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Solar Air Conditioning: A Review of Systems and Applications

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ABSTRACT : Air conditioning of building space consumes a major part of electric energy in the word economy. Conventional heating and cooling systems are having an impact on carbon dioxide emissions.

In this paper some of the solar technologies used for space heating and cooling is reviewed. These technologies can reduce both the energy consumption and environmental impact of mechanical cooling systems.

Keyword : Passive solar cooling, Heating, Solar energy, Air Conditioning.

I. INTRODUCTION

Generally, building Sector consumes 35.3%of final energy demand [1]. Parts of the major energy consumption in buildings are the heating, ventilating, and air-conditioning (HVAC) systems. They are indoor climate controls that regulate humidity and temperature to provide thermal comfort and indoor air quality. With total amount of this HVAC's energy consumption in buildings, whether is the space heating or cooling being the dominant, they are closely related to the local climate condition. Heating systems are to provide or collect and store the solar heat, and retain the heat within the building. In contrast, cooling systems are to provide cold or protect the building from direct solar radiation and improve air ventilation. Space heating is the most important building energy user in cold countries, whereas, air conditioning is a major contributor to peak electricity demand in hot climate countries during summer. Air-conditioning load account for 30-40%of peak load during the summer season in India. These heating and cooling loads are having an impact on CO_2 emissions, as well as on security of energy supply [1]. Therefore, renewable energy has become vital energy source for heating and cooling, particularly solar energy that utilize cost-free solar radiation from the sun.

Solar heating and cooling technologies utilize passive or active solar energy to collect solar radiation and transform the energy into usable heat. The passive relates to building envelope design whereas the active relates to the use of solar collector to heat a fluid. The objectives of this paper are to review the solar technologies for space heating and cooling.

II. SOLAR AIR CONDITIONING SYSTEMS

Solar air conditioning system can be broadly classified into three classes: solar sorption systems, solar mechanical systems and passive solar-related systems.

A. Solar sorption cooling

Some materials have an ability to attract and hold other gases or liquid. This characteristic makes them very useful in chemical separation processes. Such materials are known as sorbents and have a particular affinity for water. The process of attracting and holding moisture is described as either absorption, depending on where the desiccant undergoes a chemical change as it takes on moisture. Desiccant is one such sorbet. Absorption changes the desiccant as for example the table salt, which changes from a solid to a liquid as it absorbs moisture. Adsorption, on the other hand does not change the desiccant except by the addition of the weight of water Vapour, similar in some ways to a sponge soaking up water [2].

Absorption system are similar to vapor-compression air conditioning system but differ in the pressurization stage. In general, an evaporating refrigerant is absorbed by an absorbent on the low-pressurization side. Combinations include lithium bromide-water (LiBr-H_2O) where water vapor is the refrigerant and ammonia-water (NH_3H_2O) system where ammonia is the refrigerant [3].

The pressurization is achieved by dissolving the absorbent in the absorber section subsequently, the solution is pumped to a high pressure with an ordinary liquid pump.

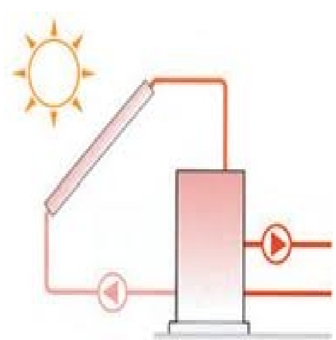

Fig. 1. Schematic Diagram of solar A/C System.

The addition of heat in the generator is used to separate the low-boiling refrigerant from the solution, In this way, the refrigerant vapor is compressed without the need for a large amount o mechanical energy that vapor-compression air conditioning system demand. The reminder of the system consists of a condenser, expansion valve and evaporator, which function in a similar way as in a vapor-compression air conditioning system.

Adsorption cooling is the other group of sorption air condition that utilizes an agent (the adsorbent)to adsorb the moisture from the air (or dry any other gas or liquid) and then uses the evaporative cooling effect to produce cooling. Solar energy can be used to regenerate the drying agent. Solid adsorbents include silica gels, zeolites synthetic zeolites, activated alumina, carbon and synthetic polymers [4]. Liquid adsorbents can be triethylene glycol solutions of lithium chloride solutions.

Many cycles have been proposed for adsorption cooling and refrigeration [5]. The principle of operation of a typical system is indicated in Fig. 2. The process followed at the points from 1 to 9 of Fig. 2, is traced on the psychometric chart of Fig. 3 Ambient air is heated and dried by a dehumidifier from point 1 to 2, regenerative cooled by exhaust air from the 2 to 3, evaporative cooled from 3 to 4, and introduced into the building. Exhaust air from the building is evaporative heated cooled from 5 to 7 by the energy removed from the supply air in the, heated by solar or other source to 8 and then passed through the dehumidifier where it regenerates the desiccant.

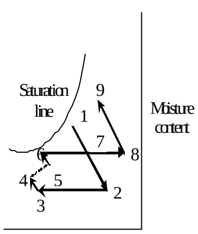

Fig. 2. Dry bulb temperature.

B. Solar-mechanical systems

These systems utilize a solar- powered prime mover to drive a convention air-conditioning system. This can be done by converting solar energy into electricity by means of photovoltaic device, and then utilize an electric motor to drive a vapour compressor. The photovoltaic panels have a low field efficiency of about 10-15 % depending on the type of cell used [6], which result in low overall efficiencies for the system.

The solar-powered prime mover can also be a Rankine engine. In a typical system, energy from the collector is stored, then transferred to a heat exchanger and finally energy is used to drive the heat engine. The heat engine drive a vapour compressor, which produces a cooling effect at the evaporator. As shown in fig 3 the efficiency of the solar collector decreases as the operating temperature increases, whereas the efficiency of the heat engine of the system increases as the operating temperature increases.

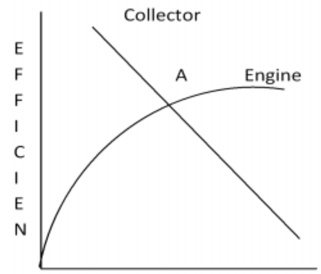

Fig. 3. Operating temperature.

The two efficiencies meet at point A (in Fig. 3) giving an optimum operating temperature for steady state operation. The combined system has overall efficiencies between 17 and 23%.

Due to the diurnal cycle the cooling load varies and also the storage tank temperature changes through the day. Therefore, designing such a system presents appreciable difficulties. When a Rankine heat engine is coupled with a constant speed air conditioner, the output of the engine seldom matches the input required by the air conditioner. Therefore, auxiliary energy must be supplied when the engine output is less than that required, or otherwise, excess energy may be used to produce electricity for other purposes.

C. Solar related air conditioning : Some components of systems installed for the purpose of heating a building can also be used to cool it but without the direct use of solar energy. Examples of these systems can be;

(*a*) *Heat pumps :* A heat pump is device that pumps heat from a low temperature source to a higher temperature sink. Heat pumps are usually vapor compression refrigeration machines where the evaporator can take heat into the system at low temperature, and the condenser can reject heat from the system at high temperature. In the heating mode a heat pump delivers thermal energy from the condenser for space heating and can be combined with solar heating. In the cooling mode the evaporator extracts heat from the air to be conditioned and rejects heat from the condenser to the atmosphere, with solar energy not contributing to the energy for cooling. The performance characteristics of an integral type solar-assisted heat pump are given in [7].

(*b*) *Rock bed regenerator :* Rock beds (or pebble beds) storage units of solar air heating systems can be night-cooled during summer to store 'cold' for use the following day. This can be accomplished by passing outside air during the night when the temperature and humidity are low, through an optional evaporative cooler, through the pebble bed and to the exhaust. During the day, the building can be cooled by passing room air through the pebble bed. A number of applications using pebble beds for solar energy storage are given in [8]. For such systems airflow rates should be kept to a minimum so as to minimize fan power requirements without affecting the performance of the pebble bed. Therefore an optimization process should be followed as part of the design.

(*c*) *Passive solar air heating and natural ventilation :* Passive solar heating and natural ventilation technologies share similar working mechanism. The driving force which controls the airflow rate is the buoyancy effect, whereby the airflow is due to the air temperature difference and so as the density difference at the inlet and outlet. Usually, the facades are designed in flexible functions basis whether to trap or store the heat; or create air movement that causes ventilation thus cooling effect.

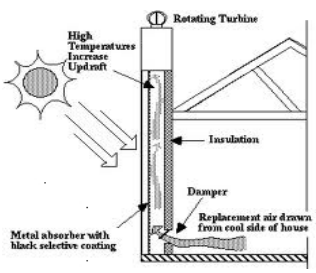

Fig. 4. Classical Trombe wall.

(*i*) *Trombe wall :* The classical Trombe wall is a massive wall that covered by an exterior glazing with an air channel in between as shown in Fig. 4. The massive wall absorbs and stores the solar energy through the glazing. Part of the energy is transferred into the building (the room) through the wall by conduction. Meanwhile, the lower temperature air enters the channel from the room through the lower vent of the wall, heated up the wall and flows upward bue to buoyancy effect. The heated air then returns to the room through the upper vent of the wall. Some of the challenges with this classical Trombe wall design are as follows: [9-12].

- Low thermal resistance.
- Inverse thermo-siphon phenomena occur during winter, at night or non-sunny day
- The uncertainty of heat transfer change in solar intensity causing temperature fluctuations of the wall
- The influences of channel width and the dimensions of the inlet and outlet openings affect the convection process and hence affect the overall heating performance
- Low aesthetic value

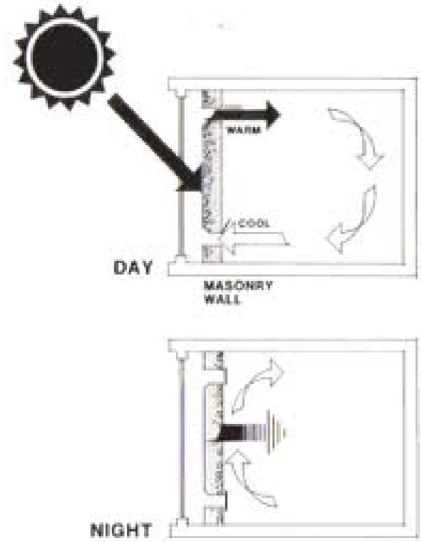

Fig. 5. Solar related air conditioning.

Studies have been carried out to improve the classical Trombe wall design. The improvement can be classified into three aspects, i.e. inlet and outlet air openings control, thermal insulation designs.

By installing adjustable dampers at the glazing and adjustable vents of the wall , the classical Trombe wall can be beneficial for winter heating and summer cooling [10] and [12]. The buoyancy forces generated by the solar heated air between the warm wall and glazing draws room air from the lower vent and the heated air is then flows out to the ambient through open lower damper. Thus, during summer the Trombe wall facilitates room air movement for summer cooling. Alternatively, in the case of Trombe wall that without adjustable damper at the glazing, the upper and lower vents are closed when the outdoor temperature is lower than the indoor [9].

(*ii*) *Solar chimney :* The purpose of the solar chimney is to generate airflow through a building, converting thermal energy into kinetic energy of air movement. The driving force which controls the airflow rate through the solar chimney is the density difference of air at inlet and outlet of the chimney It provides ventilation not only for cooling but also heating if fan is used to direct the heated air into the building when solar chimney is attached to wall the working mechanism is similar to Trombe wall. It operates as passive by supplying warm air that heated up by the solar collector into the room. For cold or moderate climate when the outdoor temperature is lower than the indoor temperature, solar chimney is functioned as passive cooling where natural ventilation is applied. However for hot climate, when the outdoor temperature is higher than the indoor, it operates as thermal insulation to reduce heat gain of the room. These three different modes are as illustrated in Fig. 6 [12]. The simplest and most obvious layout is to have a vertical chimney. Nonetheless, this may not be architectural attractive in term of aesthetics aspect. So a cheaper and less visually obtrusive format is to lay the collector along the roof slope while for greater height, a combination of both types may be used [12] and [13].

(*iii*) *Solar roof :* Methods of passive cooling by roof are such as water firm, roof pond, roof garden and thermal insulation. Solar roof ventilation may perform better then Trombe wall design in climates where the solar altitude is large. This is because roof collectors provide larger surface to collect the solar energy and hence higher air exit temperature [14]. Nevertheless, Khedari *et al.* [15] observed that with only roof solar collector system there is little potential to satisfy room thermal comfort Additional device such as Trombe wall to be used together with room solar collector would provide better cooling effect especially in hot climate.

III. CONCLUSIONS

Abundance of solar energy and the high ambient temperatures available in hot dry climates a direct solar cooling system can meet a large portion of the daily cooling load. Solar energy technologies such as slab cooling can be employed to minimize the daily cooling load requirements, by utilizing diurnal variations in temperature. The adoption of these technologies however, presents a considerable challenge to both building services, engineers and architects.

The research areas that need to be carried out to improve the existing solar technologies performance and market acceptance are the system efficiency, architectural aesthetic, and cost effectiveness aspects. They in fact have been carried out intensively Otherwise, research on development of a combination system could be an alternative.

Combination of heating and cooling systems is able to harness the solar energy throughout the year in countries with hot and cold seasons whereas hybrid of solar active and passive technologies would improve the system efficiency and effectiveness. Limitations of the technologies can be overcome by each others advantages and making the overall solar heating and cooling system feasible, more marketable and increase the public acceptance.

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