Solar-assisted cooling systems in green buildings: an overview

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Abstract
Enormous amount of energy is radiated from the sun. The electromagnetic waves emitted from the sun have three components namely i) ultra visible (UV), ii) visible (visible to human eye) and iii) solar infrared (near). The solar infrared waves transfer its energy in the form of heat to the object / building when it comes in contact with them. This solar energy is used for producing electricity, heating water, and cooling purpose etc. Hence scientists and engineers have focused their attention to invent new technologies for the effective use of solar energy. This paper highlights the use of solar energy in cooling systems. It is estimated that the demand for air-conditioning units has increased from about 25 million units (MU) in 1998 to more than 40 MU in 2006. The above demand has contributed to higher consumption of electricity and consequently to green house gas (GHG) emissions and global warming. This paper narrates the alternate method, of using solar energy for driving cooling systems in green buildings. It has been suggested to create awareness among consumers and engineers to divert their attention towards solar-assisted cooling systems for new invention and mass production with a view to reduce the unit price. The needs to encourage the research in India, especially for inventing affordable, small solar assisting air-conditioning systems in the near future, have also been emphasized. As a case study, the various data available in rural region of Karaikal were collected and analyzed to show the use of sun energy for cooling system for housing are also highlighted.

Keywords: Solar energy, closed systems, open systems, green buildings.

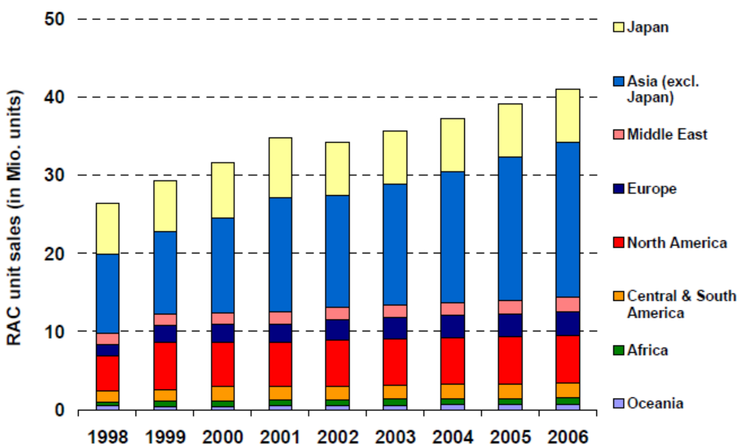
1. Introduction
Utilization of solar energy in green buildings for operating air-conditioning systems is to reduce the consumption of conventional energy and green house gas (GHS) emissions. As the use of solar energy in air-conditioning systems is quite a new technology, Engineers, Scientists, Architects of several countries world over, have diverted their attention towards invention of affordable, eco-friendly air-conditioning units or systems. The main reasons for using solar energy for air-conditioning are manifold. Some of them are: i) to reduce the use of fossil fuel consumption and thereby reduce GHG emissions; ii) to eliminate the use of refrigerants and thereby reduce ozone-depletion/global warming and iii) to reduce the consumption of electric power supply from the grids and thereby lead to considerable savings in power. The bottleneck that usually arises in solar thermal collectors used for heating and production of domestic hot water in the form of seasonal mismatch between heating demand and solar energy gains does not arise, if solar energy can be utilized for cooling of air and dehumidification. In order to reduce the amount of energy required and to minimize the investment volume/maintenance cost of air-conditioning systems, building planners should minimize the requirement of air-conditioning in buildings. However, in many cases like conference centers, theaters, department stores and multi-storey buildings etc, air-condition system is required to control the indoor temperature and air humidity. During the last decade, consumption of conventional energy for air-conditioning purposes had increased remarkably. For air-conditioning a small room up to a cooling capacity 12 kW, 11, 000 Gwh of electric energy is being used and it is expected that this value may increase by a factor of 4 to about 44, 000 Gwh by 2020.

2. Energy and Environment

Even though the performance of electrically driven chillers is relatively high in terms of energy consumption, it still requires a high amount of electricity and cause significant peak-loads in electricity grids. In typically cold climatic regions, this issue is a growing problem. Figure.1 shows the global scenario of total newly installed electric capacity due to room air-conditioner units (RAC) during 1998 to 2006. During summer severe shortage in electricity usually occurs due to the increase in the number of air-conditioning appliances, which has become a usual phenomenon, in a country like India-which is traditionally a power-starved/deficit country. In some countries, where the awareness or the impact of energy deficit has been well understood by the Govt. and people, building regulations are in place to limit the use of air-conditioning systems with conventional energy and the emphasis is on renewable energies for that purpose. Such an approach of using alternate energy forms will reduce consumption at peak load conditions. Another issue is leakage of refrigerant from air-conditioning appliances, particularly in automotive sector, which adds to global warming. On the other hand, the refrigerants used in thermally driven air-conditioners are eco-friendly and hence do not contribute to global warming.

Fig.1. *Cumulative newly installed electric capacity due to RAC unites*

(Source: European solar thermal industry federation)



3. Demand

The demand for air-conditioners is increasing day-by-day globally. Figure 2 shows the annual sales of room air-conditioners (RACs) in the different regions of the world. Worldwide the number of units sold has increased from about 26 million units (MU) in 1988 to more than 40 MU in 2006. At the same time, the market for centralized cooling equipment like small RAC split units, multi-split systems, centralized chilled water technology etc., have remained almost stable. To meet the needs of private residence worldwide, new eco-friendly small capacity range air-conditioners are required.

4. Innovative Solutions

During the last decade, to meet the growing demand for energy and to reduce environmental pollution, researchers opened the market for active solar systems. Figure 3 shows the whole set of technologies available to use solar energy for cooling. In general, the above technologies use solar heat to drive the cooling process. Thermally-driven cooling machines such as ab-or-ad-sorption chillers are driven by solar energy. A solar cooling installation consists of a typical solar thermal system made up of solar collectors, storage tank, control unit, pipes and pumps and a thermally-driven cooling machine. The high efficiency collectors namely double-glazed flat plate collectors or evacuated tube collectors are used in solar cooling systems. New developments for the medium temperature range (100-250^{o}C) could increase the overall efficiency of the cooling systems.

Fig.2. *Annual sales of small room air conditioners (RAC unites)*

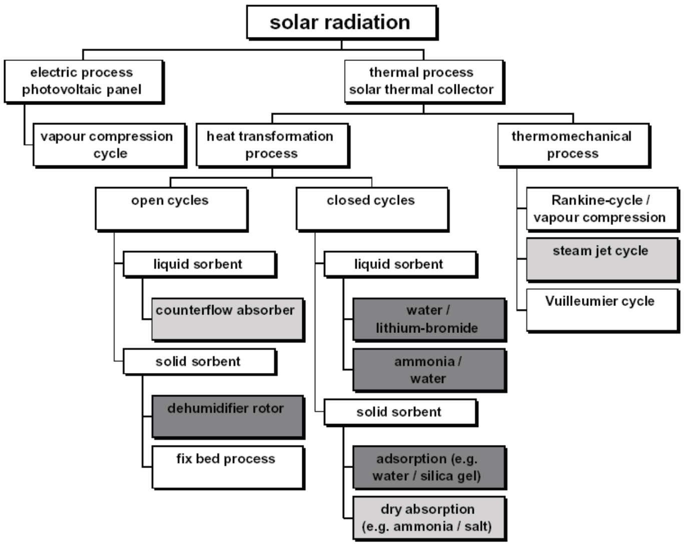
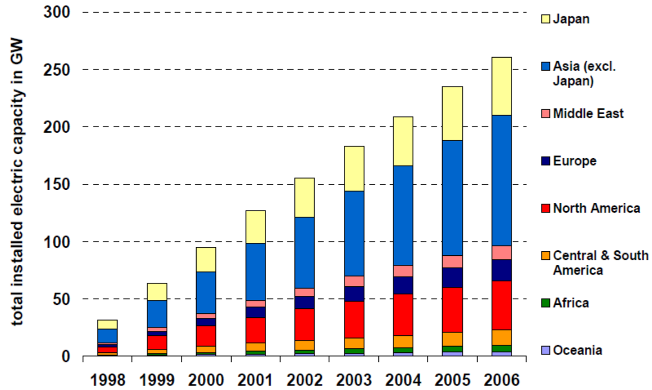


Fig.3. *Overview on physical ways to convert solar radiation into cooling or air-conditioning (Source: BRITA in Pubs)*



5. Solar Assisted Air-Conditioning

Solar assisted air-conditioning (SAAC) is one of the most widely used application for solar cooling. The solar assisted air-conditioning systems can be classified into: i) Closed systems -These are thermally-driven chillers which provide chilled water conditioned air i.e. cooled, dehumidified air is supplied by air handling units or distributed through a chilled water network to the designated rooms. The absorption chillers (most common) and adsorption chillers are available in the market; ii) Open systems - A complete air-conditioning is allowed by supplying cooled and dehumidified air in accordance with the comfort conditions. The refrigerant used for this purpose is water. Desiccant cooling systems using a rotating dehumidification wheel with solid sorbent is the most common system used for cooling purpose. The salient features of the closed and open cycles are listed in Table. 1.

Table 1. *Overview of the most common solar assisted air conditioning technologies*

method	closed cycle		open cycle	
refrigerant cycle	closed refrigerant cycle		refrigerant (water) is in contact to the atmosphere	
principle	chilled water		dehumidification of air and evaporative cooling	
phase of sorbent	solid	liquid	solid	liquid
				
typical material pairs	water - silica gel	water - water/ lithiumbromide, ammonia/water	water - silica gel, water - lithiumchloride	water - calcium chloride, water - lithium chloride
market available technology	adsorption chiller	absorption chiller	desiccant cooling	close to market introduction
typical cooling capacity [kW cold]	adsorption chiller: 50-430 kW	absorption chiller: 15 kW - 5 MW	20 kW - 350 kW (per Module)	-
typical COP	0.5-0.7	0.6-0.75 (single effect)	0.5->1	>1
driving temperature	60-90°C	80-110°C	45-95°C	45-70°C
solar collectors	vacuum tubes, flat plate collectors	vacuum tubes	flat plate collectors, solar air collectors	flat plate collectors, solar air collectors

6. Costs

Solar assisted air-conditioning systems require more technical apparatus than conventional systems. The re-cooling systems is larger in thermally-driven chillers (co-efficient of performance-COP is low) than the electrically-driven compression systems (i.e. the amount of heat to be removed is high). Therefore, the cost of thermally-driven chillers in term of refrigeration is higher than conventional systems and as a result higher investment cost is required for solar cooling. But there is relevant reduction in the operation costs. In general, the total cost (including capital costs, operating costs and maintenance costs etc.) of solar thermal methods are usually higher than the cost of conventional systems.

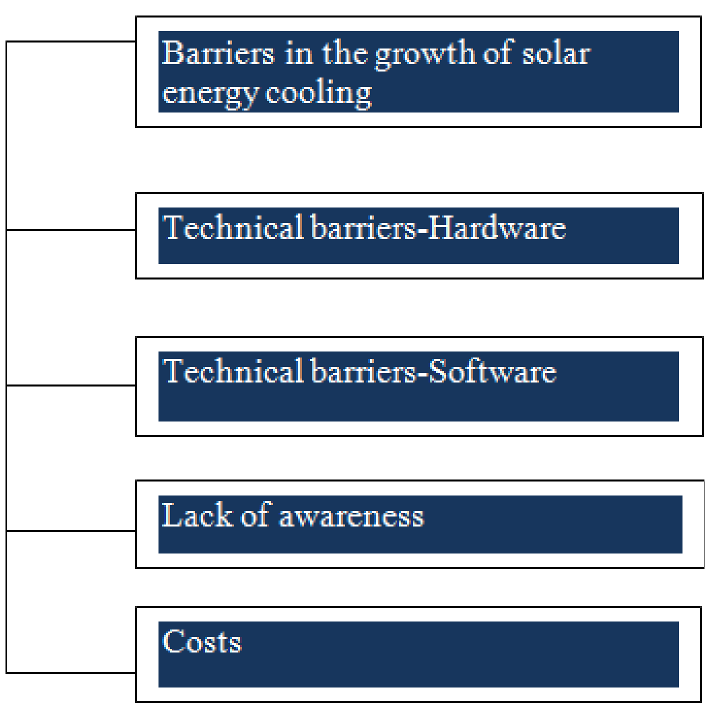
7. Applications of Solar Cooling Systems

Solar cooling systems are used in the following buildings effectively in well developed countries like UK, USA: i) Hotels - The installation of solar air-conditioner raises the share value of environmental-conscious tourists. Although the annual cost of a solar assisted air-conditioning system is higher than a conventional system, the resulting additional accommodation costs per guest per night are expected to be low compared to the average accommodation cost. The maximum cooling demand is required in the afternoon and evening and therefore appropriate measures in building construction and system design are necessary to optimize the solar system utilization. The medium cooling capacity systems which are available on the market can also be used based on need and comfort; ii) Private building sector - The market share of the combined domestic hot water production and heating support in transition periods has been increasing recently in central Europe. These systems can also be used as solar air-conditioning in summer (i.e.) reversible heat pumps for heating and cooling and no addition cooling back up; iii) Factories - Government should take steps to implement the solar assisted cooling systems in factories in a phased manner. In the first phase, the built-up area housing the administration and accounts department could be persuaded to use solar cooling and in the second phase, the remaining built-up areas could be modified to use solar cooling. As the built-up area in a typical industry is large, solar cooling fraction will not be very high. Another advantage is that the projects can be built faster than conventional works; iv) Office buildings-Normally internal loads due to the presence/use of large number of computers are significant and hence have to be accounted for calculating the cooling load. However, the planner should consider the holiday breaks if any that are normally available to make the project economical.

8. Barriers to Growth

In spite of specific advantages of using solar cooling systems, it has not been that widely used, which may be due to the following barriers (Figure 4). However, it is only a matter of time, the engineers, architects and scientists may evolve the best strategies thereby help to overcome these barriers

Fig.4. *Types of barriers*



The typical technical barriers in hardware are: i) lack of small capacity units (split units are needed); ii) lack of package-solutions like: domestic hot water, space heating and air-conditioning for residential and small commercial applications; iii) only few solar collectors are available for medium temperatures of 100-250°C; iv) the Co-efficient of thermal efficiency is low v) wet cooling tower is often needed. The technical barriers in software are: i)The available skills of planners and installers are very less today; ii) the design of hydraulic is not standardized iii) lack of knowledge in planning and designing, as the solar technology is a emerging field. But solar cooling system is more standardized; (iv) lack of awareness on the part of consumers and professionals and (v) relatively higher investment at initial stage/no financial incentive for solar thermal, which thus pushes back the growth of the solar cooling.

9. Real Time Implementation

Following areas are selected as examples of solar assisted cooling systems

Example1: Air-conditioning of a information office, Berlin

Implemented technology for cooling: Gravity cooling system
Installed cooling capacity : 2 x York WFC 10
Absorption cooling, chiller 35kW$_o$
Installed solar technology and Collectors area: Evacuated tube collectors, Gross area: 348 m^2
Absorber area: 244 m^2
Application: Office
Area of conditioned space: approx.1,300 m^2
Status of project: operation from 2001-2002

Example 2: Air-conditioning of Transport building, Berlin

Implemented technology for cooling: Gravity cooling system, Cold ceiling, Cooling coil, Fan coil
Installed cooling capacity : 2 x York WFC 10,
Absorption cooling machines 35kW$_o$ 1 x York YCWM 60, Compression chiller 65 kW$_o$ 1 x York YCWZB33AB, Compression chiller 180 kW$_o$
Installed solar technology and Collectors area : High efficient flat plate collectors, Gross area: 229 m^{2}Absorber area: 209m^2
Application: Office
Area of conditioned space: approx.1.500 m^2
Status of project: operation from 2001

Example 3: Air-Conditioning of a seminar room, Freiburg

Use: air-conditioning of the seminar room and the cafeteria in an office building of the local chamber for trade & commerce
Site: Freiburg (south-west Germany)
Solar thermal collector filed: 100 m^2 of air
collectors as the only heat source cooling system: desiccant cooling system (10.200 m3 per hour) with silica gel rotor
Specifics: No back-up system, no storage, Simple solar system, simple integration into the air-conditioning plant

10. Recommendations and Suggestions

Solar cooling is the only solution to meet the ever-increasing energy demand for cooling purpose. It uses less convention fuels / electricity and thereby avoids CO_2 emissions. Due to the proven and strong advantages, the Government should take necessary steps at the earliest in a time-bound manner to overcome the barriers so as to pull back the growth of solar cooling. With the above view some of the suggestions or recommendations are listed below: i) Fundamental research in development of new cooling cycles and development of systems with higher temperature lift, are needed in order to remove the wet cooling towers and thereby reduce the size and cost. Such research should be encouraged with liberal funding and support from the Government; ii) Applied research and development in manufacturing of small capacity systems, development of hydraulic concepts, development of advanced modeling and simulation tools should be started immediately; iii) For creating awareness, specific training courses for professionals, inclusion of solar cooling technologies in the engineering curriculum, organizing campaigns for the immediate benefit of builders, architects, electricity supply companies etc. should be planned with the aid and support of Government, iv) Announcement of financial incentive schemes, award of white or renewable energy certificate scheme to the best consumer who implements the solar cooling system effectively in their buildings; v)Regulatory measures like inclusion of the above concept and systems within the regulatory framework of building regulations; reduction of cooling loads through solar cooling/ use of renewable energy for cooling; vi) prohibition of refrigerants which traditionally contribute to high global warming should be done periodically.

11. Case Study

For the case study Karaikal was chosen for effective implementation of green concepts through solar assisted cooling system. Karaikal is small town, which is located on the coast of Bay of Bengal and a part of United Territory of Puducherry. Around 60% of the populations are living in rural areas of Karaikal district. It is located on 10°58’29”N latitude and 79°49’43”E departure and hence it is receiving enormous of amount of heat and light energy from sun. This energy can be used for producing electricity, cooking food and heating water. The enormous amount of heat from sun can be used for cooling purpose through photo-voltaic panels.

12. Concluding Remarks

The concept of solar-assisted cooling systems i.e. use of solar energy for air-conditioning units to reduce the use of conventional energy (electricity) is highlighted. The two types of solar assisted cooling systems namely, closed systems and open systems with salient features have been described briefly. The cost of the systems barriers to growth and suggestion to overcome these barriers has also been highlighted. The effective implementations of this system in Berlin, Freiburg of Germany are presented to create awareness among public. Since this system is a emerging technology, the cost of the system may be higher than the conventional system. Further research is needed to invent cost effective, small solar assisted cooling systems. India can save considerable amount of electricity by using solar energy in air-conditioning in the coming decades. The use of solar heat for cooling purpose through photo-voltaic panel for housing are also highlighted especially for the rural region of Karaikal as a case study.

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