Solar energy is one of the most major sustainable energy sources. In Comparison to other sources, solar power can be described by the reality which it is obtainable, almost, anywhere, moreover, it is neat and has no poor impacts on the atmosphere. It could be used in one of the next two methods: by converting irradiance to electric power, by utilizing photovoltaic cells, or by converting irradiance into frontal thermal power utilizing collectors. Climatic conditions decrease the level of solar irradiance that hits the Earth's surface before dissipating about 20% to 30% of the incident light and adjusting its spectrum. After crossing meantime, the atmosphere of Earth, about one half of the solar radiation is in the visible electromagnetic spectrum with the other half is mostly in the infrared and ultraviolet spectrum [1].

Iraq, due to the high temperatures encountered, an important quantity of electric power is employed in houses for conditioning of air. Due to its proximity near the solar-built region, the solar irradiance rate and the air-conditioning demand for commercial constructions simultaneously approach peak rates. Iraq obtains a large quantity of energy from the sun more than (6.5-7) kWh/m^2, in comparison to the United States that is 3.6 kWh/m^2 and Europe's 2.5 kWh/m^2 [2]. The refrigeration systems that depend on Solar radiation have a great possibility where the solar radiation is obtainable all year round [3]. The advantage of utilizing solar power for the units of air conditioning is that the solar radiation availability and the demand for cooling have reached peak rates simultaneously and relatively.

2. SOLAR COLLECTORS

2.1.Flat Plate Collectors

It is one of the major shapes of collectors today. The flat plate is firstly invented to meet the need for the system of solar water heating and was later used to produce solar air conditioning. The elements of collectors of flat plate types are: a transparent cover or shell, absorber, frame and insulator as shown in Fig.1. Only a low quantity of energy released from the absorber that transfers through the cover, while the transparent cover impedes the wind from transporting the heat collected by convection. The frame and cover keep the absorber from snow and rain. Typically, aluminium and galvanized steel used for manufacturing the frame materials [4]. The insulator helps reducing the loss of heat by conduction. Insulator materials are typically mineral wool or polyurethane foam, and in some cases materials of mineral fibre such as rock wool, glass wool or fiberglass have been used. Materials such as Glass are solar radiation transparent with short-waves and absorbent for long spectrum re-irradiance from absorbing materials or absorbers of black plate forms. The infrared irradiance is absorbed by glass from the black plate and emitted in different directions, part is released to the black plate. The irradiance again is absorbed by black plate and the temperature continues to rise until an equilibrium is found between short-wave energy gain and long-wave energy loss. The collectors of flat plate types are employed for heating to a temperature of around 90°C for heating of places or water. Parts of them are successful till on the days with clouds.

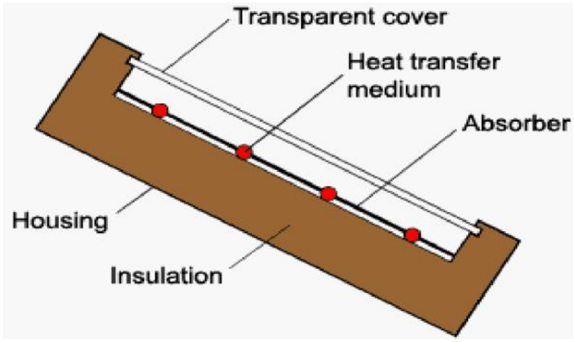

Fig. 1: Components of flat plate collector [4]

Gupta et. al [5] estimated the output analysis of office construction solar refrigeration in existence of flat plate collector with square structure of 15 m length and width. The building with height of 3.5 m and a total ground area of 225 m^2. The building was split into five areas with a north-facing orientation. The study was conducted by the simulations of a standard building of office assumed to be situated at four various cities, covering four climate areas in India, including Ahmedabad (dry and hot), Bangalore (moderate), Chennai (humid and warm) and Delhi (composite). Outcomes showed that the peak solar fraction was 0.71, 0.75, 0.77 and 0.78 for dry and hot, mild, warm and humid and composite environments, respectively. Main power reserves were larger about 55-62% for the moderate climate (Bangalore) and lower about 44-55% for (Chennai) that was warm and humid. It was in the range of 54-62% for the dry and hot weather (Ahmedabad) and for the composite weather (Delhi) it was about 51-61%. The solar collector of the flat plate shape in existence of nanofluid of water/silver has been analysed in MATLAB [6]. They stated that there was a better understanding between observed and expected amounts at various circumstances and rates of flow. The flat plate solar collector has been used to exchange traditional AC in seven rooms of lecture of the UGM Department of Engineering Physics **by Widiharto et. al** [7]. In Engineering Physics, the peak solar radiation was 4,802 kWh/m^2.day. The theoretical solar power attainability from the database of NASA was obtained utilizing Homer by chipping altitude and latitude location of the Department of Physics of Engineering. The studied cooling loads in lecture rooms of Engineering Physics was 15.63 kW. The average *GT* was 4.802 kWh/m^2·day, where it the solar radiance effectiveness per day was supposed to start at 8 a.m. till 4 p.m. (8 hours), so 4.802 kWh/m^2·day = 4.802/8

= 0.6 kW/m^2). The planned system's performance coefficient (COP) was around 0.84 that could utilize other flat plate collector kinds with every region identical to each value of efficiency.

Hussain et. al [8] proposed an experimental and computational estimations for the traditional refrigeration of collectors of flat-plate type for monitoring the overheating at recession situations. Experiments and computations were performed on a commonly Enerworks Heat Safe (EHS) domestic collector of flat-plate type combined with a back-situated channel of air. Theoretical estimations were carried out using a numerical model of three-dimensional finite-volume verified versus an experimental work conducted by the researchers. They noticed that the collector incorporated with a better-designed back-situated channel of air refrigeration and a regulation valve at the opening of outlet could be capable for supplying acceptable heat transfer levels and sustain the peak absorber plate temperature over a reasonable limits of stagnation situations. From the experiments performed, it was shown that the optimum volume of the air-channel back-mounted collector could be identified with a right tilting angle, associating to it the overheating of the collectors could be managed in a passive way under stagnation circumstances.

Aman et. al [9] established a solar-powered aqua-ammonia absorption cooler of power 10 kW. The aim of his study was to optimize the absorption chiller output that could be used with a leading origin of lower temperature like solar power for residential air conditioning purposes. In order that estimating the effectiveness of the residential refrigeration device, both energy and exergy analyzes were performed. The test confirmed that the absorber was the most exergy loss (63%) accompanied by the generator (13%) as well as the condenser (11%). It was noted that reducing the temperature of absorber and condenser to the ambient temperature did not considerably affect the total output of the system. So, the absorption chiller of ammonia water with heat provided by a collector of a flat plate type with environment air refrigeration of the condenser and absorber could be used for small-scale applications. Also **Mezher et. al** [10] built, installed and operated a prototype of solar refrigeration device using the flat plate collector. The studied device displayed a chilling power of 0.15 ton with a performance coefficient of 0.48, and the obtained minimum temperature of evaporator was 14.2 °C. The outcomes provided a better explanation for the usage of methanol as a refrigerant with the solar absorption device, and the device could operate in a continuous cycle of operation. That analysis provided a fundamental explanation for the solar refrigeration device design. The study outcomes were employed to model a one-ton air cooling device utilizing solar power and the refrigerant used was the methanol. While **Bux et. al** [11] concluded that the flat plate collector water heater (SWH) could be efficiently utilized in summer to produce cooling influence by using Vapor absorption cooling cycle.

Gandhi& Arakerimath [12] evaluated the refrigeration effect of the solar water heating unit and the vapor absorption cooling system using a commercial flat plate collector of 100-liter solar water heating in India. The system consisted of an absorber plate where the radiation dropped after passing through two 4 mm thick transparent covers with space 1.5 cm. They concluded that by using the vapor absorption refrigeration system, the solar flat plate collector water heater (SWH) could be used effectively in the summer to achieve refrigeration effect. The maximum temperature drop at the evaporator was 7 to 8 °C, while the actual COP of the system was approximately 0.78 compared to the peak device COP of 3.11 and the additional cooling loop cost was very small.

2.2. Evacuated Tube Collector (ETC)

Evacuated tube solar collector (ETC) is widely used worldwide because of its higher thermal efficiency in addition to high working temperature in comparison to solar collector of flat plate type. ETC efficiency is significantly improved by the existence of vacuum between the evacuated tube collector (ETC) absorber and cover. That is primarily because the decrease of heat loss due to conduction and convection. The basic elements of the (ETC) collector are the evacuated tube, manifold, heat pipe and header pipes as seen in Fig.2 [4]. High power absorption rises the values of solar fraction and instant efficiency. There are a variety of evacuated tube collector designs. The simplest method includes a flat plate with a flow pattern connected to the cylinder of evacuated glass. The evacuated tube absorbs solar power [13].

Fig. 2: Components of evacuated tube collector [4]

Badar et al. [14] created a theoretical steady state prototype to test the single vacuum pipe collector thermal output with coaxial tubing (kind of direct flow) combining both of single and two-phase flows. The assumption in the analysis was that the flow was laminar and that the Nusselt number proposed to be stable for the total laminar range (Re < 2300) to predict the convective heat transfer coefficient corresponding to the fully developed temperature and velocity profiles. At better vacuum status (10-5 mbar), the estimated efficiency profile to the flow of single phase diverges greatly from the experimental work with the temperature of collector, but suitable for the conduction of gas within the envelope of glass at a so lower pressure (<< 1 mbar) because of the identical enhance in the gross coefficient of heat loss (U-value). The incidence and spread of condensation and flow boiling within the pipe of collector at the condition of saturation was assumed for the flow of two-phase. The simulation outcomes showed that in case of flow of liquid-single-phase, the efficiency of collector reduced with the decrease of mass flow. As soon as the liquid approached the point of boiling at a specific rate of mass flow, no substantial decreasing of output was noticed, which was consistent with the experimental test. **Zambolin et. al** [15] conducted a thermal output comparison in two styles, the typical glazed flat plate and the collectors with vacuum tubes, where the collectors have been mounted in parallel and checked under similar operating circumstances. The first study aim was to compare outcomes in steady-state and quasi-dynamic examination ways. In addition, the aim was the description and comparison of the daily energy quality of the two collector styles. The so-called input/output diagram was an efficient means of defining and evaluating daily results, so it has been used to plot the gathered solar energy versus the daily fallen solar radiance. exams were conducted under many conditions to create various traditional uses (space heating, hot water, solar cooling). Outcomes were also viewed with regard to daily efficiency against daily mean decreased temperature variation: that allowed the two collectors comparison properties to be represented when working at varying circumstances, in particular at a broad variety of angles of incidence.

Enhanced protocol for the empirical evaluation of ocular performance in evacuated solar tube collectors had presented by **Zambolin et al** [16]. Evacuated tube solar collectors were typically a lot efficient and effective than traditional collectors of flat plate type, especially at lower radiation and temperature. It is therefore the most effective solar collector. It is widely employed for water heating, the cooking, solar refrigeration and electrical power production [17, 18].

Gao et al. [19] presented a comparison for power output of a U-pipe evacuated tube solar collector (UpETsc) and a water-in-glass evacuated tube solar collector (WGETsc). The requirement and activity of designing WGETsc comprising thermal mass has been experimentally supported. The output of WGETsc and UpETsc devices with the same curve of efficiency has been compared. The mean WGETsc was lower than the thermal efficiency of UpETsc; the storage energy of WGETsc was 25–35 % lower than that of UpETsc due to the thermal mass effect of fluid for rates of flow of 10–70 $kg/h.m^2$. The thermal mass of fluid has been ignored, so the utilized energy production would be overestimated in computational models. Furthermore, the rate of flow might also influence thermal performance of device. The optimal design for rate of mass flow at Beijing for UpETsc and WGETsc was approximately 20–40 $kg/h.m^2$ and 20–60 $kg/h.m^2$ in respective case; a high rate of flow would decrease energy accumulation efficiency.

In India, the Thermosyphon concept used in modern evacuated solar water heater, was used for residential applications, where the vacuum of evacuated tubes decreases the convection and conduction heat loss. As the air was extracted from the solar tube to create a vacuum, this decreases the heat loss by conduction and convection from the tube inside. As an outcome, temperatures of wind are cold and had a lower impact on the evacuated water heater performance. The effect of less loss of heat was the quick water heating in comparison to the solar water heater of flat plate collector [20]. also, **Selvakumar et al** [21] carried out experimentally locating of the evacuated pipe collectors at various inclination angles. The tube comprised of borosilicate glass. The tube diameter was 47 mm, and the length was 1500 mm. The heat loss convection coefficient might differ with regard to the angle of inclination. As heat transfer by radiation was used in the evacuated pipes, the coefficient of heat loss convection could not cause a significant drop in temperature. The temperature measurements obtained from the experiments showed that the outcome was not different with respect to the angle of inclination.

The position of tilting angle of the solar collector of evacuated tube type has been investigated by **Al-Mashat et. al** [22] using Al_2O_3/water nanofluid at Baghdad environment from the start of April till the March end 2012. It was discovered that the optimum tilting angle was 41° yearly for ETSC. The enhancement in collector performance by using nanofluid particles was studied by **Hussain et al** [23] using silver material (Ag (30 nm)) + distilled water and the Nanofluid titanium oxide material (ZrO_2 (50 nm)) + distilled water as the operating fluid. For high working fluid thermal conductivity, the solar productivity would be improved relative to the performance of the distilled water. Two nanoparticle kinds have been utilized to be evaluated at various concentrations (0, 1, 3 and 5 % vol.), rates of flow of mass (30, 60 and 90 $lit/hr.m^2$) and the filtered water used as the focused operating liquid. The experiments outcomes showed that, the concentration at 1 percent vol. explained a negligible effects relative to distilled water. In addition, the nanofluids utilization of (Ag (30 nm) + filtered water) and (ZrO_2 (50 nm) + distilled water) as an operating fluid may enhance flat plate collector thermal performance relative to distilled water, especially at the higher inlet temperatures. Nanofluid solar collector performance of (Ag (30 nm) + distilled water) was higher compared to the nanofluid (ZrO_2 (50 nm) + distilled water) because the low size of silver particle in comparison to zirconium oxide and high silver thermal conductivity. Nanofluid type was a main agent in boosting transfer of heat as well as enhancing the evacuated pipe collector efficiency.

2.3.Photovoltaic Thermal Collector

Newly, the best professional technology of solar has been utilized to transform solar radiation to thermal energy and electricity that combined into a single device, the titling photovoltaic thermal (PVT) device that combines photovoltaic and components of solar thermal. The fundamental idea of the device is the heat generation from photovoltaic (PV) units and the thermal energy generated is utilized segregately by devices of solar thermal. Fig.3 displays the basic model of the system of PVT. Various operating fluids are utilized in the PVT system for its cooling, like water and air [24, 25].

Shahad et. al [26] made a comparison between the performance analysis of the PV unit and the solar photovoltaic/thermal (PV/T) device that cooled by water at different rates of flow of (0.5, 1, 1.5, and 2 L/min) which included the thermal and electrical efficiency. The experimental study was conducted at Hilla, Iraq's climate conditions (32.46 °N, 44.42 °E). Solar radiation, front and back slab temperatures of solar device PV and PV/T, ambient air, wind and flowing water velocity were calculated. Moreover, the PV unit and PV/T solar system's electrical power was calculated. The results indicated that the PV/T solar system's peak boost proportion of electrical efficiency relative to the PV module in March was 18.86 % at 2 L/min flow rate. The least boost in flow rate in July was 13.36% at 0.5 L/min. The PV/T solar unit's average gross efficiency improvement ratio relative to the PV module was 81% at a rate of flow of 2 L/min in March, and the least enhancement was 74.08% at the 0.5 L/min rate of flow in July. The cooling water peak mean temperature increase in March was 11.28 °C at the 0.5 L/min flow rate, and the least rise in July was 2.69 °C at the 2 L/min flow rate.

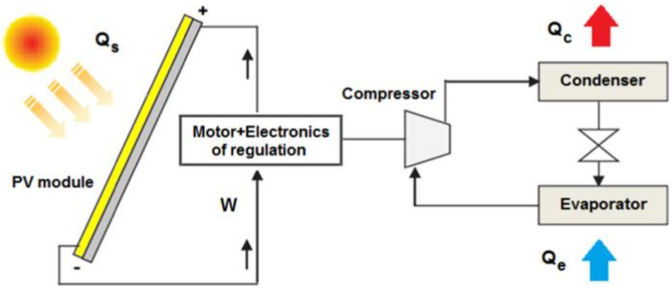

Fig. 3: Solar photovoltaic collector [25].

A new photovoltaic thermal (PV/T) collector named serpen-direct with a PV/T serpentine unit has been designed by **Sachit et al** [27]. Theoretically, The PV/T output for serpentine-direct flow was validated and compared to the standard serpentine flow system using MATLAB Simulink. Factors like outlet temperature of the water, temperature of cell and PV and thermal efficiency were measured at various rates of mass flow ranging from 0.01 kg/s to 0.1 kg/s and two-level solar radiation 300 W/m^2 and 700 W/m^2 in respective case. Results have shown that the serpentine-direct flow absorber structure gave a better performance for the system than the serpentine flow construction with the same test conditions. peak PV and thermal efficiency were 12.51% and 57.66%, respectively, for serpentine direct flow and 12.43% and 54.68%, respectively, for serpentine flow system.

The impact of SiC, SiO_2 and TiO_2 Nanoparticles in existence of water as their base liquid on the electrical and collector thermal efficiency of a photovoltaic thermal (PV/T) type fitted with a pour intrusion had been estimated by **Hasan et. al** [28]. Their device comprised of four pipes in parallel situation as well as 36 nozzles which pump the liquid into the PV/T collector's back directly. The PVT collector's electrical efficiency was evaluated in dependence on the PV/T absorber plate average temperature. A higher electrical and thermal performance was reported by the SiC/water nanofluid array. Thermal, electrical and the combinedly photovoltaic thermal efficiency was 12.75%, 97.75% and 85% respectively, with 1000 W/m^2 solar radiation, 0.167 kg/s rate of flow and 30 °C atmospheric temperature. In addition, the P_{max} of PV/T in existence of Nanofluid SiC improved by 62.5% in comparison with the traditional PV unit.

2.4.Parabolic Trough Solar Collector

Parabolic trough solar collector (PTSC) is a type of matured solar concentrator which is a parabolic shape and mounted as a linear fashion and assembled in existence of a mirrors grid to shape a reflector of parabolic form and a focal length receiver and connected with a laser beam [29] as shown in Fig.4. Synthetic oil is utilized as a fluid for transfer of heat because its ability for having a high temperature load in the range of 100–500 °C. It is a longitudinal concentrated collector [30]. The sun' s reflected irradiance absorbed by the receiver. Such intense irradiance heats the liquid which travels into the absorber pipe as a consequence of which the irradiance is transformed to thermal power. PTSC is the collector that has typical high temperature [31, 32].

The solar radiance power harvesting idea by the use of nanofluid-based concentrating parabolic solar collectors (NCPSCs) has been introduced by **Khullar et. al** [33]. A comparison has been made between the computational outcomes and the scores of experiments of traditional concentrating solar parabolic collectors at identical circumstances. It has been noticed that keeping the exterior circumstances constant like temperatures of ambient/inlet, speed of wind, solar radiation, rate of flow, ratio of concentration, etc. the NCPSC had approximately 5–10% greater efficiency in comparison to the traditional parabolic collector. The theoretical outcomes have clearly shown that the NCPSC have the absorbing solar radiation power ability greater sufficiently than the traditional parabolic trough.

Hamzah et. al [34] manufactured an interrupted absorption cooling unit under Hillah weather in Iraq. The absorption system comprised of parabolic trough solar concentrator (PTSC) was utilized as a reflector of solar mirror with 2 m^2 aperture area, carbon steel tube, a vacuum glass envelope with a 1.5 in diameter as a receiver, a tank for water storing, condenser and an evaporator. The solution of ammonia-water (NH_4OH) was utilized as an operating fluid with various concentrations (25%, 30%, 35%, 40%). The quality and vision of the system were assessed during a year from May 2014 to July 2015 by measuring pressure and temperature at various components of the unit. The peak temperature and pressure was approximately to be 120ºC and 12 bar in respective case. The performance coefficient was about from 0.01 to 0.09.

Fig.4: The Parabolic Trough Solar Collectors in two different tracking positions [36].

De Risi et. al [35] conducted an innovative Solar Transparent Parabolic Through Collector (TPTC) operating in existence of nanofluid that is gas-based. The usage of directly emitted nanoparticles made it possible to compensate for the relatively low coefficient of heat transfer of gases by increasing the surface of interchange. The suggested solar collector was modeled in order to facilitate the physical unit characterization behavior on the hypotheses of quasi-steady state circumstances. After that, the design utilized for running an optimizing protocol for identifying the TPTC major geometric and operating variables. Computations have explained that the peak thermal efficiency of TPTC was 62.5%, with a 650 °C exit temperature of nanofluid and a nanoparticle volume concentration of 0.3%. Where Nanoparticles contribute to a greater thermal conductivity for the flow and high transfer levels of heat from the warm pipe to the operating liquid resulting in a low absorber temperatures and low thermal losses [36].

Ammonia-water absorption refrigeration device with parabolic trough collector, which concentrates solar power in a receiver tube for heating water was tried by **Stanciu et. al** [37]. Time-dependence of refrigeration load was regarded for a domestic two-story home cooling. The outcomes stated that there was a particular size for storage tank combined with a particular collector dimension that guarantee the longest continual refrigeration device working at considered permanent rates of mass flow within the device. Also **Fan et. al** [38] performed heat transfer models and laboratory experiments to determine the quality of PTCs. Efficiencies of collector of 40-55% were achieved under various weather circumstances. Primary energy ratio (PER) amounts have been determined and compared for the powered solar absorption heat pump (AHP) system and the system of oil/water heat exchanger (OWHE). The outcomes revealed that the running of the device of PTC was not price-active in overcast times at lower direct normal insolation (DNI). In days with clouds and higher DNI duration at a short time (e.g. 2 hours) and the OWHE device working was higher than the AHP device working, where the device of the AHP required more preheating power before the device working**.**

The low residential silica gel-water adsorption refrigeration efficiency of a device in existence of a reflective concentrator parabolic collector domain powered adsorption (silica gel-water) refrigeration device at hot and arid climate experimentally investigated by **Reda et. al** [39]. The system consisted of a 36 m^2 entire space, an 8 kW refrigeration power adsorption cooler with silica gel-water. The findings of the domain test of the summer period showed that at daily solar irradiance ranging from 21 to 27 MJ/m^2, the utilized collectors had a higher and often constant efficiency of thermal power. The daily output of solar collectors through the device operation varied from approximately 50-78%. The adsorption cooler output showed 0.41 mean daily (COP) of the chiller. While **Wang et. al** [40] made computations by TRNSYS utilizing the calculated meteorological information and the predicted load of building with the particular construction and building form, the daily and monthly activity demonstrated that solar irradiance had a major effect on the useful energy proportion given by collectors, A higher immediate solar fraction at the sunshine period while a so lower mean daily solar fraction has noticed from the computation outcomes, that implied that energy storage was essential to boost device quality and minimize supplementary utilization of energy.

2.5.Compound Parabolic Collector

Winston was the first one that designed the Compound Parabolic Collector (CPC). CPC collector comprises of a receiver as well as a flat or a pattern of tubular shape at the centre point of the concentrator parabola. Since various parts of parabola are needed for making up the collector, so it is named as " compound " as seen in Fig.5. It is a non-image concentrators set that do not do a sun concentrator portrait. The normal concentration ratio is 2–3. Indeed, the concentration ratio of about 6 may be selected, that shows a large area of surface and so may not be used [41]. A narrow literature on the use of nanofluids in the CPC method has been analysed.

Abdul Ameer et. al [42] carried out a theoretical and experimental research for a solar-powered continuous flow absorption refrigeration unit using a compound parabolic concentrator (CPC) solar collector and two couples of working fluids, LiBr-H_2O and diethyl ether-ethanol. The experimental outcomes revealed that the peak thermal efficiency at approximately 12:00 p.m. at 21st of each month from January to June (0.48, 0.512, 0.57, 0.606, 0.618 and 0.67) respectively when the rate of flow was about 0.0277 kg/s and the efficiency of thermal energy boosted (0.5, 0.512, 0.58, 0.63, 0.637 and 0.69) at the rate of flow of water of 0.0377 kg/s. In addition, the temperature of hot water was 98 °C and 94 °C at the two rates of mass flow, respectively. In the mathematical model, the thermal efficiency at 12:00 p.m. for the 21st of each month ranged from (0.67-0.73) to the rate of flow of (0.0277 kg/s) for a ratio of concentration of about 4.5 at the same climate conditions.

Fig. 5: Compound Parabolic Collector (CPC) [42]

Lu et. al [43] experimentally evaluated thermal output of the Nanofluid CuO/water for the collector. Impact of rate of padding, fluid based type, concentration of mass of nanoparticle and working temperature on the properties of heat transfer of evaporation of the open thermosyphon has been evaluated and explained. Experimental outcomes showed that the appropriate padding ratio of the evaporator was 60 % and the open thermosyphon thermal output improved mostly in existence of a rise in operating temperature, the highest coefficient of heat transfer reached was approximately 30 % at concentration of Nanofluid mass of 1.2 %. Likely, there is another work carried out experimentally by **Liu et. al** [44] presented a thermoeconomic assessment technique for the CuO/water nanofluid cooled water storage system, that presented thermodynamic output impact on cost savings, and a cooled storage system was tested, which could save more than 15% of electricity costs without any increase in energy usage. The findings explained that the disparity between apex and; power prices of valley was not the only variable in economic outcomes; the storing device thermodynamic output was the most significant aspect, and a very huge price difference was an obstacle to its utilization, rather than more cost reduction. All these provided a new path for the thermal storing technique applying. On the other hand, **Abdul Ameer & Shahad** [45, 46] built and designed a two-dimensional compound, parabolic, concentrator solar collector of mild steel sheet with serpentine copper tube fixed on a flat plate absorber for Iraqi climate. The two-dimensional parabolic compound concentrator was built to have a concentration ratio of 5. The serpentine copper tube was attached to the absorber plate of flat mild steel. There was black coating on the copper tube and flat plate. During the August, September and October months, the collector was tested in Iraqi weather. The results explained that the peak absorber temperature has been noticed in the August month due to higher solar radiation of (120°C, 95°C and 82°C) than other two months (Sept. and Oct.) respectively, maximum reflector temperature and aperture cover surface temperature were measured in August (69°C and 43°C) respectively and the absorber surface temperature peaks after maximum solar radiation.

2.6.Solar Dishes

Solar dish collector (SD) is shaped on the basis on a point focusing concentration system with a dimensional ratio of concentration of approximately 3000. The concentrators are positioned on a frame having a system of tracking with two-axis in order that the dish obeys the sun as shown in Fig.6 [47]. It produces so higher focused irradiance, so it is appropriate for a greater temperature receiver like the heater of Stirling engine, Brayton-cycle gas receiver, thermochemical reactor, etc. The high operating temperature results in a greater efficiency [48]. The pressure and temperature are typically around 200 bar and 700 °C in respective case [49]. The Solar dish concentrators have an ability for generating powers of about 0.01 to 0.5 MW [50]. Also, solar power had utilized for producing of electricity, cooling and heating of a space and hot water for domestic applications, for a mercantile tower in Tehran in a hybrid solid oxide fuel cell (SOFC) system, a solar parabolic dish, a LiBr-H_2O absorption cooler device of a dual-acting type and an organic Rankine cycle [51]. On the other hand, **Prado et. al** [52] constructed, characterized and evaluated the output of a concentrator of solar dish type to desalinate water. The unit can be created by fitting an equatorial mount for facing the sun and mirroring a satellite. Also, installing the system of distillation by utilizing a flask of glass, a pipe of copper and a pipe of silicone. The device has been characterized by experiments on the basis of the key variables that describe the concentrator. Whatever, in order that evaluating the system power. The computer has been used for thermal power simulation and also it is experimentally advocated. Lastly, in order that analyzing the concentrator quality of the solar dish with regard to the desalination of water, tests were performed with the injection of saline solution semi-continuous sort including of 0–4% of salt concentrations of sea. The distilled water production approximately between 4.95 kg/m^2.day (0%) and 4.11 kg/m^2.day (4%), as an outcome of colligation impacts. The concentrator of solar dish was therefore constructed in existence of a system of simplified distillation which provided adequate drinking water per square meter to satisfy the daily requirements of as minimum two adults.

Fig 6: Photograph of Solar Dish [47]

Concentrator dish collectors got further attention because of their higher thermal performance at temperatures of middle and higher levels. They display a greater importance compared to different concentrators kinds due to their high concentration proportions for applications of a greater temperature [53]. Many researches have therefore done on the modelling for achieving higher efficiency of thermal power, a greater temperature of output and, as a result, Nanofluids technologies have already stated for boosting the solar dishes thermal output [54].

2.7. Linear Fresnel Reflector

Linear Fresnel reflectors (LFRs) are a promising concentration technologies to temperatures more than 400 °C. Although they display several similarities to the parabolic trough collectors, they are more beneficial in comparison with the PTSC [55]. They are combined with main and minor reflectors. The main reflectors are flat or curved in existence of longitudinal grooms on a single surface. The groom angle is chosen according to the suitable spectrum of the incident beam radiation [56].

The receivers are minor reflectors; typically, evacuated pipes; LFRs work with a tracking devices of single-axis but only the main reflectors proceed [57]. So they had some advantages in comparison to the parabolic trough collector; LFRs have a less optical performance compared to them [58]. Too little tests have done for examining the LFRs efficiency at utilizing the Nanofluids. **Bellos et. al** [59] tested numerically the efficiency of LFR thermal power in existence of the Nanofluid Syltherm 800/CuO for the 2, 4 and 6% concentration by using CFD technique. Collector reflectors are flat mirrors of a 27 m^2 total pure area of aperture, while the supplementary reflector has a parabolic form. The temperature of inlet was between 350 K and 650 K for the study. They noticed that the thermal efficiency improvement was approximately 0.28 % when nanofluids were used as a working fluids.

3. HYBRID AIR CONDITIONING

The hybrid devices are the collection of a novel devices and an existent operating systems. Usually, the hybrid air-conditioning system was built for improving the vapor-compression model. Hybrid air conditioning types include solid desiccant and liquid desiccant, solar adsorption, cascade vapor compression with absorption cycle style solar-biomass hybrid system and solar absorption and vapor compression dependent hybrid air conditioning.

3.1.Solar Absorption and Vapor Compression System Based Hybrid Air Conditioning

Hybrid solar absorption and vapor compression devices was shown to be benefit from everyday solar radiation for energy savings and support for green energy use. Fig.7 shows the fundamental setup of the solar absorption of hybrid type and vapor compression unit. Always, the unit work independently by two various methods depending on the available weather conditions. Solar energy can be collected throughout the sunny day, and the absorption cooler can supply cooled building air. The advantages are the increased use of clean energy and energy savings. In comparison, at cloudy or rainy days, the device is based only on the vapor compression unit, that provides electricity from the power plant. Therefore, the arrangement adds to the environmental impact of greenhouse gases [60]. In 2010, **Al-Alili et al**. [61] identified the absorption cycle that solar-powered at utilizing the Transient System Simulator (TRNSYS) software and the Abu Dhabi Typical Meteorological Year 2 data. They employed evacuated pipe collectors for powering an ammonia-water refrigerator of 10 Kw capacity. They observed that cost savings had been decreased by up to 24.5 %.

Leite et al. [62] provided the adsorption cooler characterization and sizing as a portion of a 20 kW central air refrigeration system to cool a rooms collection covering a field of 110 m^2. The device consisted of a storing tank for chilled water storage provided by an activated Carbon methanol adsorption cooler, a storing tank for storage of hot water, supplied by solar power and natural gas, and a fan-coil. They obtained 10,300 L of cold water with temperatures ranging between 10 °C and 14 °C. Regarding the average entire daily radiation value at João Pessoa (7°8' S, 34°50' WG) and a solar-powered reproducing heat cover equal to 70%, the expected performance coefficient (COP) of the adsorption chiller was found to be around 0.6. Moreover**, Lin et al**. [63] stated that economy and thermodynamics are major factors for achieving 15 % of energy savings from total energy consumption through a variety of operational techniques.

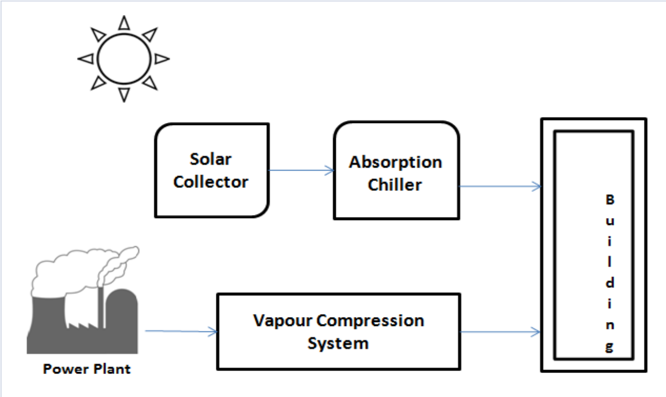

Fig.7: System configuration without low temperature storage [60]

Different operating modes has been analyzed in separate cases by **Zhang et al** [64] for estimating the optimal size and the working methods for decreasing service billing costs at Austin field, Texas. Three traditional control methods (full storing tank, cooler seniority and storing tank seniority) with limits on the peak chillers number operating at on-maximum and off-maximum durations that were simulated. The findings showed that the 3.5 million gallons (13,249 m^3) storage tank had the shortest single payback period and the estimated overall capital cost was within the budget. Full storage technique was identified to summer period and a seniority storage technique to winter season was chosen. The yearly bill cost saving was calculated to be $907,231 and the easy payback period was 12.5 years. However, experimental work has been performed by **Boonnasa & Namprakai** [65] to calculate the optimum potential for storing cooled water and the related working technique for air cooling charges for various electricity tariffs. It was concluded that the most suitable was the cooled water storing with a 450 RT (2 units) chiller working continually, 9413 RT-h storing thermal energy and 5175 m^3 volume. The capacity and peak demand of the mechanical chiller (MAC) could be reduced by more than 2 times and 31.2% in respective case. It could move power usage by 35.7% from the on-maximum to the off-maximum times. The economic results revealed that the payback period(PB), the internal rate of return (IRR) and the net present value (NPV) were 10 y, 21% and 0.834 MUS$ relative to the new factory, with PB, IRR and NPV being 1.8 y, 66% and 1.28 MUS$ in respective case.

Yin et al. [66] analysed various operational techniques by adding various forms of cooling modes to the University of Shanghai Jiao Tong. They examined a solar absorption model in existence of a fan coil refrigeration form as well as a solar absorption ceiling refrigeration form, illustrating that the ceiling cooling device provided higher potential results where performance enhanced by 23.5%. Moreover, **Al-Alili et al.** [67] analyzed the effects on the economic and environmental evaluation of various collector slopes. The results indicated that the highest energy gain from the seasonal collector was when the angle of slope was equal to the latitude of the local collector. Also the results showed that, for tilt angles, the amount of energy produced by the supplementary heater rose higher than the 24.4^{o} even though the energy output from the collector was too identical to that of low angles of tilt.

Rosiek et. al [68] identified the quality of the air-conditioning device that is solar-assisted with two reservoirs mounted in the Research Center of Solar Energy (CIESOL) building. The device majorly consisted of a collector matrix, an absorption chiller that was driven by hot-water, a cooling tower, two tanks for hot water storage, a supplementary heater and two storages for cold water. The outcomes indicated an accurate ANN's estimates with a Root Mean Square Error (RMSE) with less than 0.70% and virtually zero variance, that could be regarded quite acceptable. While a monitoring strategy conducted by **Marc et al.** [69] which was a static designing for evaluating cooler behavior with a cooling power of 30 kW (EAW LB30 refrigerator operating with lithium bromide and water), and it cooled four halls in the University building on Island of Reunion, that was located in a tropical weather and established their area of activity. The results from experiments were examined and the steady-state cooler prototype and the identifying way were established. The strong accordance between both the estimation and the outcomes of experiments guaranteed the design to be used not only for the design of the installation, but also for the monitoring and control of its performance. **Albers** [70] proposed simplification of the numerical process by taking a few hypotheses as no backup device was regarded, electricity for pumping and storage effects were ignored and no energy material was regarded. He deduced from that simplification, the seasonal energy efficiency ratio (SEER) was greater than 0.75, the electrical efficiency was 35% greater and the water usage decreased about 70%.

Most profitable storage of lower temperature was storage of refrigerated water where **Rismanchi et al**. [71] Obtained 35% of cost savings for office buildings in Malaysia for a total of 100–2000 tons of cooling (TR) (352–7034 kW) for two full storing tanks and load levelling storing tanks strategies.

3.2. Solid and Liquid Desiccant Air Conditioning

Solar desiccant refrigeration system has been extensively studied and developed throughout the world over the last few years. It was identified that, it is an eco-friendly and, in some cases, economically advantageous, where it can boost indoor air quality and decrease power consumption [72].

The simple solar desiccant refrigeration device typically comprises the desiccant cycle and the evaporative system. The traditional solar desiccant evaporative refrigeration system (SDEC) consists majorly of: (1) A solar module consisting of a collector, a tank for water storage and a backup heater; (2) A desiccant module that consists of a desiccant wheel, a heat reproduction coil, desiccant materials (utilizing silica gel), and a flexible heat exchanger of air-to-air type; and (3) evaporative chillers. The scheme of the standard SDEC device is explained in the Fig. 8 [73]. The SDEC device deals the provided air sensible and latent load individually. The solar desiccant refrigeration unit operating concepts is that, the desiccant element in the desiccant wheel is firstly dried and the solar desiccant refrigeration unit heats outdoor air (1–2), The dehumidified operation air is then chilled for temperature of atmospheric by an air-to-air sensible heat Exchanger of rotary type (2–3). The processing air is then chilled by the evaporative chiller (3–4) and finally have supplied for the cooled space. In the reproduction air stream, the going back air is chilled by an another evaporative chiller (5–6) for the heat exchanger efficiency enhancing. Then it is heated to the reproduction temperature by means of a heater of air (7–8). The process of continual air dehumidification sates the material of desiccant that should be reproduced for function continuation. The thermal power is thus provided for the reproduction heat coil in reproduction applications. A backup heater is normally incorporated when there is inadequate solar power **[74]**. Actually, a number of scientific articles have focused at the efficiency of the world's solar desiccant refrigeration system.

Khan et. al [75] used a solar regeneration desiccant wheel instead of a cooled water coil based dehumidifier. Computations were performed by utilizing EnergyPlus on a reference media of construction of office for examining the solar power contribution to the consumption of the Devoted Outdoor Air System (DOAS) overall power assisted by desiccant wheel with a radiation refrigeration unit. A comparison has been made between the desiccant dependent DOAS and the DOAS assisted by cooling coil incorporated with the radiation refrigeration unit for assessing the output of the system and power savings effect. Computations have been made for various solar collector areas to assess main power savings. Findings suggested that from 7.4% to 28.6% of energy savings (depending on the different areas of collectors) would be accomplished due to solar reproduction in DOAS assisted by desiccant. The effect of distinct areas of solar collector on the energy savings potential was also identified. While **Al-Ahmedi** [76] provided a study on the rising request for air cooling in Iraq due to economy and business growth, which has enhanced the request for buying power over the last years. It was also focused on decreasing fossil fuel consumption and introduced a solar refrigeration system in Iraq that would be economic and environmentally friendly. It was deduced that each area had its own features and demands, as in Iraq case, and the DEC would be a viable option for the Iraqi area, because its cheapness and had a best efficiency too. Solar heating technique has matured. It was very significant to choose a heat reservoir with a good design and volume, because it enhances the system efficiency.

Ma et. al [77] examined the possibility of three distinct solar-assisted cooling units for standard office buildings with medium size at the whole eight Australian capitals utilizing the entire EnergyPlus construction simulation software. The study included: solar absorption cooling (SAC) unit, hybrid solar desiccant-compression cooling (SDCC) unit and solar desiccant-evaporative cooling (SDEC) unit. The analysis showed that the SDEC mechanism was the less power consumption in Darwin and Brisbane, with an annual energy savings of 56.9% and 82.1% in comparison to the traditional VAV system.

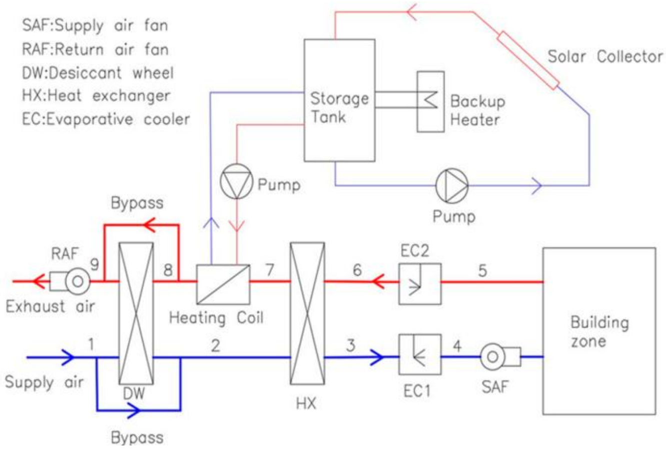

Fig. 8. The scheme of the basic solar desiccant evaporative refrigeration system [73].

Safizadeh [78] studied the experimental and theoretical analyzes and enhancement of a novel solar/waste heat-assisted air cooling device for implementations in tropical areas using heat-driven solar/waste two-stage membrane dehumidification and desiccant technologies. The better performance of the dehumidification with two-stage and a system of energy recovery was accomplished if, as many as possible, dehumidification and cooling have been performed by the membrane system. On the other hand, the evaporatively chilled sportive dehumidification system (ECOS) was necessary for achieving the recommended state of dehumidification, while the evaporative refrigeration loop in the ECOS system had an important impact on the enhancement of dehumidification quality and the decrease of air temperature. The evaluation of the devices showed that the total electricity usage was decreased by 50% relative to that of the traditional air conditioning unit. While **Rafique et al.** [79] performed a theoretical evaluation of evaporative refrigeration devices that were desiccant-based at five areas in Saudi Arabia. It was noticed that the thermal COP of device was in the range of 0.275-0.476 focused on various situations. Also they stated that an improvement of 15% in evaporative chiller performance achieved an improvement of 15-25% in the unit thermal COP. Moreover, **Santori et al**. [80] performed by using MatLab/Simulinka a dynamic multi-level solar adsorption refrigeration device simulation for establishing associations between various input parameters and climate data. The Fourier analysis deduced that the most important variables influencing the COP of the device were the surrounding air temperature, the condensation power of the adsorption cooler, the cooling effect of the refrigerator and the power of heating that used by the refrigerator.

3.3. Adsorption Air Conditioning

Adsorption refrigeration system is an eco-friendly technology for air conditioning. Because the adsorption refrigeration unit needs a source of thermal energy of lower grade type with a minimum electrical power, so it can therefore be considered as an alternative for conventional vapor compression technologies mostly used in residences and other locations. Incorporating adsorption refrigeration units with solar power or wastage heat will decrease the need to fossil fuels, doing them possible suggestions to a net zero power construction process [81].

Berdja et. al [82] conducted an experimental revelation of a refrigerator prototype utilizing a cooling adsorption pipe collector where solar energy could be absorbed directly. Depending on the cooling impact and the power absorbed in the collector-adsorber, the thermal COP of the model was found about 0.49 and depends on the cooling impact and the solar irradiation, the COP of solar collector was found equal to 0.081. Also, **Palomba et. al** [83] presented the hybrid adsorption-compression device principles made in Modelica by utilizing the free software Dymola. It was noticed that, in order to properly manipulate the advantages of the implemented cascade setup, the adsorption device would have a typical refrigeration capacity of 50% greater than the typical compression cooler refrigeration capacity. The conclusions drawn also stated that the created model would be appropriate for assessment, without excrescent mathematical attempt on the quality of the model, and a relevant average to technologic analysis. The adopted language particularity and the chosen libraries of open source contribute to the higher systems usability, which could easily be modified for various settings and hybrid systems. Moreover, **Farman** [84] investigated an improvement for the Solar Adsorption Cooling performance with Genetic Algorithms (GA). The successful model of the generator has led to fine process and improved outcomes. They also paid a lot of concern to the design effect on the device performance considering several variables which have an impact on the adsorptive solar ice maker system performance. That variables involved Geographic Variables, Operational Factors, Concentration Variables and Environment Variables. The unit was checked for the duration from May to August 2012. The peak solar adsorption device (COP) was about 0.49 by normal computation and about 0.4883 by using genetic optimizations, in order that there is a consistent harmony between the conventional approach and the genetic optimization. The proportion of concentration of X0 kg Methanol/kg (A.C) of the current solar adsorption method was about 0.29 as an outcome of experimental research and 0.286 as a result of genetic optimisation. The peak desorbed mass was nearly 600 g Methanol/3 kg (A.C) that was of great performance to form 1 kg of ice at 900 W/m^2 mean solar irradiation in Iraq. On the other hand, **Alkhair et. al** [85] experimentally evaluated the parameters which have the most successful effect on the activity of the solar air cooling unit. These main constraints are very attentive in a system's performance and efficiency, like the cycles number till the unit approaches a stable state condition, the period of switching between loops, and the transient period required to the unit to be stable between two loops. The device was experimentally examined in various steps for determining the real loops number in which the unit could achieve the optimum operating conditions. The loops number required to the unit for achieving the stable working circumstances was found to be 5 cycles (about 70 minutes), and the optimum switching time was noticed to be 5.3 minutes, after which the produced temperature of the cooled water outlet could be nearly stable at approximately 17.3ºC.

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4. VARIOUS DESIGNS OF ABSORPTION REFRIGERATION UNIT

In reality, in many countries, absorption cooling devices are utilized for air conditioning in medium and larger capacities. Several of them work with water vapor or heat from the industrial operation. Furthermore, only a few of them actually operate with solar energy. There are several kinds of solar refrigeration technologies utilized around the world.

4.1. Single-Effect Absorption System

The easiest and most widely utilized model is a single-acting absorption cooling unit. Two design structures utilized with dependence on the operating fluid. Fig.9 explains a single-acting model utilizing non-volatile absorbents such as LiBr /water [86].

A single-acting absorption cooler is a viable option for domestic considerations. The condenser and absorber cooling medium may be air or water, but most of the marketed available are cooled by water. The heat supplied of high temperature for the generator is utilized for evaporating the refrigerant existed in the solution (released for the condenser environment) and is used for heating the solution from the temperature of the absorber (released for the absorber environment). The heat exchanger enables the absorber solution to be preheated prior to the generator entering by usage of the heat from the hot solution which leaves the generator [86]. **Marcos et al.** [87] developed a modern way for optimizing the COP for air- and water-chilled absorption coolers. This approach calculated the impact temperatures of condensation on COP and the variance in the concentration of solution, specifically specifying the limit of crystallization for various strategies. Also, **Gonzalez-Gil et al.** [88] constructed an adiabatic absorber with flat sheets that allows LiBr-H_2O absorption systems air chilled by air at Madrid to operate far from crystallization limits and at higher temperature of surrounding for LiBr/H_2O absorption systems air chilled directly. A strong consistency existed between the projections and the outcomes of experiments for most of the absorber's properties operating factors. Lastly, it was noted that the suggested absorber structure allows LiBr/H_2O absorption systems air chilled for operating away from crystallization bounds till at about 40 °C temperatures of circumstances.

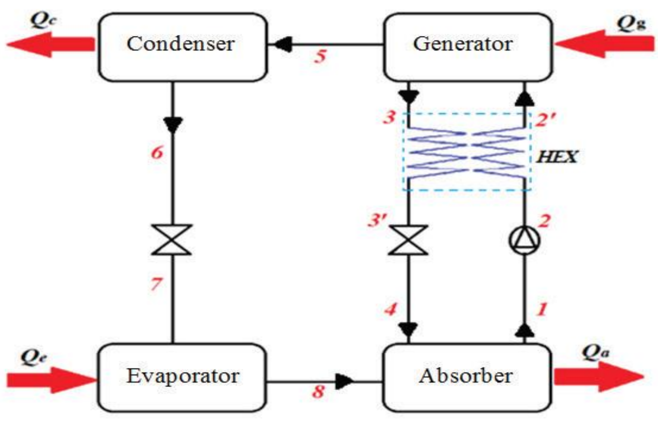

Fig. 9: A single-acting LiBr/water absorption cooling system [86]

Only a little experimental studies were performed to investigate the efficiency of the residential absorption cooler cooled by air. **Gonzalez-Gil et al**. [89] assessed the efficiency of an absorption cooler cooled directly by air in summer 2010, centered on test outcomes of many days in Madrid. The system was working effectively, with COP of about 0.6. Refrigeration capacity ranged from 2 kW to 3.8 kW, that accounted for around 85% of the total output of the prototype. The temperatures of cooled water varied mainly between 14°C and 16°C with 12.8 °C minimum calculated value. The system was capable to fulfill an average of 65% of the refrigeration request corresponds to 40 m^2 space. During around one hundred hours of process no signs of crystallization were found. Moreover, a 4.5 kW absorption cooler that cooled by air powered by flat-plat vacuum collectors was tested by **Lizarte et al.** [90] that air-conditioned a 40 m^2 room situated in Madrid with a 42.2 m^2 overall area of aperture, an exterior plate heat exchanger of 25 kW and a volume of storage of 1.5 m^3. The daily outcomes of the whole attempt also have been given. No problems of crystallization of solution increasing in the prototype until at the temperature of generator feed of 109 °C. The least temperature reached in cooled water was about 14.3 °C and 0.53 and 0.06 average values of COP and SCOP in respective case. Moreover, **Uçkan et. al** [91] presented a solar-powered single-effect and used lithium bromide as an absorber and water as a refrigerant at 35.17 kW cooling power, consisting of an evacuated pipe collector using 95 m^2 space of aperture, and a collector's inclination of 30° with the horizon. The hot water storage capacity was 3 m^3. The system cooled a ground area of 270 m^2. The outcome was that the COP of the chiller oscillated between 0.69 and 0.67 between 8:00 a.m. and 14:00 pm, afterwards, the COP of chiller gradually decreased from 14:00 to 18:00 between 0.69 and 0.57. The cooler absorption average output was noticed to be 0.63. The unit optimization results revealed that the unit provided a building air cooling of 270 m^2. The mean absorption COP was about 0.62.

4.2. Double-Effect Absorption System

The absorption refrigeration unit for the dual-acting sequence is displayed in Fig. 10. The system comprised of an evaporator (ev), absorber (a), condenser (c), weak solution pump (p), solution heat exchangers (HX1 and HX2), high pressure generator (HPG), two solution expansion valves (EV2 and EV3), low pressure generator (LPG) and two refrigerant expansion valves (EV1 and EV4). There are three various levels of pressure, which are HPG, LPG and pressure of evaporation. The level of the absorber inlet and outlet pressure is the same as the inlet of the evaporator, and the level of the outlet pressure and the condenser and LPG inlet and outlet at the same level of pressure, while the HPG is at a different pressure. Heat of higher temperature from an exterior root supplied for the generator to first effect. The vapor refrigerant generated in the second-acting generator is condensed at higher pressure. The rejected heat is utilized to create another refrigerant vapor from the first-acting generator solution. The device design is regarded as an absorption device with a series-flow-dual acting [92]. A dual-acting absorption device is regarded to be an integration of two single-acting absorption devices with a COP_{single} value. In one unit of external source

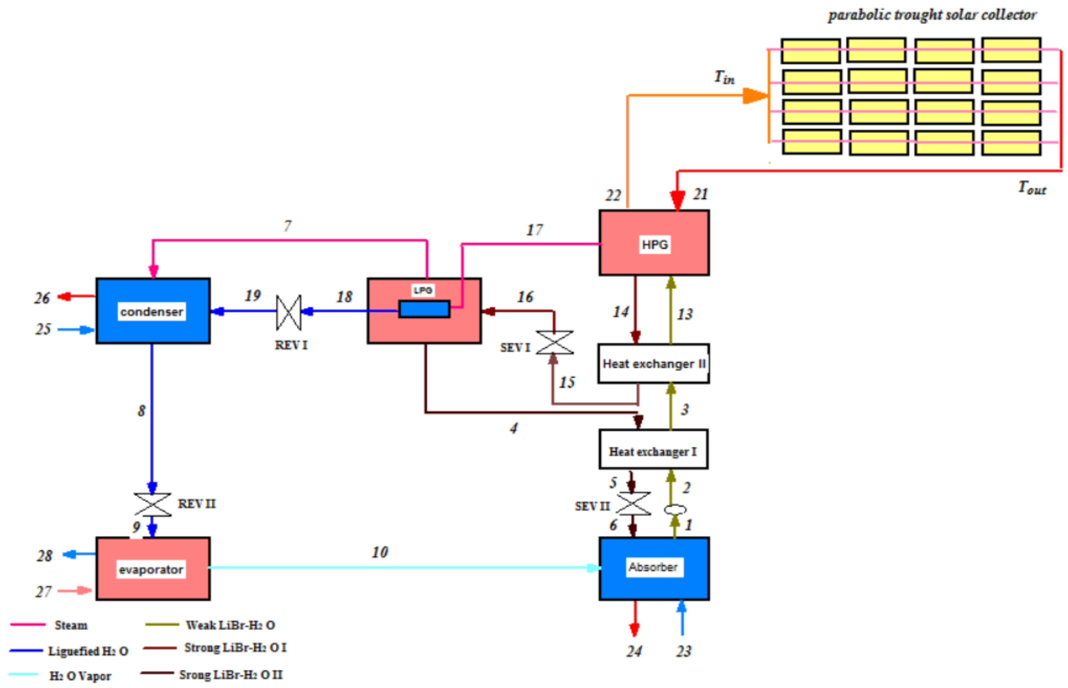

Fig.10: The schematic illustration of solar assisted series flow dual acting absorption refrigeration device [92].

input of heat, the refrigeration impact generated from the first-acting generator refrigerant is 1COP_{single}. In any absorption device of single-effect, the condenser heat released can be presumed to be roughly equal to the refrigeration power acquired. So the second generator's heat supply is 1× COP_{single}. The refrigeration impact generated by the second-acting generator is (1×COP_{single}) ×COP_{single}. Hence, the dual-acting absorption COP is COP_{double} = COP_{single}+$(COP_{single})^2$. In accordance with the analysis, absorption unit with dual-acting has a 0.96 COP at 0.6 equivalent single-acting device COP [93].

Petela et. al [94] noted through his computations that, the refrigeration capacity performance increases at different levels, greater than 34 W per 1 m^2 of collector, by leading temperature changing of the chiller during the season of refrigeration. It is also probable to be greater than doubling the refrigeration impact for a few hours with regard to a specified procedure for control of temperature. While **González et. al** [95] used a solar air collector that was dual-channel single-pass through the experimentation. Based on the results obtained, the modeling and computation tasks were carried out to assess the options of utilizing hot air offered by the solar air heater (SAH), when working at summer circumstances in a closed cycle, a heat exchanger of air-to-water type is used for producing a domestic hot water (DHW). The device was tested by emulation in two various structures for the Valladolid (Spain) case study at the duration from May to September at various flows of air in the closed cycle. Findings revealed that daily savings could alternate from 27%-85% across various working conditions; a setup in which water of make-up was supplied to the heat exchanger was favorable; at a designated storing tank of heated water of the least possible size. Also **Cascetta et. al** [96] analyzed a three various kinds of collectors (FPC, ETC and PTC) and two various coolers: single acting used with FPC and ETC collectors and (LiBr-H_2O) dual acting to PTC collectors. It was deduced that, in the analysis of summer months, the PTC collectors have been more effective than the ETC and FPC collectors due to the additional boiler did not operate during the months of summer, letting a minimum energy usage to air refrigeration. At winter study, collectors of ETC type were greater effective than PTC and FPC, with a primary savings of energy of 58%.

4.3. Multi-Effect Absorption Refrigeration Cycle

The major purpose of a greater impact system is for raising the efficiency of the device when a heat source of high temperature is present. The phrase "multi-effect" implies that the process must be designed where heat removed from a stage of great-temperature is employed as an input of heat at a stage of lower temperature for producing another refrigeration impact at a stage of low-temperature as shown in Fig.11 [97].

Azhar & Siddiqui [98]. Investigated and compared the Vapor Absorption Loop Triple Effect and Single and Double Acting by using LiBr-H_2O as an operating pair. The compressed natural gas (CNG) and liquefied petroleum gas (LPG) were chosen as the energy origins because the system with triple-effect need heat with quietly high temperatures. The experiment was conducted for various temperatures for evaporator and condenser; the absorber temperature has considered to be equivalent to the major condenser temperature. Both LiBr salt temperature and concentration in the generator with high-pressure to which the heat was provided differed simultaneously with set pressures/temperatures in the medium and high-pressure condensers. the Peak COP of the collector with single effect loop was noted to be 0.7 to 0.86, and for double effect loop was 1.2 to 1.55, while it is found to be up to 2.16 in the triple effect loop, also the improvement in the double effect loop COP reached 56 to 81% of the single acting loop, and for the triple acting was 103 to 152% greater than that for the single loop. Moreover, the COP reduced with a temperature rise of major absorber/condenser and rises with an evaporator temperature rise. The dual acting loop operational cost was between 57 and 68% of the single acting loop and that of the triple acting loop was between 60 and 75 % of the double effect loop and between 40 and 45% of the single effect loop while the triple effect loop was more effective, so it would be more cost efficient compared to single and dual acting loops. In another work for **Shirazi** [99], that focused on the combination of LiBr-H_2O single-, dual-and triple-acting absorption coolers with collectors. He observed that the SHC triple-acting cooler has the more power-sufficient and eco-friendly environment quality, led to decreases in the hotel's main energy consumption between 47% and 62% and cases of office building examination in comparison to the based traditional systems, more than 75% public funds would be required in order that the revealed systems could provide satisfying payback durations (e.g. within 2 to 6 years) , the parabolic pipe collectors and evacuated flat plate collectors have been proposed for such implementations and the chiller worked with a performance coefficient of about 0.9-1.1 at a temperature of steady supply of ~168 °C, generating 6-7 kW cooling. In addition**, Xu &Wang** [100] investigated the choice of good cooler to solar absorption refrigeration units with CPC. They utilized LiBr-water absorption coolers included a chiller with single effect, an absorption chiller double effect and a novel chiller with variable effect has been built. The unit of alternating acting has higher solar refrigeration fraction, low supplementary input of heat and solar efficiency with high value. The unit of single acting has middle solar fraction, high supplementary input of heat and middle solar efficiency. The unit of double effect has a low solar refrigeration fraction, low supplementary heat input and solar efficiency with low value. The wider area of the solar collector raised the solar cooling proportion and decreased the supplementary heat supply. The units of Variable and double effect has a higher mean solar efficiency with a wider area of solar collector, whereas the unit of single effect has a lower efficiency of average solar. The storing tank volume had a greater acting on the variable effect unit and the unit of double effect because of the high storing tank temperature.

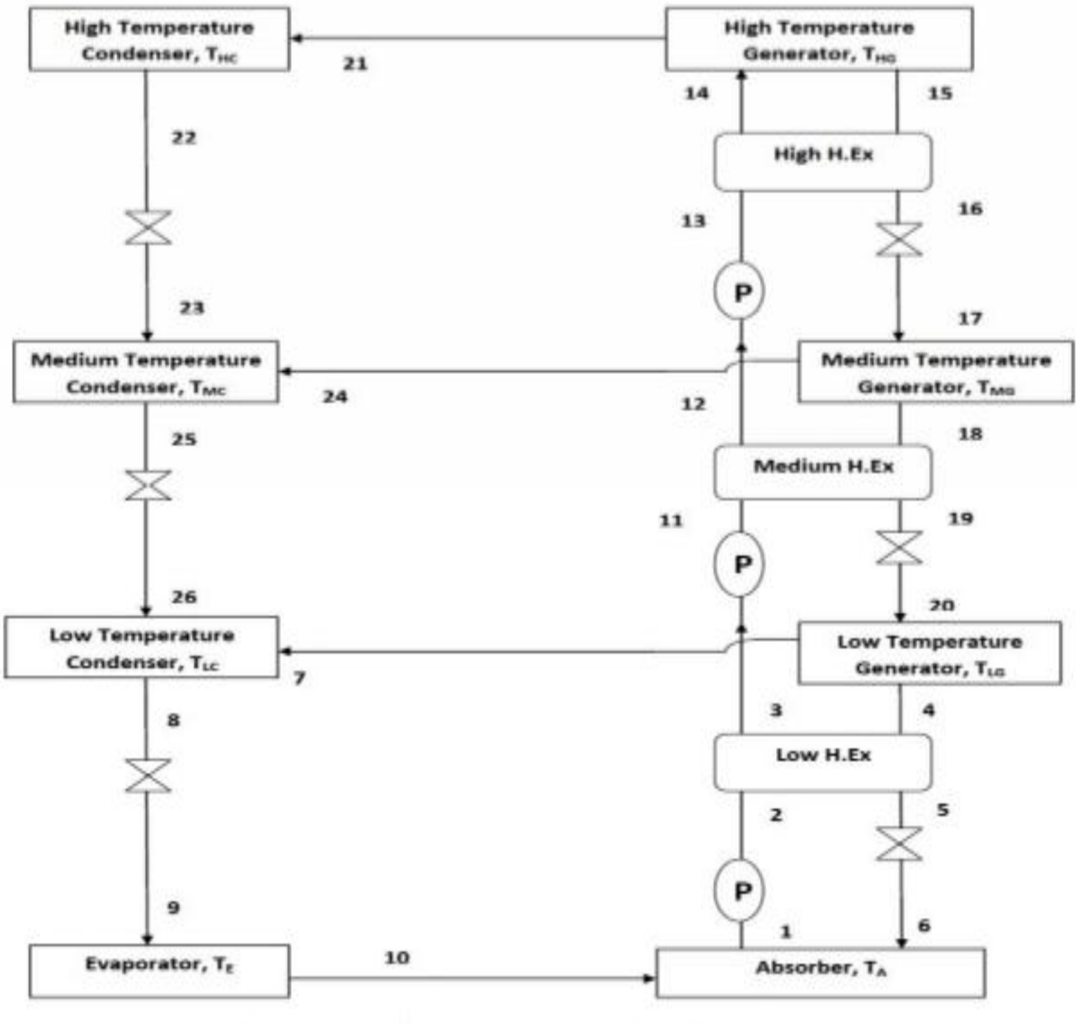

Fig. 11: A Triple Effect (Parallel) Vapor Absorption System [97]

4.4. Half-Effect Absorption Refrigeration Cycle

The scheme of the half-acting absorption device is illustrated in Fig.12. It comprised of two absorbers, an evaporator, a condenser, two generators, two pumps, two heat exchangers and three expansion valves. The system of half-acting absorption has two refrigerant-absorbent solution loops. The evaporated refrigerant is generated in the generator2 and then transferred to the condenser. At the condenser, the refrigerant condenses and then expands in the expansion valve3 after that, the refrigerant evaporates at the evaporator. As the refrigerant absorbs thermal energy from the ambient, the refrigeration operation is generated at the evaporator. The evaporated refrigerant is transferred for the absorber1. The vapor combines with the weak solution produced by the generator1 and a heat releases from the lower pressure absorber1. Afterwards, the weak solution is injected to the lower pressure generator1 by crossing into the heat exchanger1, which boosts the solution temperature. Portion of the refrigerant evaporates in the lower pressure generator1 and leaves straight to the higher pressure absorber2. At the higher pressure absorber2, the low concentrated refrigerant absorber is generated and drained to the higher pressure generator2 by going into the heat exchanger2. The loop repeated in the generator2 [101].

Dwivedi & Mishra [102] improved the output of the system with half-effect by adding the Loop Heat Pipe (LHP) between the high absorber, high generator and the condenser (which had been eventually substituted by the LHP) for heat exchange with intra-cycle. The computations demonstrated that COPI and COPII enhanced by 64% and 27%, respectively. The temperature of the LHP condenser T_{Cond} was also dependent on the temperature of the generator T_G. At higher T_G levels, the rise in COPII was greater than that in COPI. The mean heat leakage from the Q_{Leak} LHP was approximately 14.38 kW and the mean heat used by the Q_{Cond} LHP was determined to be 79.52 kW. In addition, **Hussein** [103] developed and simulated the unit of absorption cooling using a solar receiver of flat-plate type with a mixture of ($LiBr$-H_2O) as an operating fluid, and to choose the best possible form of absorption refrigeration system that is suitable for use in Iraq. The weather conditions for the city of Erbil has been chosen. Performance Coefficient(COP) for single, double (series and parallel), triple and half absorption cooling impacts were computed and configured. Programs of TRNSYS and EES were used to simulate and represent COP Estimation, hot water temperature and rate of heat transfer. The receiver effective field of solar flat-plate has also been calculated and optimized for five proposed areas (140, 150, 160, 170 and 180 m^2). The indicated results explain that the preferred form of the four absorption-chilling systems had a single effect with a COP of 0.80 at a temperature of generator 81 °C. The outcomes also demonstrated that the optimal field of the receiver of solar flat-plate was 160 m^2 since it had accomplished the peak cooling and consuming capability of the generator (50 and 62.5 kW respectively).

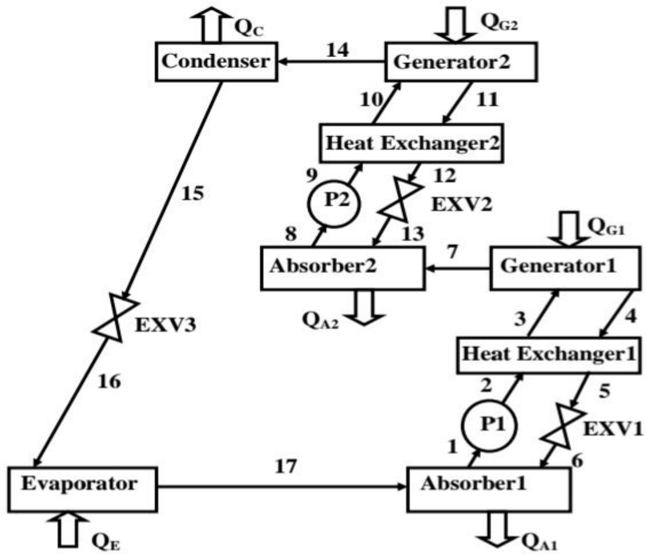

Fig. 12: A Half Effect Vapor Absorption System [102]

4.5. Absorption Refrigeration Cycle with GAX

The absorption loop with GAX cooling comprised of: generator (GE), absorber (AB), rectifier (RE), economizer (EC), condenser (CO), evaporator (EV), precooler (PR), throttled valves (TV) and a solution pump (SP). The variation between a typical single acting loop and GAX is the recovery of internal heat; the generator recovers a portion of the absorbed thermal energy, that results a thermal energy reduction that is providing in the system, raising the system COPth for achieving this impact, a couple of heat exchangers and a pump must be connected to the device if a hydronic cycle is used for transfer of heat. Fig.13 provides a graphical comparison between the conventional single acting absorption unit and the GAX unit used by **Mehr et. al** [104] who compared the absorption loop of GAX thermoeconomic output and a GAX hybrid absorption loop where a compressor has used for rising the pressure of absorber. For making that, the GAX (SGAX) and hybrid GAX (HGAX) absorption cooling loop for the ammonia–water has been compromised and configured from the thermodynamics and economics point of view. The studies of parameters have been executed and, with the genetic algorithm (GA) aid, the quality has been fine-tuned on the basis of the COP and the efficiency of the exergy and also the system product cost. Findings showed that while the HGAX loop shows improved output from the view point of both the first and the second thermodynamics laws in comparison to the GAX loop, the system product cost for the HGAX loop was higher. Under optimal weather conditions, the HGAX loop system product cost was estimated at $180.5/GJ, as well as the SGAX loop equivalent value was calculated at $159.1/GJ. The exergoeconomic analyzes also indicated that the condenser had the least exergoeconomic factor, f, in both models. Also influenced by nature, a new graphical draw was implemented for fuel demonstrated costs, cost of product, investment of capital, the cost of working and repairs and the costs accompanied with the destroy and loss of exergy in the components of the unit. In regards, due to the influencing by nature, a modern graphical diagram was introduced for demonstrating product costs, fuel costs, costs of operating and maintenance, capital investment and costs accompanied with the depletion and energy loss within the components of the device. **Barrera et. al** [105] investigated the analysis of the experimental examinations done with the advanced Solar-GAX absorption cooling device, configured for chilling capacity of 10.5 kW (3 ton) with the mixture of aqua-ammonia. The device developed to work at about 200 °C heat source temperatures, comprised of a generator and absorber of a falling layer kind and an absorber and condenser cooled by air of the finned tube type, which is a choice to areas with water lack. Temperatures of energy source of 160 °C have been developed to simulate the circumstances in which solar thermal concentration technology was used to provide heat to the system. A 3.17 kW partial load with a 0.15 COP have achieved when the Solar-GAX device was controlled at a 120 °C temperature of generator at a 200 °C generator operating temperature with a10.5 kW design power. The absorption device that was air-cooled has been tested at temperatures of ambient higher than 30°C. In addition, at temperatures of ambient 28 °C, a cooling power of 7 kW was reached, with such a 0.35 kg/min flow rate of ammonia mass and a rate of water flow 15 kg/min, for diluted solution temperatures at 140 °C, a 0.2 to 0.3 COP on the side of water and 0.25 to 0.45 on the side of ammonia was obtained under the conditions.

4.6. Absorption Cooling Cycle with Absorber-Heat-Recovery

It has been stated that the solution heat exchanger usage enhances the COP of system. The solution of absorber rich-refrigerant may be heated prior to the generator entering by removing thermal energy from the generator hot solution. The rich-refrigerant solution temperature can be enhanced greatly by adding an absorber-heat-recovery. Compared with GAX, the absorber is split into two parts. Energy is removed with a various temperatures. The lowest temperature part removes energy for the environment as expected. Therefore, the greater temperature part is utilized for the rich-refrigerant solution preheating as displayed in Fig.14. The generator heat input is therefore decreased which increases the COP [106].

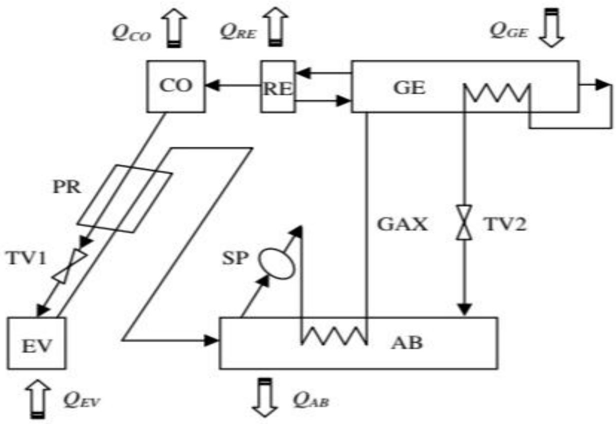

Fig.13. The absorption cooling loop with GAX [105]

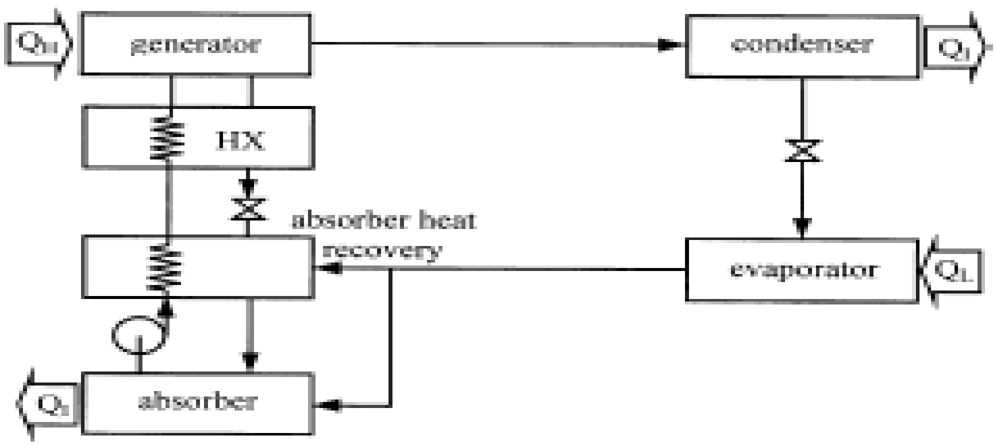

Fig.14. The absorption cooling system with an absorber heat recovery [111]

5. AVAILABLE WORKING PAIRS

There are available more than 40 refrigerant and 200 absorbent compounds. Table (1) provides a list of such potential working pairs for absorption systems.

Table 1. Possible working pairs for absorption systems [107, 108]

Refrigerant	Boiling point (° C)	Melting point (° C)	H_{fg} (kJ/kg)	Absorbent
Propane	−42	-188	428	Water , ethanol and Ethyl Ether
H_2O	100	0	2256	Salts / LiBr / Ionic liquid / LiBr based multi-component salt mixtures (single salt+ LiBr, binary salt systems +LiBr, ternary salt system+ LiBr) / $ZnCl_2$ / ZnBr / $LiClO_3$ / $CaCl_2$/ Acids / H_3PO_4/ H_2SO_4/ Alkali thiocyanates / Bases Alkali hydroxides.
NH_3	-33.34	-77.74	1369	$LiNO_3$ / H_2O / Alkali / $LiNO_3$ + H_2O / Sodium-Thiocynatc {NaSCN} / $MnCl_2.CaCl_2$ / Ionic liquid
1-propanol	97	-127	689	LiBr / LiCl / $ZnCl_2$ / $ZnBr_2$
Methyl chloride	-24.2	-97	406	DME / TEG
Methanol	64.7	-97.6	1100	H_2O / LiCl /Ionic liquid / LiI /LiBr / $ZnCl_2$/ $ZnBr_2$ / LiI. $ZnBr_2$/ LiBr.$ZnBr_2$ / H_2O. LiBr / LiCl. LiBr/ LiSCN
Ethanol	78.4	-114	846	LiBr / H_2O / LiI /LiCl / $ZnCl_2$ / $ZnBr_2$ / Tri /LiBr.$ZnBr_2$
Dimethyl ether	−24.9	-141	460	Water, ethanol, Acetone and Ethyl Ether
Isobutane	−11.72	-215.97	341.78	Ethanol and Ethyl Ether
n-Butane	−0.5	-168.53	385	Ethyl Ether, ethanol and water
Acetaldehyde	20.8	-123	584	Water , ethanol and Ethyl Ether
Methacrolein	68.4	-81	413.75	Water and ethanol
Low pressure freons				DMF / DMAC / / DMETEG / NMP / Ionic liquid / DMEU / MCL

6. CONCLUSIONS

Solar refrigeration is an inventive and appealing alternate to decrease the maximum energy consumption produced by the vapor compression devices undue utilization, particularly through the summer duration. The use importance of solar power is primarily because of the power concur need and supplying. In reality, refrigeration is needed at the availability of solar radiance in abundant case. Moreover, the vast solar technology plurality utilizes unharmed operating fluids.

The research addresses synthetically various facets of the topic of solar refrigeration. On the basis of a detailed literature review, different types of current technologies have been identified by utilizing of thermal and electrical choices. The rank of market and latest evolutions in solar refrigeration strategies have been reported. A suitable indicator for comparing different solar refrigeration systems have also been conversed. It is obvious that the whole solar refrigeration devices have a tremendous possibility because of the climatic and power benefits, such as power saving and reducing emissions of CO_2. The comparative analysis of the various thermal refrigeration choices indicates that:

1- Any solar assisted absorption cooling device output depends on many factors such as; Geographical position, solar-driven absorption cooling technologies and the available working fluid pair.

2- Several countries are trying to utilize renewable energy as a result of pollution problems, more costly and limited fossil fuel resources.

3- Solar power is the most available renewable power source, has been of significant interest due to its promising benefits. Because of the sunlight richness during the year, solar energy can easily be collected all over the world.

4- Although the solar photovoltaic device can provide both electricity and cooling, solar thermal cooling is so effective.

5- Solar refrigeration systems are utilized throughout the world for industrial and home refrigeration applications.

Such refrigeration devices are more appropriate in remote places or in islands where traditional cooling is stressful and solar power is always available. Such devices are also more appropriate than traditional cooling systems due to its pollution-free operating fluids (alternate to chlorofluorocarbons).

6- Double-acting absorption technology powered by parabolic trough collectors has the highest performance coefficient. Absorption chillers are a praised for their simple and quiet operation.

7- The adsorption loop is lower effective than the absorption loop but needs lower temperatures of heat source (usually between 65–90 °C). In addition, adsorption devices do not have moving elements and lower repair costs. The key dare to these devices is for increasing the adsorbent bed thermal conductivity and to withstand intermittent cycles.

8- Nanoparticles gives a greater thermal conductivity for the flow, so a greater rates of transfer of heat from the hot pipe for the operating fluid occur.

9- Solar dishes display a larger interest between different types of concentrators due to their high concentration ratios for applications of high-temperatures.

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