Healing global warming with Solar Air conditioning: a review

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Abstract—Energy is an inevitable need for inhabitants of modern world. A major portion of electrical energy is consumed in air conditioning (heating or cooling) in conventional ACs (operated by Vapour compression refrigeration cycle) and the refrigerants (like R12 or R22) used in this cycle poses a huge threat to global warming and a major effect of global warming is its implication on rising temperature. So using our archaic methodology, we are not only depleting our exhaustible source of energy but also incrementing our future cooling load by increasing temperature. All these reasons tend to shift the research directions to the usage of renewable sources of energy, particularly solar energy due to its high availability in nature and cleanliness properties. This study depicts a review of different solar assisted cooling techniques along with their applications, merits and demerits, specially focusing on solar absorption techniques. A new state of the art technology of Solar Hybrid cooling has also been described. Feasibility of installation of solar Air conditioning systems is verified depending on the duration of cooling requirement and location respectively. This knowledge will assist the researchers and manufacturers to investigate the applicability and feasibility parameters for deploying various solar assisted cooling systems.

Index Terms—Vapour compression refrigeration cycle, Solar vapour absorption system, cooling load, Thermal energy storage.

I. INTRODUCTION

Energy is the part and parcel of the modern world. For overall development of a country (economic and technological), availability of energy in abundance is a pre-requisite. This insatiable energy demand of humans is growing at a high pace whereas the fossil fuel sources that mainly cater this demand is limited and is assumed to be getting decremented at a rate of 2-3 % every year from 2016 (International Energy Agency). Human beings always have the desire to reside in comfortable conditions to alleviate the sultry effects. About one-third of world’s energy is consumed by buildings and commercial sectors, and HVAC systems as the most energy consuming devices among the building energy components [1][2][14]. Electricity consumption increased significantly by 50% from 2003-04 to 2010-2011 [14]. Therefore, implementation of renewable energy assisted cooling techniques can lower down the fossil fuel dependency and will thrive towards attaining the World’s energy and environmental policies [1]. Among all the available renewable energy sources, solar energy is the prominent one for cooling as it is available with high intensity and is in phase with the peak cooling demand period [3]. The Vienna Convention for the Protection of the Ozone Layer (1985), Kyoto protocol rules (1988), Montreal Protocol (1987) have emancipated the worldly concern for sustainable growth with low CO2 emission, reduction of Freon producing gases like CFCs (that destroys the ozonosphere) [4]-[8][26]. Various techniques for capturing solar power have been devised and efficiency of the associated devices have also been enhanced with constant scientific researches. Usage and acceptability of Solar powered devices like water heaters, cookers, power generation, air heaters and dryers have gained momentum in the past few years [6]. Highly populated Countries like China, India need to move towards greener and cleaner technology for powering air conditioning where the cooling demand can be substantially high in the upcoming years.

II. SOLAR ENERGY AND ITS COLLECTION

Sun is a fusion reactor which produces total energy output of 3.8X 10^26 MW but Earth receives a small fraction of it, nearly about 1.74X 10^11 MW. For determining the feasibility for installation of any solar technology, we need to find out few parameters, like, location (latitude and longitude of the place) [3], peak cooling demand period and solar insolation of the place where AC is to be installed [10]. Solar energy can be collected in many forms, by converting it into thermal energy sources as in solar thermal collectors, by converting it into electricity as in PVs[11] or in some chemical forms as in PCMs (which are growing popularity as thermal latent energy storage devices) [3][12]. Solar thermal collectors are a pre-requisite entity for conversion of solar energy into thermal energy. Depending on the temperature requirement of the working fluid, various types of solar collectors can be installed which are broadly classified as concentrating and non-concentrating collectors [13].

III. SOLAR COOLING TECHNOLOGIES

Solar cooling technologies are broadly classified into three types [14]. But for satisfying cooling demands, state of the art technologies mostly prefer solar thermal and solar combined power cooling as in these cases there has been direct use of thermal energy in its low grade form.
IV. SOLAR ELECTRICAL COOLING

In this cooling technology, solar energy is used to produce Direct Current (DC) electrical energy with the Thermo-electric Module. PV based electricity production has been highly accepted in many countries and thus, the DC electricity generated needs associated devices like inverter, battery and Vapour Compression AC system [6]. This will lead to lower grid demand but the production of Freon still persists with solar electrical cooling as it produces the high grade electrical energy to be used in the archaic vapour compression AC unit. Peltier cooling technology has the ability to cater low cooling demands, but is highly advantageous when coupled to the back side of PV for cooling the cell, so that the cell temperature can be reduced, which otherwise can lower down the cell efficiency and accelerate cell degradation [16].

V. SOLAR THERMAL COOLING

Solar thermal Cooling are preferable to solar electrical cooling as the formal can collect solar heat with solar thermal collectors up to an efficiency of about 80% with state of the art thermal collectors [17] whereas the later technology direct convert solar energy into electricity with an efficiency of up to 35%, rest goes as waste in form of heat energy[ 6] along with the release due to leakage of CFCs and HCFCs which are ozone depleting gases [3][19][22].

Dessicant systems are used to induce or reduce the moisture content of the supplying air depending on the vapour pressure difference between air and solution. In dehumidification process, the dessicant absorbs moisture and gets diluted and inefficient for further use, which leads to the requirement of regeneration to a useful level of concentration. Absorbents that can work satisfactorily in solar energy range are Tri-Ethylene Glycol and LiCl-H₂O [18][19]. The main constriction for widespread implementation of dessicant system is the need to maintain the constant dessicant mixing ratio by controlling its temperature and concentration which in turn maintains the equilibrium vapour pressure of the solution [15][19].

Solar assisted vapour absorption system is highly popular for its multiple advantages like higher COP than its counterpart cooling methodologies. Most of the researchers suggested solar assisted VARS and performed numerical modeling for deploying the system at various location of the world based on their different solar irradiations influenced by the latitude and longitude. These papers suggested the use of LiBr-water as the best working pair as this pair does not need rectifier and analyser as Lithium bromide is non-volatile and water can easily vaporize with solar heat received from solar thermal collectors (Evacuated Tube Collector being mostly used for vaporizing water) [3][20]-[23]. Researchers conducted modeling and simulation to determine the viability of the system and deduced that further researches can alleviate the cost and elevate the efficiency of the components involved in the system [20]. Associated net TEWI (Kg of CO₂) production with solar VARS is lower than 4.5 % as that of Vapour Compression System (R134a) [3]. When Carbon taxation is impended as per the Clean Development Mechanism (CDM) and the present cost of VARS being reduced, then have a huge potential to compete with the conventional AC techniques.
Adsorption technology have been widely used for various applications, differs from the absorption technique as it’s a surface phenomenon whereas absorption is a volumetric phenomenon. Adsorption cooling has been used now-a-days in vehicle cooling [4] due to its vibration free and corrosive resistant properties when powered by high temperature vehicle exhaust unlike absorption which vibrate for its absorbent and corrode above 200°C [6].

In the thermo-mechanical solar cooling system, the thermal energy is converted to the mechanical energy. Then the mechanical energy is utilized to produce the refrigeration effect. When the steam ejector cycle is integrated with a parabolic solar collector, then it’s a solar operated steam ejector cycle. The steam produced by the solar collector is passing through the steam ejector. Steam ejector replaces electrically driven compressor of conventional AC systems but the cycle is operated in VCRS cycle only [24].

VI. SOLAR COMBINED COOLING

Hybrid solar air conditioner which couples the use of Photovoltaic/thermal collector along with Vapour compression system has been a state of the art technique. By the experimental investigation, it has been observed that the efficiency and indoor comfort condition improves in hybrid AC as compared to conventional standalone Vapour compression AC system and in some condition, COP is more than unity. When desiccant is incorporated in an AC, then it takes care of the moisture part and it reduces the load of an AC significantly in hot and humid parts [25]. In hybrid system, Sun acts as an additional heat source to assist the energy needed to drive the cooling process of a conventional air conditioning system which in turn reduces the electrical consumption required to run the compressor. The difference between the standalone and hybrid system is the technique by which gas is changed back in to a liquid so that it may be used again. Usual air conditioning system uses a compressor to increase the pressure of the gas, forcing it to become a liquid again through the use of the condenser coil while in Solar hybrid Air Conditioning System, it uses solar heat from the sun to superheat the refrigerant which enables the refrigerant to begin changing state at the top 2/3rd’s of the condenser coil.

The improvement in effectiveness of heat exchanger of solar thermal collector may further reduce the dependency and share of electrical compressor which, in turn will lower down the operating cost of the system [Centre of Energy and Environment setup, MNIT].

VII. CONCLUSION

Solar cooling has been regarded as a very promising application for solar thermal energy in countries with high insolation and high cooling loads. This solution has been demonstrated in different configurations and applications, but currently it’s not that prevalent in Indian market. A lot of research needs to be done on cost reduction, system quality improvement, energy performance enhancement, and better building and process integration to make it easily adoptable by common people [20]-[23]. With these objectives in mind, R&D should aim at improving thermally driven cooling components and enhancing system performance, integration and reducing material costs of each component present in VARS. In Europe, solar thermal assisted cooling systems are getting widespread over the last two decades [27]. A few years ago, market development and commercialization started in the residential sector in Mediterranean countries (e.g. Spain, Hong Kong) [28] and in the office building sector in Asia (India, Singapore, China) [29]. The analysis of the first commercial market development phase highlights a substantial potential to accelerate this development with further R&D work. Solar thermal driven air-conditioning and refrigeration systems have high capital costs due to multiple system components, i.e. cooling equipment, solar collectors and heat storage appliances, and have not been cost-competitive with conventional electrically-driven cooling systems. But the best part of it is that it employ refrigerants with no ozone depleting potential and no, or very small, global warming potential. Most systems use water as refrigerant.

So far, mainly pilot plants and a few commercial plants have been in operation, limited know-how is one of the major barriers for widespread installation of solar air-conditioning and refrigeration systems. Only a small number of professionals are well informed on both solar thermal and air-conditioning in buildings. Due to this limited experience with solar cooling-refrigeration systems, steps are taken to encourage the dissemination of existing know-how and improve system quality. Places in north-western part like Rajasthan and Gujarat has high solar intensity which makes it a worthy option for solar powered devices and systems [29]. The awareness of global warming has been intensified in recent times and has reinvigorated the quest for alternative energy sources that are independent of fossil fuels and contribute less to global warming [26].
**VIII. ABBREVIATIONS**

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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>COP</td>
<td>Coefficient of Performance</td>
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<tr>
<td>CFC</td>
<td>Chloro Fluoro Carbon</td>
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<td>DC</td>
<td>Direct Current</td>
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<tr>
<td>HVAC</td>
<td>Heating, Ventilation and Air Conditioning</td>
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<td>TEWI</td>
<td>Total Equivalent Warming Impact</td>
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<td>VARS</td>
<td>Vapour Absorption Refrigeration System</td>
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<td>VCRS</td>
<td>Vapour Compression Refrigeration System</td>
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