Solar air conditioning and its role in alleviating the energy crisis of the Mediterranean hotels

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**ABSTRACT**

The Intergovernmental Panel on Climate Change (IPCC) has estimated that the Mediterranean region could experience an increase in annual mean temperatures up to 4.5 °C by 2080. Within the same timeframe, fossil fuel stocks are predicted to diminish, resulting in ever-increasing fuel prices. Furthermore, there is continuous political pressure to impose greenhouse gas levies and quotas for industries and services alike, thus adding to their operational expenditure. The region's climate change and increased fuel prices not only raise their operating costs but may also suffer from reduced tourist flows if the airline industry is forced to increase travel prices. It is in this context of a predicted 'energy crisis' that this study was undertaken in order to evaluate the extent to which hotels can future-proof their operations. Integration of renewable energy sources into hotel operations is perceived as the most promising form of crisis mitigation. In the Mediterranean region, the availability of solar irradiation is abundant and free from microclimatic limitations associated with wind energy in comparison. Therefore, solar assisted air conditioning was identified as a key strategy because its operational principal dictates that the greatest availability of energy coincides with the peak demands.

The aim of this paper is to review the currently available solar air conditioning technologies, their energy saving potential and technical limitations. The study is based on a literature review supplemented with information available from equipment vendors. Subsequently, the objective of this paper is to set solar air conditioning equipment selection criteria that could assist hotels of various service classes in their energy planning and equipment upgrades.

1. INTRODUCTION

1.1 General

The Mediterranean region is a popular tourist destination and many Mediterranean countries have come to heavily rely on the income provided by tourism. Traditionally, the region has been associated with mild climate and unsurpassing natural beauty. However, the past decade has established a new climate pattern for the area that includes extreme and extended heat waves and draughts. Eight of the hottest years on record in the northern hemisphere fall within the past decade and 18 within the past two decades, years 2005 and 1998 tying for the first place (Union of Concerned Scientists, 2006). At the same time, the era of cheap fossil fuel has come to an end, and newly awakened concerns about fossil fuel security have further made dependency on them less desirable. In addition, the mean annual temperatures are predicted to rise in the order of 2.27-4.52 °C between 2050 and 2080 further exacerbating the problem (McCarthy *et al.*, 2001).

1.2 The problem

The Mediterranean tourism industry is very much facing the above dilemma with increasing operational costs, cooling costs in particular, as hotel guests have become increasingly demanding in terms of thermal comfort during their hotel stays. In addition, a part of the travelling expenses may have to be absorbed by the hotel industry in the future if and when the airline industry is forced to increase travel prices. It is in this context of a predicted 'energy crisis' within the hotel industry that this study was undertaken in order to evaluate the extent to which hotels can future-proof their operations. Integration of renewable energy sources into hotel operations is perceived as the most promising form of crisis mitigation. In the Mediterranean region, the availability of solar irradiation is abundant and free from microclimatic limitations associated with wind energy in comparison. Therefore, solar assisted air conditioning was identified as a key strategy because its operational principal dictates that the greatest availability of energy coincides with the peak demands.

1.3 The remedy

Reduction of internal loads represents the first order of action to be taken when embarking on improving en-
nergy efficiency. Internal loads can be reduced in many ways but it is particularly beneficial to control the use of lighting and other heat producing equipment. By shifting towards low energy lighting and rational use of equipment, double benefits can be reaped, namely direct energy savings together with internal load reduction. Of equal importance is to apply passive strategies such as solar shading of windows to regulate unwanted solar gains (Santamouris, 2005). Similarly, other building envelope related improvements can be introduced, for example roof insulation (Delorme et al., 2004).

Finally, the second order of action has to do with improving the cooling plant, and solar cooling stands out as an attractive alternative for conventional electrically driven air conditioning systems in the Mediterranean region. Therefore, it is suggested that solar cooling could play an important part in alleviating the pressure from the ever increasing cooling demands and fossil fuel prices. This paper takes a look at the available solar cooling technologies and discusses their applicability within the Mediterranean hotel industry.

2. HISTORY OF SOLAR COOLING

Solar heating and cooling has been in the agenda of the International Energy Agency (IEA) since 1977 (IEA, 2007). The first energy crisis that led into the establishment of the Agency also gave impetus for launching systematic research and development activities in the area of solar heating and cooling applications. However, the R&D activities over the past thirty years in solar cooling in particular have not lead into large scale commercialisation of the technology. Several pilot plants have been built and successfully operated but their purpose has been to test and prove the technical feasibility of solar thermal cooling processes rather than to make the technology economically viable and competitive. The decades of cheap fossil fuel did little to help promoting the technology and subsequently it was not until the late 1990s that renewable energy gained new momentum in the energy agendas of local governments and international organisations alike.

Solar cooling was reintroduced into the agenda of the IEA in 1999 under Task 25: Solar assisted air conditioning of buildings. The task was completed in 2004. Since then a new task, Task 38: Solar thermal cooling and air conditioning, was launched and is expected to complete in 2010. Solar thermal water heating applications are gaining market share and the reported annual collector yield i.e. the energy produced in 2004 was 58.1 TWh corresponding to an oil equivalent of 9.3 billion litres and CO₂ emissions reduction of 25.4 million tons (IEA, 2007). The healthy increase in demand of solar water heating systems has had a positive impact on solar thermal panel prices as well as on fuelling further research and development activities in panel efficiency and larger temperature range. Improved solar thermal panel characteristics in turn make solar assisted air conditioning applications possible by enabling higher water temperatures that are required in solar cooling processes.

3. SOLAR AIR CONDITIONING TYPES

3.1 General

Solar energy can be utilised in two ways to power air conditioning, namely through photovoltaic (PV) power generation or via solar thermal processes. PV power generation can be coupled with conventional air compression type cooling systems. However, due to low efficiencies and subsequently high price of PV electricity conversion, such systems are not economically viable. PV assisted cooling has its applications in residential use where relatively small panel areas can shave off peak power demands and thus assist in more efficient utilisation of national grids. As for large commercial applications, such as hotels that are the main focus of this paper, thermally driven cooling processes are perceived as the primary solutions for comfort cooling. Both system types are briefly discussed below.

3.2 Solar hybrid air conditioning

A hybrid air conditioning system has been developed in America based on the principle of conventional cooling systems. A battery bank is added to allow electricity storage and dual wiring enables the operation of the equipment both by AC and DC current. Therefore, the system can be connected to photovoltaic panels and solar electricity can be stored during the daytime and used in the evening. Furthermore, the equipment’s ability to utilise direct current has made it possible to reach higher efficiencies and subsequently the manufacturer claims a coefficient of performance (COP) of 6.94 for a unit with 18000 BTU (5.3 kWh) of cooling and 11000 BTU (3.2 kWh) of heating capacity (SolCool One, 2006). The battery bank can be sized for 12-24 hour storage capacity and hooked into 300 W direct feed PV panels. The system is scalable and the current installed retail costs are quoted at around US$1140/kWh of cooling. Direct current lighting and ceiling fans can be connected to the battery bank as well and an air filtering process is built into the system thus improving indoor air quality. The system has its merits particularly in areas where grid power is intermittent and unreliable. Further, it is claimed that the system energy consumption is less than one fifth of that of high efficiency conventional AC systems (SolCool One, 2006).
3.3 Thermally driven cooling systems

Thermally driven cooling systems can be divided into three categories, namely absorption, adsorption and desiccant systems. All systems are briefly discussed below. It is beyond the scope of this paper to explain the processes in detail but rather to consolidate the commercially available solar cooling technologies for comparison and in particular to evaluate their application in the Mediterranean tourism industry.

3.3.1 Absorption chillers

An absorption chiller consists of a generator, condenser, absorber and an evaporator. Absorption process utilises a working pair of liquids that enables heat absorption. Lithium-bromide (Li-Br) is commonly used for cooling applications and provides chilled water at 5 °C. Ammonium-water working pair is used in refrigeration and can provide chilled water below 0 °C. The process follows a principle that the refrigerant (water) is evaporated at low pressure thus extracting heat from a low temperature heat source. The refrigerant vapour then flows from the evaporator to the absorber where it is absorbed by a concentrated solution of liquids (working pair as explained above). The absorber must be cooled in order to keep the process going. The diluted solution is then pumped to the generator where it is heated above its boiling point by the driving heat source and the vapour is released at high pressure. The vapour is cooled and liquefied in the condenser thereby releasing heat that needs to be rejected via a cooling medium. Finally, the refrigerant flows back to the evaporator through an expansion valve so as to lower its pressure and the cycle begins again (Altener Project, 2002). An absorption chiller can replace a conventional chiller and utilise the same cooling tower and cooled air distribution infrastructures making it a good candidate for retrofits. The technology is mature and widely commercially available and the estimated specific costs of cold production are around 250 €/kW not including the point of use distribution infrastructure (IEA, 2002b). The manufactured equipment has traditionally been large in capacity (15-5000 kW) (Delorme et al., 2004) but the current R&D activities are concentrated on developing of small scale (<5 kW) machines for domestic applications.

3.3.2 Adsorption chillers

Instead of liquid-working pair as in absorption chillers, the adsorption process utilises liquid-solid working pair where the porous solid adsorbs the liquid refrigerant. Typical working pairs are water/silica gel, water/zeolite, ammonia/activated carbon and methanol/activated carbon but the only pair commercially available is water/silica gel (Altener Project, 2002). An adsorption cooling machine consists of two sorbent compartments, a condenser and an evaporator. According to the working principle of adsorption, the refrigerant is gasified and driven off from the ‘hot’ sorbent compartment by the use of hot water from the heat source in order to be condensed in the condenser. The heat of condensation is removed by cooling water and the condensate is sprayed in the evaporator where it evaporates under low pressure thus producing the cooling effect. The vapour refrigerant is then adsorbed by the other sorbent compartment, the ‘cold’ side and heat is removed by cooling water. The operation continues until full saturation of the adsorbent in one compartment and full regeneration in the other are achieved after which their functions are reversed. This alternate heating and cooling of the adsorber makes the process time dependent unlike the absorption process that operates as a continuous loop (Altener Project, 2002). Driving temperatures of 60-80 °C can successfully op-
erate an adsorption machine and COP in the order of 0.6 can be expected. The adsorption machine requires no pumps thus further reducing its electrical power consumption. Furthermore, the equipment is robust and low maintenance but bulky and heavy on the negative side. Adsorption machines in capacities of 50-500 kW are commercially available but due to the limited demand and number of manufacturers, the current prices are higher in comparison to absorption chillers (IEA, 2002c). Hybrid systems are under development where a booster pump is added in order to improve the vapour flow from the regenerator bed to the condenser thus making the regeneration easier and possible with lower driving temperatures (as low as 50 °C with COP of 0.52) (IEA, 2002a).

3.3.3 Desiccant cooling systems
Desiccant cooling combines evaporative cooling with desiccant dehumidification. Outdoor air is first dehumidified so that evaporative cooling for heat rejection can be utilised without over-humidifying the air supply (Altener Project, 2002).

The dehumidification can be realised either by the use of solid or liquid desiccants. Rotating wheels or periodically operated fixed-bed systems employ solid desiccants whereas liquid desiccants come in the form of packed towers.

Liquid desiccant system is an open-cycle absorption system meaning that the refrigerant comes in direct contact with the environment. Due to that, limited number of working fluid pairs can be utilised and most commonly salts such as lithium or calcium chloride dissolved in water are used. These salts enable the absorption of humidity in the air by lowering the water vapour pressure. External heat source is required to regenerate the salt solution and driving temperatures of about 60-70 °C suffice (Altener Project, 2002). Desiccant cooling systems are available in 20-350 kW capacities (Delorme et al., 2004). Liquid desiccant systems can store cooling capacity by concentrating the salt solution. Therefore, the system can regenerate when solar energy is available and utilise it when cooling is needed independent of the heat supply. This storage capacity that is of compact form, indefinite in storage time and requires no insulation is the key advantage of desiccant cooling systems. The process can further be enhanced by employing a cooling system, either water or air, into the absorption process that creates a high concentration difference thus increasing the storage capacity (Altener Project, 2002).

3.4 Solar collectors required for solar AC
Solar collectors required for each cooling system depend on the driving temperature of the heat source. Desiccant cooling can utilise standard flat plate collectors and solar air collectors whereas single-effect absorption machine typically requires high efficiency evacuated tube collectors. The highest temperatures can be produced by fixed mounted evacuated tube collectors using optical concentration or tracking collectors using high optical concentration (Altener Project, 2002; Delorme et al., 2004). The specific costs of solar collectors are estimated as follows:
- flat plate collectors: 153-614 €/m²
- evacuated tube collectors: 511-1278 €/m²
(Solarfrost, no date)

4. SELECTION CRITERIA FOR SOLAR COOLING EQUIPMENT

4.1 Cooling loads
An essential prerequisite for selection of the appropriate cooling equipment is an accurate estimate of the cooling loads. Quite often conventional air conditioning systems are oversized which leads into partial load operation of the equipment. Partial load operation is inefficient and wasteful in terms of energy consumption. Therefore, the importance of load estimation cannot be overemphasized.

Some of the parameters that influence the cooling loads are building materials, use of thermal mass, geometry and orientation (glazing in particular) together with the internal heat gains and climatic conditions (outdoor temperature and humidity) of the site (Henning and Albers, 2004). As discussed earlier, cooling loads can be significantly reduced by applying bioclimatic design principles into a building. Such measures are the easiest and cheapest to integrate during the design phase but an array of improvements can be implemented on existing buildings, such as shading devices (up to 19% savings) or roof insulation (3-6% savings) to name a few. In addition, internal loads can be further reduced with energy efficient lighting (10-13% savings) (Delorme et al., 2004).

4.2 Selection of equipment
The primary selection criteria for solar cooling equipment are the cooling loads and the required hygienic air change of the cooled space. Secondly, a decision between all air, all water or hybrid system is to be made. It is to be noted that air tightness of a building plays an important role when selecting the cooled medium distribution system. For an efficient operation of supply/return air systems the building envelope has to be tight enough. Subsequently, the climatic conditions such as the availability of solar radiation, ambient temperatures and relative humidity need to be considered as different solutions are applicable in different climatic conditions (Henning and Albers, 2004). Furthermore, the need for
backup system requires careful evaluation in connection with the desired solar fraction of the operation; 100% solar fraction may not be economically viable. It is to be noted that the investment costs of solar cooling are higher than those of conventional AC due to low COP that requires large solar collector areas. Secondly, some of the equipment are produced in small quantities and have not yet reaped the benefits of price reduction due to mass production, although desiccant cooling can already be competitive in price (Delorme et al., 2004). Maintenance costs of solar AC, on the other hand, are expected to be lower due to equipment robustness and small number of moving parts.

5. CONCLUSIONS

Solar cooling has the potential of significantly reducing the electricity consumption of the Mediterranean hotels. Although most of the current solar cooling applications are demonstration projects in nature, the technologies are mature. Research and development activities are concentrated in improving the COP as well as making the equipment smaller in size and more affordable. It is of vital importance to select the right equipment for each application depending on the desired performance specifications. Careful analysis of internal loads is required to size and specify the equipment correctly. Hotel operators and other stakeholders need to break free from considering only the financial payback and embrace the long term benefits of solar cooling that contribute towards energy independence and environmentally friendly goals in a larger scale.

REFERENCES