Utilization of Solar Energy for Cooling Applications: a Review

Utilización de la Energía Solar para Aplicaciones de Enfriamiento: una Revisión

Utilização de Energia Solar para Aplicações de Resfriamento: uma Revisão

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Summary. - Major portion of energy in the residential sector is consumed to provide the human comfort. The use of conventional energy resources creates the problem of global warming. Due to severe impact of released gases on the environment, there is needed to use the alternative energy resources to maintain the human comfort zone. The use of different solar energy conversion techniques is making a promising contribution to provide the clean energy. The purpose of this study is to provide an overview of recent advancement in the use of solar energy to provide the indoor climate comfort. The use of non-concentrating and concentrating conversion techniques are investigated in detail. The study also discusses about the enticements of solar energy to attract the investment in the merger of solar energy and human comfort industries.

Keywords: human comfort; solar energy; heating; cooling; solar thermal; humidification.

Resumen. - *La mayor parte de la energía en el sector residencial se consume para proporcionar el confort humano. El uso de recursos energéticos convencionales crea el problema del calentamiento global. Debido al severo impacto de los gases liberados en el medio ambiente, es necesario utilizar recursos energéticos alternativos para mantener la zona de confort humano. El uso de diferentes técnicas de conversión de energía solar está haciendo una contribución prometedora para proporcionar energía limpia. El propósito de este estudio es proporcionar una visión general de los avances recientes en el uso de la energía solar para proporcionar el confort climático interior. Se investiga en detalle el uso de técnicas de conversión no concentradoras y concentradoras. El estudio también analiza los incentivos de la energía solar para atraer inversiones en la fusión de las industrias de energía solar y comodidad humana.*

Palabras clave: *comodidad humana; energía solar; calefacción; enfriamiento; solar térmica; humidificación.*

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***Resumo**. - Grande parte da energia no setor residencial é consumida para proporcionar o conforto humano. O uso de recursos energéticos convencionais cria o problema do aquecimento global. Devido ao forte impacto dos gases liberados no meio ambiente, existe a necessidade de utilizar os recursos energéticos alternativos para manter a zona de conforto humano. O uso de diferentes técnicas de conversão de energia solar está dando uma contribuição promissora para fornecer energia limpa. O objetivo deste estudo é fornecer uma visão geral do avanço recente no uso da energia solar para proporcionar conforto climático interno. O uso de técnicas de conversão de não concentração e concentração é investigado em detalhes. O estudo também discute os atrativos da energia solar para atrair investimentos na fusão das indústrias de energia solar e conforto humano*

***Palavras-chave:** conforto humano; energia solar; aquecimento; resfriamento; solar térmico; umidificar.*

1. Introduction. - Environment Protection is the ultimate goal to save the world from catastrophic incidents which happened due to change in ambient conditions. Along with environment safety human comfortable is also on prime level to ensure better working in any field. Hence, due increase in demands of energy fluctuates energy prices as well as global temperature limits. Developments through all over the world produce significant changes on environment. Lifestyle of humans has been changed and sumptuous living standards required energy to perform all these actions. Greater energy demands create challenges at environment level to sustain the drawbacks of energy generation. Burning of fossil fuels produces hazardous gases in form of power plant's discharge; the same discharge in gaseous form produces air pollution which is the reason of many health issues. Impact of these gases on global warming is also alarming and need to be reduced due fluctuations in climates of entire globe.

The problem of dangerous globe climate fluctuations required reduction of fossil fuels burning and utilized renewable energy approaches for energy generations like solar, Wind etc. The renewable energy utilization for energy production is the only way to reduce the greenhouse gas emissions and mitigate the effect of climate changing. Figure 1 indicates the harmful effects of fossil fuel power plants on human society. [1] To reduce carbon emissions produced by burning of fossil fuel in Iran, hence several hybrid renewable energy systems have been utilized for electricity generation. The collection and evaluation of data been performed and concluded that hybrid energy configuration provide the intended results like price of electricity is .15$/KWh and 15.6% investment return. The study indicates three advantages like CO2 reduction, interest of stake holder and sustainable energy source. [2]

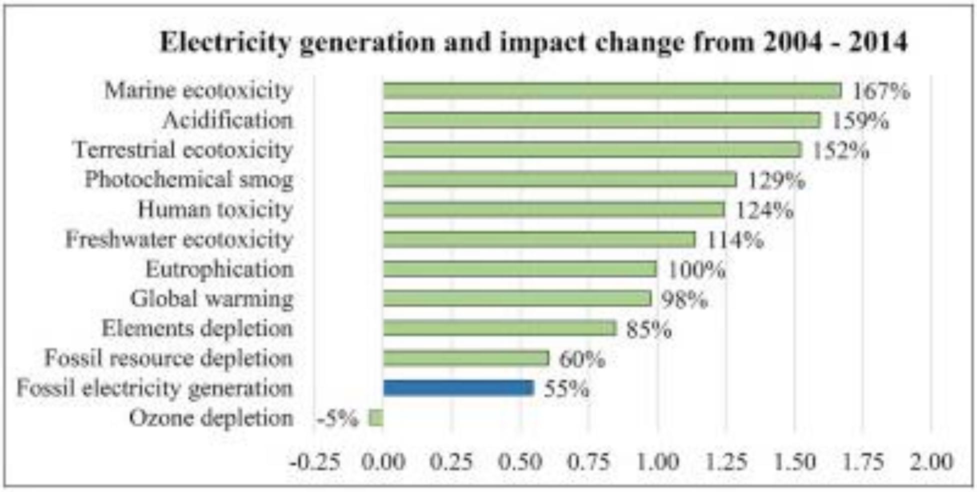

Figure I.- Fossil fuels impact on Environment [13]

Due myriad negative impacts on environment, increase in fuel prices and shortage of fuel compel governments to introduce new policies for adopting renewable energy for electricity generation. [3,4] Due consistent shortages in fossil fuel supply from reservoirs and due apex in carbon emissions, advanced countries are adopting renewable energy on large scale. [5,6]

2. Fossil fuels and Energy Shortage. – Dependency on fossil fuels needs to be reduced due adverse effects on environment, however peoples of policy making, and energy analysis divisions do believe in that utilization of renewable energy is the prime solution to mitigate emissions and generate energy. [7,8] most of carbon emissions relate with power sector but transport sector also

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played a vital role in using fossil fuels and producing CO2 emissions. [9] A research study performed in 2014 on Belgium to consider the shortages and excessive amount of electricity by fossil fuels and nuclear sector. It is concluded that Belgium should replace their current power production technology to renewable in 12 years else their assets would be depleted. [10] South Asian countries are largely depending on coal power generation due abundance amount of coal especially China, India etc. Extraction of coal from mines also produce hazardous impacts on society by releasing toxic gases like Carbon Monoxide (CO) etc and effecting air quality. Hence, such countries are shifting from conventional resources to renewable because they receive 5000trillion kWh insolation on yearly basis. [11,12]

Depletion of fossil fuels is an issue which needs to be addressed, utilization of fossil fuels in energy and transport sector gradually mitigates the reservoirs of fossil fuels. Oil demands increased by 1.3% in 2018 and today share of electricity generated by Oil burning are 40% and transportation sector dependency on oil is around 96%. [13, 14]

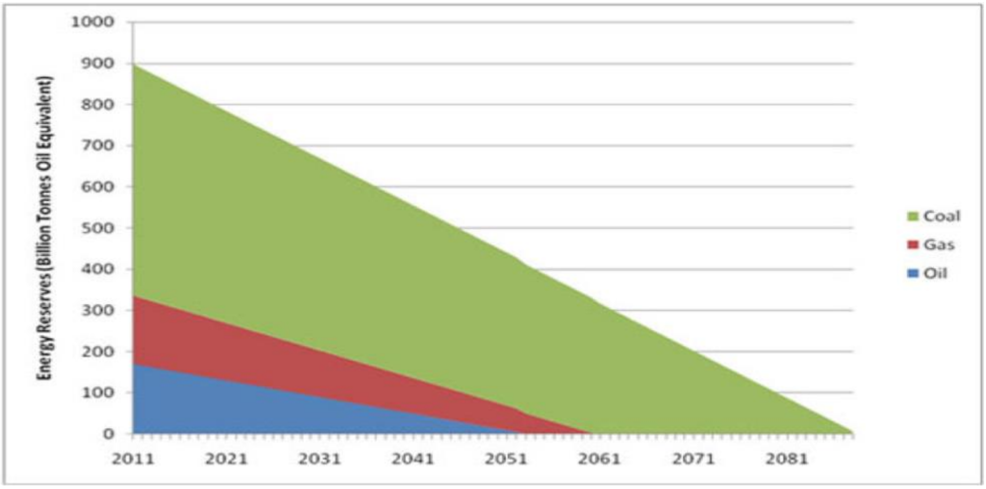

Figure II.- Energy reserves in billion tons of oil equivalent [17]

A huge number of consumptions i.e. 875 billion barrels per annum is used on transportation. Gross utilization of world is estimated about 11 billion tons per annum. Reduction of crude oil reserves is at 4 billion tons per. The current situation indicated that many oil wells reach their dead point and 1000 billion barrels remained. [15] Figure 2 indicates the reduction of fossil fuels relating rate of consumption and production. The mentioned figure indicated the endpoints of fossil fuels reserve and it is alarming for world that endpoints are very close, hence it is required to shift from fossil fuels to renewable sources which are long lasting. [16]

3. Impacts of Modern Lifestyle on Energy Demand. – Energy produced in Power plants is utilized for many applications and one of the chief requirements is to cater the cooling load. Due increased population level of the world demands of energy for HVAC system has been increased by enormous amount. Due enhancement in lifestyle the Air conditioning demands is increased, and global warming also played vital role to amplify the cooling loads demands. Vapor compression systems are mostly utilized by residential buildings which impose pressures on national grids as well as causing environmental pollutions due to energy production through fossil fuels. [17]

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Residential building sector consumed around 55% of the global energy production and cooling loads comprised 25% energy demands for producing thermal comfort. These Vapor compression systems for producing the intended result of cooling utilizing CFC's and HFC are as refrigerant which create serious environmental issues like Ozone Depletion. Figure 3 represents the increment in HVAC demand. [18]

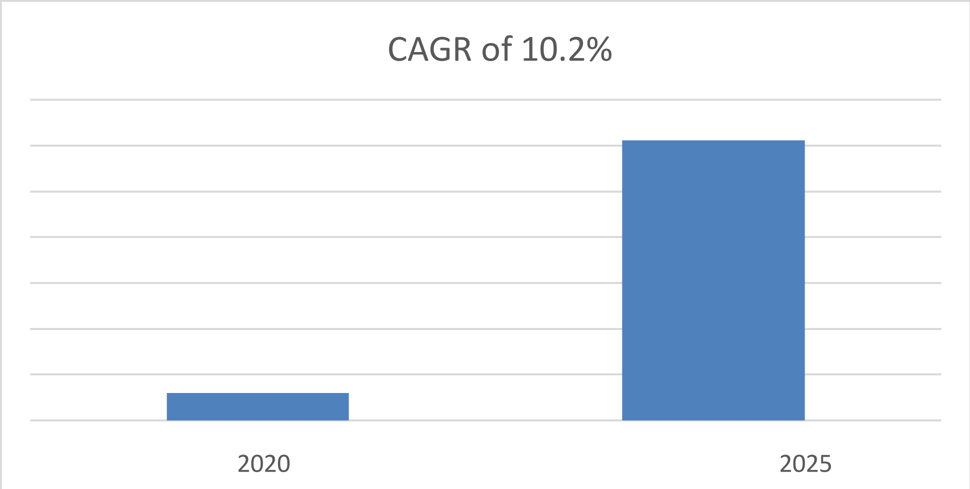

Figure III.- Growth trend of HVAC Demand [19]

Global warming is the intendant results of modern living standards because luxurious transport and houses demands of energy like energy required for cooling of building and refrigeration purposes etc. which comes from burning of fossil fuels. The population of world around 7.59 billion peoples depend on many natural resources. Increased energy demands produce adverse effects like acid rain is one of the most highlighted issue regarding environmental pollution. The sulphur dioxide from coal power plants combines with water content in air and results in acid rain which can acidify lakes and streams, which are chief sources of fresh drinking water in many countries of world. [19] Release of refrigerants i.e., chlorofluorocarbons (CFC's) are very cumbersome for Ozone layer in stratosphere. Due increase in temperature and alterations in lifestyle, human comfort zone is necessary for their health, but it brings many drawbacks like utilization of HVAC systems in buildings produce harmful effects to ozone layer and consumed major portion of electricity in household appliances. The equality maintained by Ozone for earth is due to its Ultraviolet rays' absorption (240-320 nm) and Infrared absorption. Ozone depletion allowed the Ultraviolet rays which enhances the rate of skin cancer, eye damage etc. Figure 4 represents the schematic of Ozone depletion process. [20]

In China, a study has been performed to investigate the effect of CFCs releasing from obsolete residential refrigerators and comparison conducted between other recognized ozone depletion substituents. The results revealed that the per annum increments in residual CFC-11 and CFC-12 has reached to higher value of 4600 and 2300 tons respectively in 2011 and now decreasing to zero until 2020. The amounts of HCFC-141b and HFC-134a are increasing and contribution ratio to ozone depletion will increase from 25% in 2011 to 34% in 2018. Hence, obsolete household refrigerators in china contribute its maximum to ozone depletion. [21]

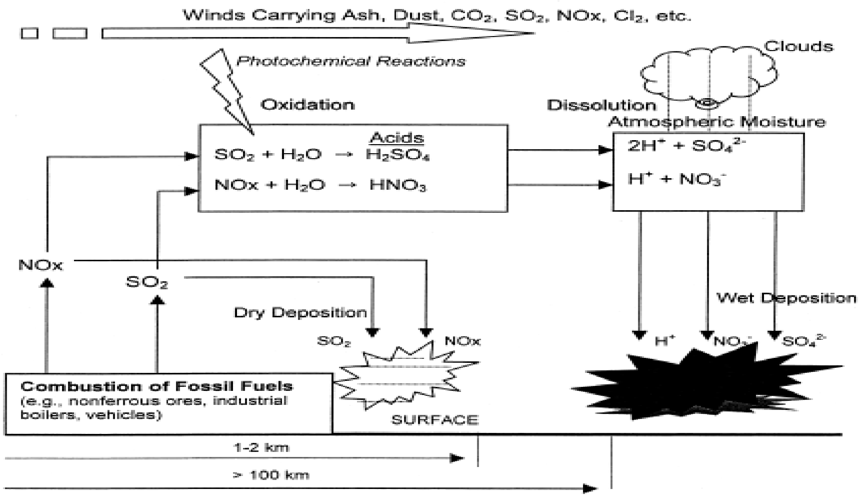

Figure IV.-Schematic of Ozone depletion [20]

The current world challenges are controlling and mitigating the harmful effects of greenhouse gases, the projected intensity of carbon in 2050 is around 0.45 kg of C/yr.W. The intensity is much lower than fossil fuels. To achieve this goal the contribution of fossil fuels in power generation would alter to limited extent. Reduction in dependency of fossil fuel power system can control the steep shortage of fuel. The calculated amount of power required to meet the carbon intensity challenge in 2050 is 10TW from any other source and CO2 amount will be 550ppm. [23] The major issues of environment are release of CFC's and CO2 which produce serious impacts on society. Figure 5 represents data of Energy consumption for Indonesia which represents most of the energy are utilized by cooking and cooling equipment's.

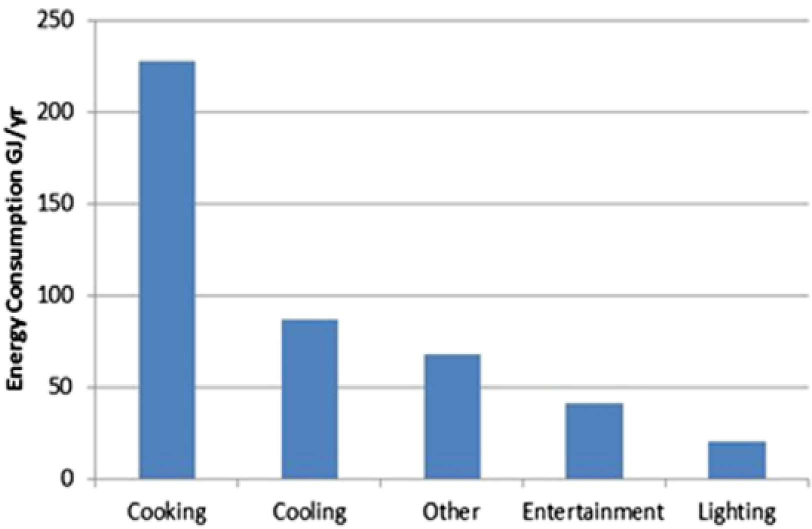

Figure V.-Energy consumption graph in Indonesia for household [22]

Hence, it is very essential to alter the power generation techniques and utilization of renewable energy for power generation purposes. Among the renewable energy Sun is the key part of the system because every renewable source derived from Sun, hence solar energy can change into enormous amount of power. The solar energy is environmentally friendly, and no pollution resulted due utilization of solar energy, the major impact of solar energy on modern lifestyle to change the residential style like consumption of solar energy for cooling purposes. Solar energy played a vital role to control the ozone depletion by controlling the utilization of CFCs due consumption of solar energy for HVAC systems. The energy generated by solar can utilized for household cooling apparatus and solar energy can directly utilized in absorption system for enhancement in Coefficient of Performance (COP). Solar energy can converted into electricity through Photovoltaic (PV) and this energy may utilize for refrigeration system, but due to very low efficiency of PV system, it is not feasible to generate energy by PV.

4. Utilization of Solar Energy for Energy Generation. - The world is now shifting from conventional technologies of energy generation to non-conventional systems. Figure 6 delineate the growth of renewable in different technologies and it is clearly didactic in Figure 6 that the growth is very rapid to maintain the stability in climate level.

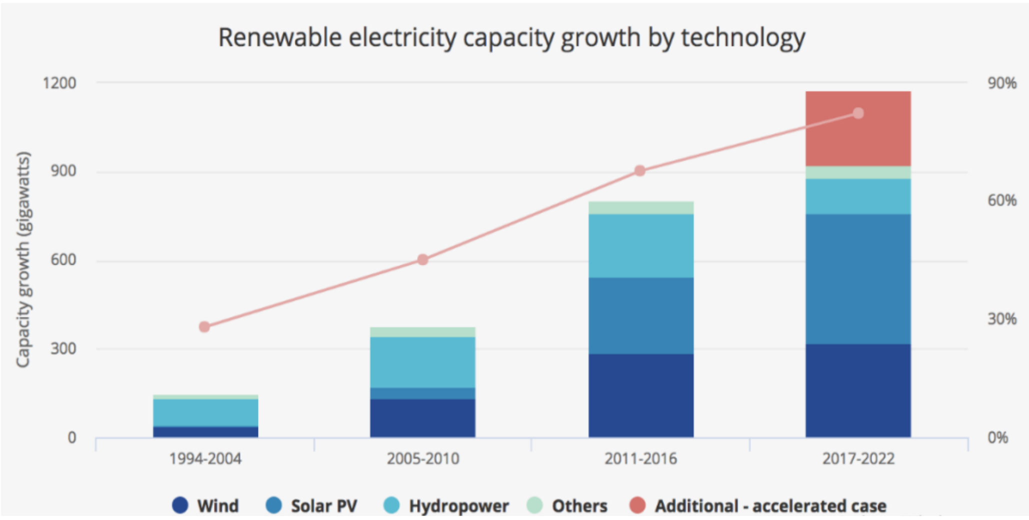

Figure VI.-Share of Electricity by Renewable [24]

Solar power among renewable energies is very mature now and most of the world achieving handsome irradiance factor. Hence, consumption of Solar energy is greater than all other renewable sources due its maturity. In 2019, United States solar power production culminate to 70 TW from Solar thermal and Photovoltaic, in comparison with 2011 when it just below 2 TW. The leading solar power utilities of United States are in California, Florida, Texas, and North Carolina. Figure 7 described the increment of solar power generation in USA.[25]

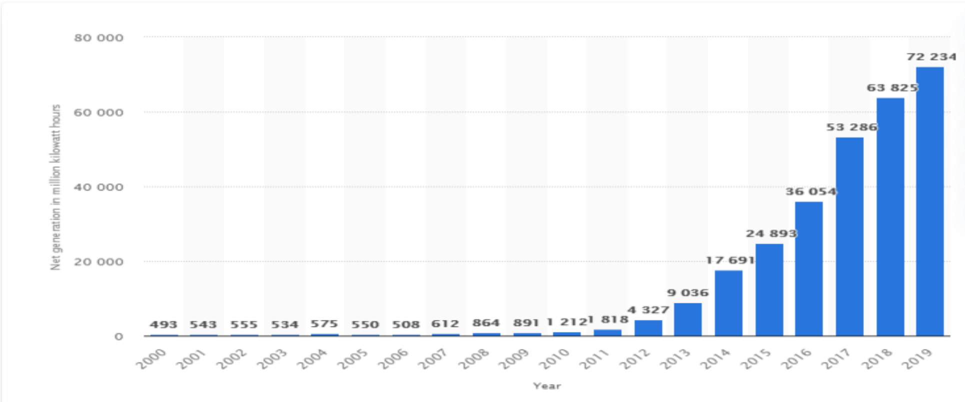

Figure VII.-Solar Power Generation in USA [25]

5. Solar Energy for Refrigeration applications. - The demand of air conditioning is increasing, and this requirement is achieved by using vapor compression systems. The utilization of vapor compression system is very expensive due high demand of electricity; hence it imposes pressure on national grids. The HVAC load comprised of sensible and latent load. A good air conditioning system should cumulatively deal with both loads. The drawback of vapor compression system is relevant to environmental pollution due green-house gases emissions. Ozone depletion in upper atmosphere is the main cause of using CFCs in conventional system. However, the demand of using such systems is increasing at a rate of 6.2% up to 2014. [26]

Solar thermal collectors instead solar PV panels are utilized for heating and cooling purposes with central air conditioning system mostly. Solar thermal collectors also used for electricity generation but require large area for installation. The main focus of this study is to delineate the HVAC utilizations of most common solar thermal collectors which are categorized in Figure 8. These below mentioned collectors are easily available in local market. These thermal collectors provide the temperature output within range of 60 to 240°C, non- concentrating thermal collectors are suitable for low temperature applications and concentrating thermal collectors are feasible for high temperature requirements. The two types of concentrating thermal collectors are discussed in detail due high utilization and easy availability in market.

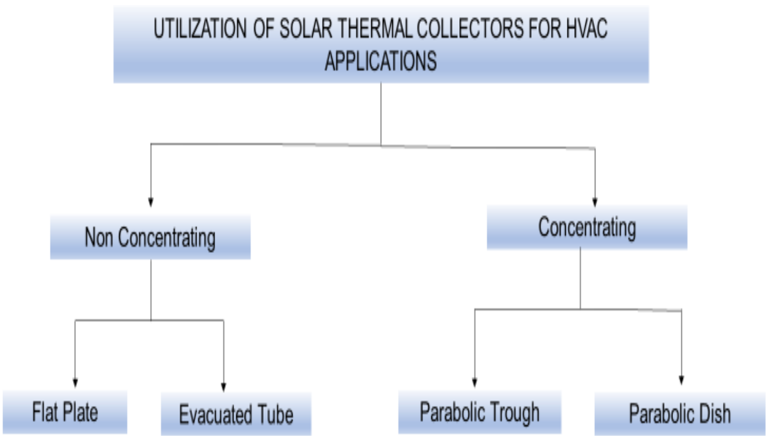

Figure VIII.-Solar energy utilization for HVAC by thermal Collectors.

5.1 Non-Concentrating Solar Thermal Collectors. - The solar thermal collector in which areas of solar energy collection and absorbing are same, hence absorbed solar energy is converted to heat and utilize for useful purposes.

5.1.1 Flat Plate Collector. - Direct conversion of solar energy into electricity is done by using PV panels and this energy can be used for conventional air conditioning and refrigeration system like vapor compression etc. However, PV panels provide poor efficiency about 15-20 % maximum. Furthermore, due intermittent nature of solar energy, storage system must be necessary. Electricity storage after generation by PV panels is much expensive than thermal storage. Hence, an alternative approach is necessary to utilize solar energy at higher efficiencies with reduced storage problems. Therefore, solar thermal collectors are utilized for harnessing solar thermal energy and its utilization into heat driven cooling technologies. The solar thermal collectors provide better efficiency upto 80% in comparison with PV panels.

Flat plate collector is solar thermal energy collection equipment utilized for space heating and cooling operations with absorption chillers, water heating and various different applications. Flat plate collectors are appropriate for low temperature purposes. Solar energy is abundant in nature and availability marked free, hence Flat plate collector capture the free solar energy and heat the water temperature up to 80°C. The water at this temperature can be utilized for space heating and for bath applications. It can be used with absorption chillers for cooling applications. [27] Space heating and cooling focusing on setup efficiency which further dependent on system components performance. The single stage 4.5 kW LiBr–H2O absorption chiller with Flat plate collector of 12m2 area was tested as a prototype. The average coefficient of thermal performance (COP) is improved almost 100%. The experimental results have revealed that the utilization of renewable energy with cold storage devices are feasible with better COP. [28]

A study conducted on solar absorption system to categorize them as single stage, double stage and multi-stage. Hence, FPC will be utilized easily with single stage due generator temperature of around 80°C with COP of 0.7. The COP of double stage rose from 0.7 to 1.4 along with increased temperature requirements in range of 100 to 150°C. Ultimately, the peak value in COP of solar absorption system approached to 1.8 with multi-stage effect driven with temperature source of 180–240°C. [29] Finally, it was concluded that with the low temperature requirements it is feasible to utilize FPC and ETC except with multi-stage solar system, concentrating collectors are very suitable to fulfill temperature requirements. [30] Solar collectors may be utilized with absorption and adsorption cooling system, adsorption system has lower value of COP with temperature requirements between 45-65°C instead of absorption system with temperature requirements ranges between 80 to 240°C. [31]

A study shown the performance of single effect 17 kW LiBr–H2O absorption cooling system. The system required energy is 30kW which received by boiler. The maximum (COP) of this system by utilizing Flat plate collector achieved around 70°C. a numerical study also performed to stimulate the practical states and declared a good match between numerical and experimental data. [32,33] An integrated Solar system of Heating and Cooling had been studied and results represents that with two Stage absorption cooler system of 100kW capacity, maximum COP achieved around 60 to 75°C. The COP achieve was 0.44 which is higher than previous COP 0.38. [34] An another study performed in Jordan in the month of May that COP value of actual system was improved to 0.55 due utilization of 1.5 ton solar cooling system. The system contained Flat Plate Collector of 14 m2 and around five heat exchangers. [35]

5.1.1 Evacuated Tube Collector. - The temperature produced by FPC is around 70°Cwhich is easily utilized for space heating and cooling system. The high temperature conventional system of heating should be replaced by an alternative source which can generate temperature more than 100°C for some requirements. The cooling technologies like absorption chiller system required heat energy which is provided by Flat Plate Collector and Evacuated Tube Collector. [36-40]

A study has been conducted on Solar heating and cooling system to investigate single stage LiBr–H2O absorption chillers. Solar thermal source utilized are Evacuated tube and Concentrating Photovoltaic solar collectors. Energy savings achieved by Evacuated tube collectors are 74% and concentrating photovoltaic collectors often reach to 100%. [41] As proceeding with solar refrigeration system, the main obstacle between these efficient system and market is the high manufacturing cost of system. However, various techniques like single bed solar system of absorption cooling method in hot temperatures were performed, and it is concluded that optimum performance point obtained at 30 l/min flow rate. Other factors like Coefficient of performance, specific cooling power and evaporator temperature were 0.55, 39 W/kg and 6.6°C. [42]

The recent advancement in adsorption cooling technologies is to couple solar thermal collector and cooling system in one single unit module. A practical system in which a simple adsorption system resides inside of evacuated glass tube collector with dimensions of length approx. 180 cm and internal diameter is around 5.5 cm. The investigations performed experimentally to optimize the adsorbent bed design and results shown that system is very cost effective and energy saving. Zeolite 13X declared best due better rate of adsorption and Solar COP of module was marked as 0.15. [43]

A research study conducted to investigate minimum collector area for one ton of refrigeration in capital of Labnan, the desired output was obtained by modelling and simulation of absorption system associated with solar energy. The findings declared minimum area required for collector per ton refrigeration is 23.3 m2 along with optimal storage of water around 1500L for 7h each day. [44]

In Malaysia, a study has been performed to investigate the optimum collector area for and slope angle along with water storage system. The evacuated tube collector and LiBr-H20 absorption cooling system are coupled, simulation was performed on TRNSYS program. Hence to achieve continuous operation 0.8 m3 warm water tank is necessary. Results delineate that 3.5 kW cooling system comprised of 35 m2 evacuated tubes and solar collector slope was 20 degrees. Figure 9 described the schematic diagram of absorption cooling system assisted with solar thermal collectors. [45]

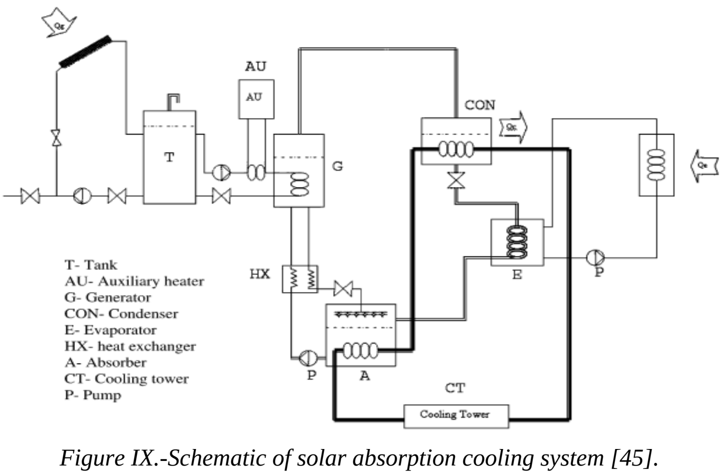

Figure IX.-Schematic of solar absorption cooling system [45].

5.1 Concentrating Solar Thermal Collectors. - The concentrating Solar thermal collectors utilize the reflection technique to concentrate the reflected solar rays on receiver where the solar energy converted into heat. This heat energy may utilize for space heating and cooling purposes etc. However, due to high temperature production, these thermal collectors can be used for power generation.

5.2.1 Parabolic Trough Collector. - The parabolic thermal collector comprised of parabolic reflector, absorber tube which contained working fluid and transparent cover. [46] Sun tracking may utilize for better performance of system. Parabolic collectors consider as an effective collector for double stage chillers because of its high temperature generation up to 400°C. [47]

The realistic conditions can best delineate the performance of PTC coupled with absorption chillers, the experimental findings considered as reliable source. A study performed in 2005 ensured that using PTC with absorption system provide a comprehensive solar assisted cooling system. Concerning the above, solar assisted double effect absorption cooling system was analyzed and concluded that COP of chiller unit was improved to the value of 1.5. [48] Another experimental study conducted on PTC with 50 m2 area integrated with 16 kW double effect system in 2010. The results indicated that the design optimization make it possible to achieve 39% cooling load [49].

The concentrating collector can provide same COP by capturing less irradiation in comparison with non-concentrating collectors which can absorb more irradiation. In this regard, a comparative study conducted on double effect absorption system integrated with PTC and FPC. It is concluded that cooling unit exhibited same performance for FPC and PTC, COP value ranges between 1.1 to 1.3. The FPC received 11 % more fractions as compared to PTC. [50]

The relation of temperature of water with COP of chiller is in direct proportion. A number of studies have been performed to evaluate the fact. A research study on PTC coupled single stage (LiBr-H_2O) absorption system concluded the COP of system ranges between 0.11 to 0.27 when temperature was around 90°C. Hence, low water temperature is directly producing its impact in form of low COP. [51] A research study conducted on double stage (LiBr-H_2O) absorption system integrated with PTC, author concluded the COP within range of 1.04 to 1.29 when temperature of working fluid was 216°C [52].

A comparative study between solar thermal collectors likes FPC, ETC and PTC had performed. The conclusion of comparison figured out that the PTC integrated with double effect absorption system provided better and efficient results. The study delineated briefly about overall efficiency of system and investment cost due utilization of thermal collectors.[53] The integrated solar cooling system ability to utilize PTC other than FPC and ETC provide better results in case of double effect absorption system. The solar energy absorbing fraction was proved highest on annual basis in PTC as compared to compound parabolic trough and FPC/ETC. [54]

The mentioned absorption cooling technique utilizing heat for separation of refrigerant from refrigerant/absorbent mixture. So many refrigerant/absorbents are under study for achieving better performance vide absorption cooling technique, however LiBr/H_2O is the most efficient solution for absorption cycle. [55] Furthermore, the absorption cooling system categorized as single effect and double effect, comparison performed between single and double effect system. Results indicated the increase of COP of double effect system and study declared that double effect system was providing 60- 70 % greater COP than single effect system. [56] The single effect require low temperature like 80- 90°C and temperature requirement of double effect is around 150-200°C.

The performance level of solar thermal collector hence depends on heat energy provided to system for splitting of refrigerant, hence performance of FPC and ETC are remarkable different than PTC due variation on temperature levels. [57]

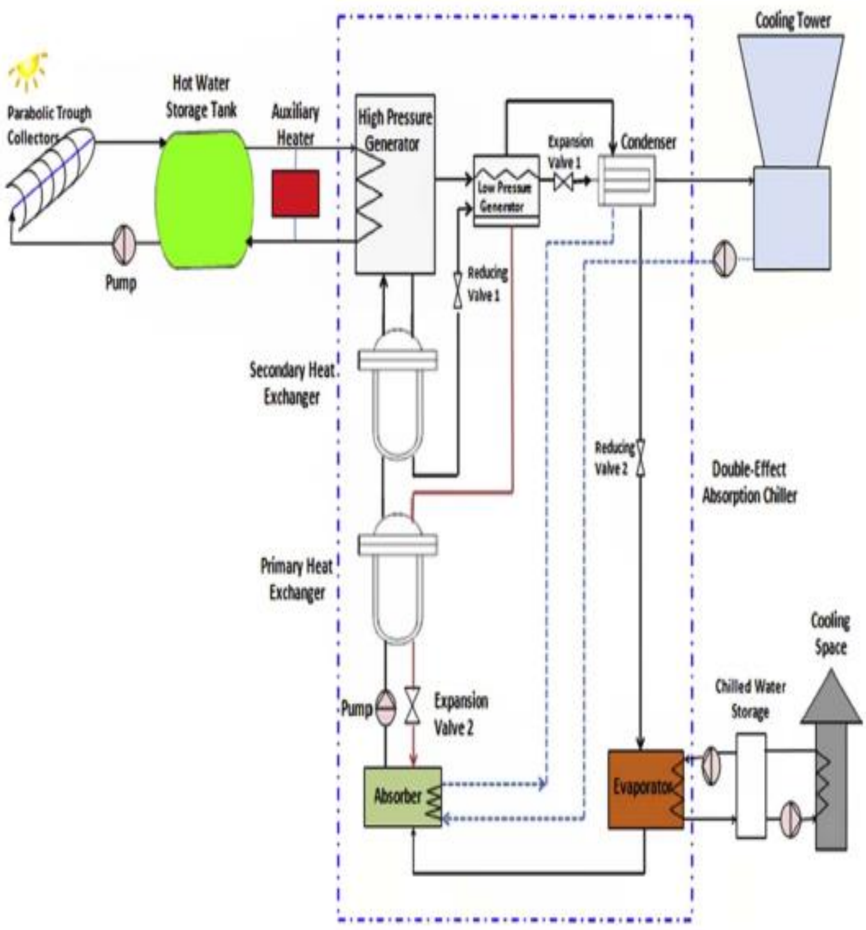

Figure X.-Double effect PTC integrated absorption cooling system schematic diagram [58].

The potential of utilizing PTC with double effect absorption system regarding cooling in buildings of residential area in UAE was studied; the model considered in Figure 11 was appropriate which provide continuous cooling at night in absence of sun. Hence, biomass energy utilized for cooling after sun set down. The building with cooling load 366kW was selected, the results concluded after research study delineated that hybrid system with 30% solar share is best suited with annual energy savings of 519322 kWh and annual operating costs were reduced by 65%. The schematic diagram of project is represented in Figure 10. The project payback period restricted to 2.5 years and environmental impact regarding reduction in carbon emissions is 304 tons/yr. [58] Another research study conducted on LiBr-H2O absorption system which investigate solar system of moderate Temperature, hence a double effect absorption chilling system with 50m2 surface area of PTC. The achieved temperature was around 200°C and study showed results around higher COP value of 1.2. [59]

Most studies revealed the performance of LiBr-H2O as working fluids; however there are other fluids available which may be utilized for solar absorption system like a study performed on solar-geothermal cooling system in which LiBr-H2O was replaced by sodium hydroxide-water. The results showed the improved COP of 0.71 was achieved. Similar study on NH3-LiNO3 as a working fluid was executed without geothermal energy source; the maximum COP attained was 0.56. Hence, there are other working fluids which may consider as an alternative approach, but LiBr-H2O is very common and easily available. [60,61]

5.2.2 Parabolic Dish Collector. - Parabolic dish collector is another type of concentrating collector which focus the beam of light on a focal point where receiver is installed. The parabolic dish collector produces heat at various temperatures. Dual axis tracking is utilized to follow Sun and dish collectors concentrate the beam of radiation on receiver at focal point. Some systems are coupled with heat engines like Stirling engine to generate electricity. The Dish collector system can raise temperature up to 1000°C and achieve maximum efficiency in conversion system of solar energy to electricity. [62]

Many studies have been performed to evaluate the performance of Dish collector, hence a study conducted on behavior of Dish collector under wind induced vibration. The effects on frequency and amplitude due to several parameters like Pitch angle, velocity of wind etc. are investigated. Another study conducted to investigate the effects of height angle and wind angle on drag and lift coefficient of dish collector. [63, 64] The utilization of dish collector for refrigeration applications are reviewed to compare the best solar thermal collector for solar refrigeration applications.

The dish collector is renowned for high temperature applications like electricity generation etc. The utilization of dish collector for refrigeration applications is made possible through various research studies like a study conducted on design and performance of a refrigeration system coupled with solar dish collector. The achieved COP of the system was 0.172 and lowest temperature achieved was 9°C. [65] The alternate of compressor in refrigeration system was very necessary due very high energy demands and environmental impacts. A research conducted in Poland on hybrid system utilizing both Flat plate collector and Dish collector for absorption system of refrigeration. The model was analyzed via TRNSYS software to evaluate the performance by simulation as well as practically. The conclusions comprised of dish collector efficiency were 70%, savings in energy consumption around 50% and simple back period in range of 8.23 years. [66]

The combination of different technologies in one unit to generate the feasible consequences, similar study had performed in Tehran on integration of Dish collector with double effect refrigeration system, Solid oxide fuel Cell (SOFC) and Organic Rankine Cycle for applications like space heating and cooling and electricity generations. The results showed that efficiencies of system were calculated as electrical efficiency of SOFC, electrical efficiency of combine system and overall thermal efficiency. The values of efficiencies are 41.5%, 48.7%, 79.5% respectively. The payback period calculated was 4.43 years. [67]

The experimental study was performed on coupled system of solar and biogas energy for power generation and cooling, heating applications. The combined system utilizes solar energy by dish collector to drive a reactor of biogas energy. The utilization of fossil fuel over year was around 57% and carbon emissions were reduced to 8.20%. [68]

The combined system coupled with solar energy is prone to higher fossil fuel consumption as compared to hybrid solar system for absorption system which comprised of FPC and PDC

(Parabolic Dish Collector). The energy savings was reached to 50% for a home of residential purpose by utilizing hybrid solar system. [69] So many research studies were conducted on performance of PDC integrated absorption system and impacts of climate on PDC coupled refrigeration system. Hence, results indicated that ambient temperature has strong influence on cooling performance of PDC driven refrigeration system. The obtained COP was around 1.6. [70]

The performance indicator of PDC is ambient temperature as suggested in above mentioned study; however, another study performed to evaluate the effect of mean temperature of cooling fluid in cooling and heating arrangement. The COP of refrigeration system coupled with PDC is dependent on mean temperature of fluid and ambient temperature also. The results showed that the PDC was providing warm water in winter for heating purposes and cooling supply in summer at HEnergia center. Figure 11 showed the solar refrigeration system which comprised of PDC at HEnergia for domestic purposes. [71]

Figure XI.-PDC installed at HEnergia center for cooling [71].

5.2.3 Cost Comparison of Solar Thermal collectors. - The economic comparison between solar thermal collectors is very essential to evaluate the payback period because payback period is the only reason to induce people regarding interest of money investment and time investment. The comparative analysis was performed between FPC, ETC and PTC. The ETC and FPC were coupled with single effect absorption chiller; however PTC was coupled with double effect absorption system. The PTC integrated refrigeration system payback period was 2.49 year and payback period of FPC and ETC was calculated about 4.75 years. Figure 12 depicted the complete cost analysis between FPC, ETC and PTC. Figure 13 and Figure 14 represented the Payback period comparison and CO2 emissions comparison between FPC, ETC and PTC. [72] Another comparison was accomplished in Riyadh, the comparison made between double effect PTC integrated refrigeration

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system and single effect ETC driven refrigeration system. The results concluded finally to utilize PTC integrated system although the cost of this was 17% higher than ETC coupled refrigeration system, but due improved thermal performance, PTC integrated system was decided to utilize. [73]

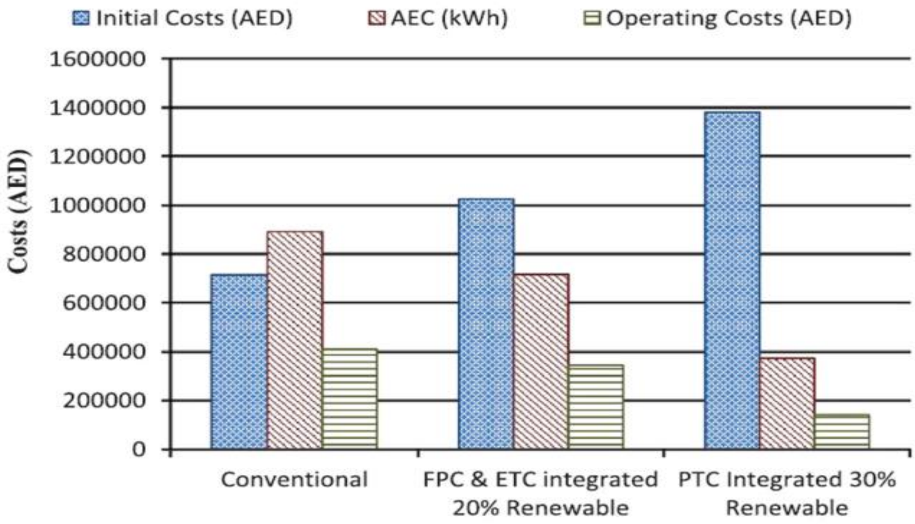

Figure XII.-Complete Cost analysis of Solar Integrated Absorption system with FPC, ETC and PTC [72].

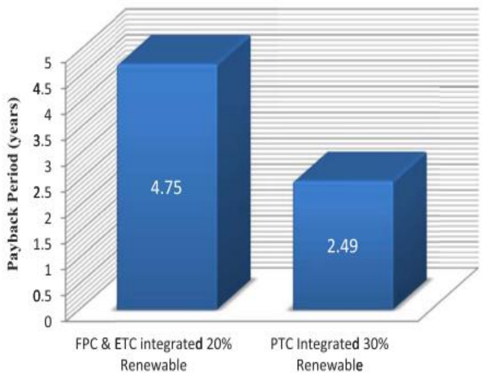

Figure XIII.-Comparison of Payback period [72].

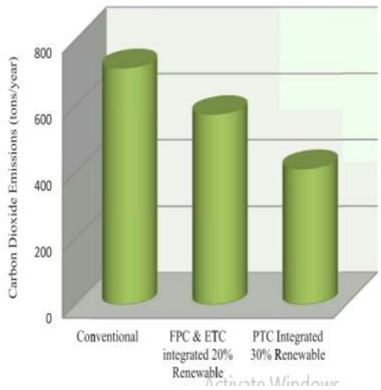

Figure XIV.- Comparison of CO_2 emissions

Moreover, some recent studies after 2021 about solar aided cooling and heating technology are discussed to show trend and recent advancements. Similarly, results of a solar adsorption cooling system using silica gel and water show that as the cooling load increased from 10 to 100 TR, the area of the condenser, evaporator, bed, and collector increased, and the mass flow rate of the collector, condenser cooling water, chilled water, and the cooling circuit increased by 9 times. The system's cost and mass of silica gel also increased with higher cooling loads, reaching $189,169.6 and 22,667 kg for 100 TR [74]. Study conducted to simulate a solar adsorption refrigeration system

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in a cold store under different climatic conditions. The system's performance characteristics were evaluated monthly, and an economic analysis was applied using the weighted cost cooling method. The results indicated that the system could be operated efficiently with a low heat source in hot and dry climates. Furthermore, the levelized cooling cost was lower in hot and dry climates compared to humid climates [75]. Various configurations, including a separable ABC-ADC system, a combined ABD-ADC in parallel operating mode, a standard single-stage ADC cycle, and other integrated systems, were compared to the suggested system. The combined ABD-ADC configuration demonstrated higher cooling capacity and COP than other systems, including a 58.34% and 27.07% increase over the single-stage ADC system's capacity and COP, respectively, at 85◦C heat source temperature [76].

The study analyzes a cooling process that uses an ammonia-water working fluid and a hybrid source (natural gas-solar) to determine the variables that affect its thermal performance. The study used experimental data from a 10.5 kW cooling capacity system and evaluated three AI techniques for modeling the thermodynamic cycle. The results show that the inlet temperature at the generator and the heat measured at the evaporator have the greatest impact on the system's performance [77,78]. Hence, absorption systems are an appealing option for cooling systems as they use less energy than VCRS systems and can work with refrigerants that emit fewer pollutants into the atmosphere. By incorporating renewable energy technologies, such as solar or geothermal power, absorption systems can also partially meet their energy demands while reducing their carbon footprint. Thus, absorption systems have the potential to significantly contribute to the decarbonization of refrigeration systems [79].

Several research shown combination of photovoltaics and cooling systems. In this regard, study about integration of an organic Rankine cycle-vapor compression refrigeration system with a photovoltaic thermal compound parabolic collector to simultaneously produce electrical power and cooling was performed. The system's performance was evaluated based on energy, exergy, and environmental criteria, considering parameters such as expander inlet temperature, packing factor, and number of collectors. The results show that the system's energy and exergy performance are best at an expander inlet temperature of 423 K and packing factor of 0.25, while its environmental performance is maximum at an expander inlet temperature of 373 K and packing factor of 0.89. Increasing the number of collectors improves the system's exergy and environmental performance [80].

This study focuses on the use of photovoltaic thermal (PVT) systems to meet electricity requirements, which can be negatively impacted by high ambient temperatures. By integrating an air duct to cool the PV module, the PVT system demonstrated improved electrical efficiency compared to a simple PV panel with no cooling effects. The thermal efficiency of the PVT system was also determined and a correlation between ambient and outlet air temperatures was developed. These findings can benefit areas where both electricity and space heating are needed [81]. Performance evaluation of PVT system is very essential because its efficiency is not much higher to meet up energy demands as compared to other energy generation units [82]. Hence, study conducted in Karachi, Pakistan focuses on the impact of dust accumulation on the performance of photovoltaic (PV) modules. The experiment, conducted over a year, found that dust deposition on PV modules caused a reduction of 14.6 W/month in power, 0.3%/month in efficiency, and 1.84% in performance ratio. The results indicate that dust accumulation can significantly reduce the performance of PV modules [83].

6. Conclusion. - The solar energy is having the ability to provide the power as well as it can be directly used in the air-conditioning and refrigeration applications without having any impact on the global warming. Therefore, it is very essential to utilize this clean energy in different applications to provide a change in the energy mix, stability and sustainability of the energy and ultimately to increase the system performance. Having minimal environmental issues, the solar energy can be used to provide indoor human comfort. Use of PV systems or the thermal systems have their own pros and cons; however, the thermal systems provide a shorter payback period compared with PV system and also capable to provide improved system performance. This study also suggested the solar integrated refrigeration system which is comparatively providing higher output values. The study provides a recommendation that different solar energy conversion techniques, with their pros and cons, can be utilized to improve the energy mix of any country.

7. Data Availability. – No data is generated during this study.

8. References

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Nota contribución de los autores:

1. Concepción y diseño del estudio
2. Adquisición de datos
3. Análisis de datos
4. Discusión de los resultados
5. Redacción del manuscrito
6. Aprobación de la versión final del manuscrito

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