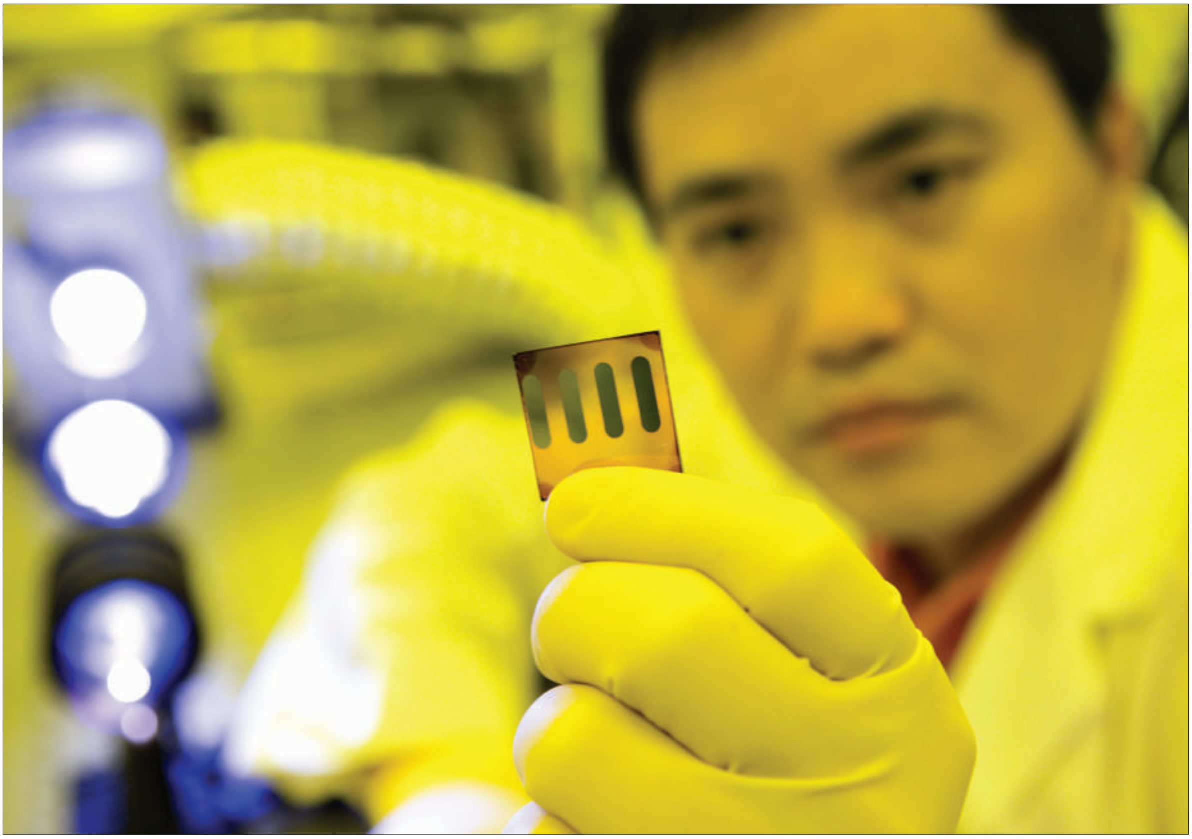

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Solar Cooling: A Potential Option for Energy Saving and Abatement of Greenhouse Gas Emissions in Africa

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ABSTRACT

This study presents Solar cooling as a potential option for energy saving and abatement of greenhouse gas emissions in Africa. Solar cooling is the use of solar thermal energy to drive a refrigeration cycle in order to operate a cooling appliance. Owing to growing need for cooling load, more and more buildings are being fitted with conventional cooling systems globally leading to a sharp rise in power consumption. On the other hand, concerns regarding the adverse environmental impact of using fossil fuels has necessitated the exploitation of alternative cooling technologies, especially solar assisted cooling. Apart from the fact that conventional, electrically driven air conditioning systems are less diffused in Africa, most countries in the continent are located near the equator with intense all-year-round solar radiation, which makes them suitable locations for the adoption of solar cooling technologies. Solar thermal energy can be coupled to any of four major conventional cooling techniques, namely absorption cooling, desiccant cooling, vapour compression and evaporative cooling. Among these, evaporative and desiccant cooling technologies appear to have the highest potential for energy savings in domestic space heating as well as Greenhouse Gas (GHG) abatement in Africa. On the other hand, although conventional vapour compression systems have high efficiency, they are not recommended for widespread use since they utilize Hydrochlorofluorocarbons (HCFCs) and Chrorofluorocarbons (CFCs), which tend to deplete the ozone layer.

Key words: Solar, refrigeration, power, greenhouse gas, equator, Africa

INTRODUCTION

With record-breaking hot summer days in the recent years, the demand for air conditioning in offices, hotels, laboratories and public buildings such as museums is increasing at an alarming rate. More and more office buildings are already being fitted with conventional cooling systems causing sharp power consumption rise (Ion, 2009). Italy and the USA (California) in Summer 2003 and Australia on Black Wednesday in 2004, for example, have already seen their electricity grids overloaded as a result of this situation. In many countries air conditioning is one of the highest energy consuming services in buildings (Anonymous, 2009). Conventional cooling technologies are generally based on electrically driven refrigerating machines, which have several disadvantages:

they lead to high levels of primary energy consumption, cause high and expensive electricity peak loads and usually employ refrigerants with negative environmental impacts. Conversely, the clever idea behind solar cooling is to use the very source of the high temperatures, i.e., the sun, to power the chillers. Indeed, a solar thermal system is most effective and the demand for cooling, at its highest when the sun is shining most intensely (Sharma and Marano, 1992). Solar energy can therefore, be used to cool buildings because the demand for cooling rises and falls almost in sync with the amount of solar energy available (Sharma and Marano, 1993; Ion, 2009). Compared to other solar energy applications, solar cooling is a relatively new, but fast growing, technology. Solar thermal energy can be coupled with established cooling technologies namely: absorption cooling (which can use solar thermal energy to vaporize the refrigerant); desiccant cooling (which can use solar thermal energy to regenerate (dry) the desiccant); vapour compression cooling (which can use solar thermal energy to operate a Rankine-cycle heat engine) and evaporative cooling (which includes heat pumps and air conditioners that can be powered by solar photovoltaic systems) (Wuppertal Institute, 2007). Although, many projects using the technology are still for demonstration purposes only, a growing number of systems are being implemented all over the world for conventional use.

Passive solar cooling based on bioclimatic strategies such as sun protection using natural screening devices or increased cooling by using ponds or water basins on the roof or close to the external walls, is widely applied and could be the first step to take in cooling a building. Since, such measures are easier and less costly to implement, they decrease the need for additional cooling and therefore, reduce overall energy demand. Sufficient insulation of the building also decreases the need for cooling, as well as for heating. If the outcome of these measures is not sufficient, a solar assisted cooling system may be an inevitable solution. In solar assisted cooling systems solar heat is used to drive the cooling process for air conditioning in buildings. Instead of using electricity, free solar thermal energy is harnessed for cooling through a thermo-chemical sorption process.

The sun shines everywhere, especially in areas located near the equator and delivers surplus heat. Most African countries are located between 30° N and 30° S of the equator and can derive maximum benefit from solar energy. Solar cooling saves electricity and has, as distinct from solar heating, absolutely no storage needs. Moreover, with energy costs expected to rise in the near future, solar cooling could become a natural alternative to conventional systems. Under adequate conditions, solar and solar-assisted air conditioning systems can be reasonable alternatives to conventional air conditioning systems. Such systems have advantages over those that use problematic coolants (CFCs), not to mention the incidental CO_2 emissions that are taking on increasingly critical values. Additionally, they can make huge energy savings in conventional energy of between 40 and 60% in chilled water systems (Wuppertal Institute, 2007). This, in turn, also reduces the pressure on electricity grids, which can sometimes reach their capacity limit on hot days. This study outlines the technologies and examines the potentials of solar air conditioning in Africa and its potential effect on climate change abatement.

JUSTIFICATION FOR SOLAR COOLING TECHNOLOGY

Although, electrically driven chillers have reached a relatively high standard in terms of energy efficiency, they still require a high amount of electricity and-even more importantly-cause significant peak loads in electricity grids. This is becoming a growing problem in regions with cooling dominated climates such as most parts of Africa. According to ESTIF (2006) (Fig. 1) the total newly installed electric capacity due to Room Air-Conditioner (RAC) units since 1998 has been

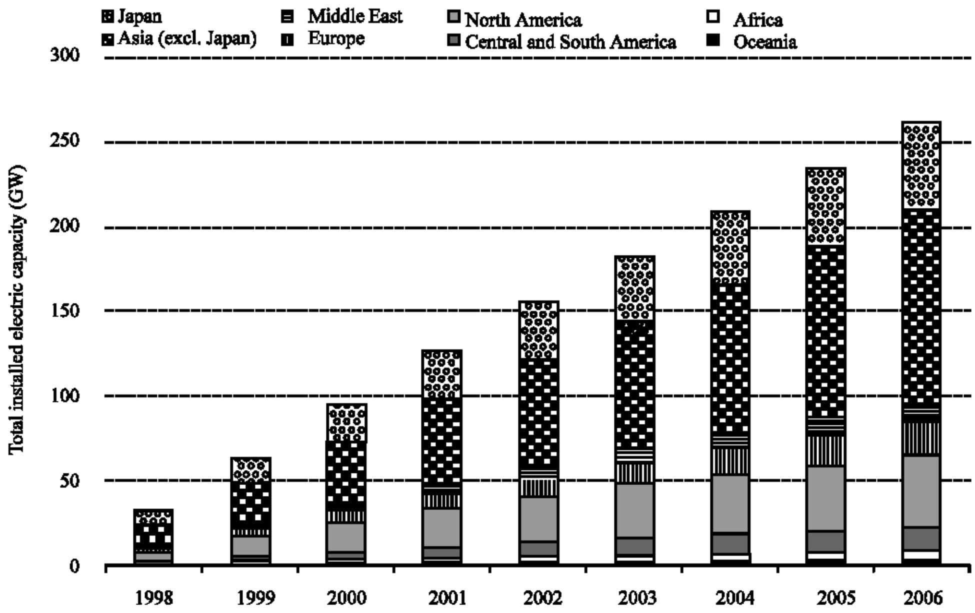

Fig. 1: Cumulative newly installed electric capacity due to RAC units. ESTIF (2006)

increasing especially in Asia and the Americas. This is assuming a replacement of 10% year^{-1} and an average electric capacity of 1.2 kW unit^{-1}. It is also quite clear from the figure that Africa has much fewer new RAC installations in comparison with Europe, Asia or North America, an indication that there is large room for growth, particularly in the use of solar air cooling technology (Sabatelli *et al.*, 2006). In recent years, an increasing number of cases have occurred, in which summer electricity shortages were created due to air-conditioning appliances. The dominance of small, split systems in private residences is a common trend worldwide. Therefore, in order to limit the negative impact of peak energy consumption on the electricity network management, new environmentally sound concepts for the small capacity range are of particular importance. This underlines the necessity of new solutions with lower electricity consumption and in particular reduced consumption at peak electrical loads. This could translate into both energy savings and also reduction in future emissions of climate change agents. Refrigerant leakage in air-conditioning appliances-in particular in the automotive sector-has led to several legislative initiatives towards limitation or even prohibition of classical fluorized refrigerants. On the other hand, virtually all thermally driven technologies use refrigerants which have no adverse global warming potential.

PRINCIPLES OF SOLAR AIR CONDITIONING

In solar cooling systems, heat energy from the sun is used to drive the cooling process. Thermally driven cooling machines, such as ab-or ad-sorption chillers have been used for decades, but have been powered mainly by industrial waste heat or by district heat. The basic principle behind (solar-) thermal driven cooling (Fig. 2) is the thermo-chemical process of sorption: a liquid or gaseous substance is either attached to a solid, porous material (adsorption) or is taken in by a liquid or solid material (absorption). The sorbent such as silica gel (or any other substance with a large inner surface area) is provided with solar heat and is dehumidified. After this drying, or desorption, the process can be repeated in the opposite direction. When providing water vapour or steam, it is stored in the porous storage medium (adsorption) and simultaneously heat is released.

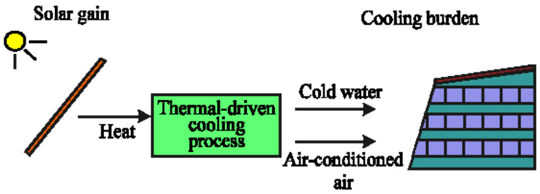

Fig. 2: Basic structure of a solar air conditioning system. Hug (2009)

One of the most widely adopted applications of solar cooling is air conditioning (often termed solar assisted air conditioning). Depending on the operating principle used, it is possible to distinguish between closed chillers, which provide cold water and open, sorption-based systems, which are used to condition air directly. Open systems normally employ a combination of sorptive air dehumidification and evaporative cooling, which is used in ventilation systems for treating air. Sorption-based air-conditioning is in effect a mature technology. In open systems, both the humidified exhaust air and supply air serve as coolants. The supply air is blown directly into the room through a heat recovery process and minimum supply air temperatures lie between 16 and 18°C. In addition to the available refrigerating capacity, the relationship between drive heat and realized cold energy termed Coefficient of Performance (COP) is also an essential performance index of such systems.

Components of a solar cooling system: A solar cooling installation consists of a typical solar thermal system made up of solar collectors, storage tank, control unit, pipes, pumps and a thermally driven cooling machine. To date, most collectors used in solar cooling systems are the high efficiency collectors available in the market today (often double-glazed flat plate collectors or evacuated tube collectors). New developments for the medium temperature range (100-250°C) could increase the overall efficiency of the cooling process (ESTIF, 2006).

TYPES OF SOLAR COOLING SYSTEMS

There are several ways of coupling solar thermal technology with conventional cooling technologies, namely absorption cooling, desiccant cooling, vapour compression cooling and evaporative cooling (Wuppertal Institute, 2007; Grieco and Sharma, 2008). Each solar cooling technology has specific features, advantages and disadvantages which shall be highlighted in this section. Although solar assisted air cooling offers great advantages, a fundamental problem arises from the inherently higher costs of solar heat compared to heat energy produced by fossil fuel systems or waste heat (Balaras *et al.*, 2007). Compared to conventional cooling systems, the initial costs are about 2 to 2.5 times higher.

Absorption cooling: Absorption cooling technology is a form of heat pump technology, which uses solar thermal energy to change the refrigerant into a vapour. Absorption systems typically use ammonia, hydrogen gas and water. At normal conditions ammonia is a gas with a boiling point of -33°C, but the absorption cooling system is at elevated pressure such that the ammonia is held in a liquid state at room temperature.

The evaporator part of the absorption cooling system contains the hydrogen, which lowers the partial pressure of the ammonia by filling the space created, so that not all of the pressure is exerted by ammonia. The boiling point of the ammonia is lowered so that it will now boil below room temperature, as though it was not under the pressure of the absorption system. When the ammonia boils, it removes some of the heat from the evaporator, thus producing the desired cool temperature.

The next step is the absorption phase, which involves the separation of the NH_3 from the H_2 thus transforming the ammonia gas back into its liquid state. Separating the hydrogen is relatively simple as ammonia readily mixes with water whereas hydrogen does not. The gases flow into the absorber, which is a cascade of tubes where the mixture of gases flows while water drips from mixing with the gases separating the hydrogen from the NH_3. At this point, it is necessary to separate the ammonia from the water. This is achieved by heating the ammonia water mixture until the ammonia evaporates out. This phase is known as the generator.

The water is then circulated back through the absorption phase. The next phase of the process is known as the condenser and is where a heat exchanger cools the ammonia gas to room temperature, reverting back into a liquid state because of the pressure and the absents of hydrogen. The condensed ammonia is now suitable as a refrigerant and the process starts all over again. The key aspect of the absorption cooling system is that it cools by using heat energy, rather than mechanical energy. The mechanisms of an absorption chiller have to be integrated more closely than those of a compression system. This results in all absorption systems being contained within a single compact unit. It is for this same reason that there are few variations between absorption cooling units. The main variations between models seem to be in the heat source and also in the number of stages or phases. Originally, steam or high-temperature water was the energy source for absorption chillers. However today, this is being replaced with direct firing using an integral boiler because of its improved efficiency.

Chillers: Compared to open systems, heat-driven (absorption or adsorption) chillers most closely resemble common vapour-compression systems in terms of their integration into buildings. The chillers provide cold water at temperatures between 4 and 20°C (Broeze and van der Sluis, 2009). They can therefore be used for central air-conditioning as well as cooling systems with decentralised air treatment (such as fan coils and cooling ceilings). Standard configurations for single-stage chillers produce COP values (COP = Coefficient of Performance) of around 0.6 to 0.7.

Absorption chillers: Solar-powered absorption chillers use hot water from solar collectors to desorb already-pressurized refrigerant from an absorbent/refrigerant mixture (such as water/lithium bromide and ammonia/water). Condensation and evaporation of the refrigerant vapour provides the same cooling effect as that provided by mechanical cooling systems. Although absorption chillers require some electricity for pumping the mixture, the amount is very small compared to that consumed by a compressor in a conventional electric air conditioner. A solar actuated cooling system consists of a cooling tank with an evaporator integrated into the lid, which contains water as a coolant. In addition, there are one or more zeolite containers, a hand vacuum pump and a parabolic collector. In order to adequately dry the zeolite, a temperature of over 250°C is necessary, making a concentrating system necessary. Flat collectors cannot reach such a high temperature. A solar boiler parabolic collector will be used for the described cooling system.

Absorption chillers are the most widely used chillers throughout the world although most of the installations are located in countries with mild climate such as southern Europe, China and the Mediterranean (ESTIF, 2006; Sparber *et al.*, 2007). Thermal compression of the refrigerant is achieved by using a liquid refrigerant/sorbent solution and a heat source, thereby replacing the

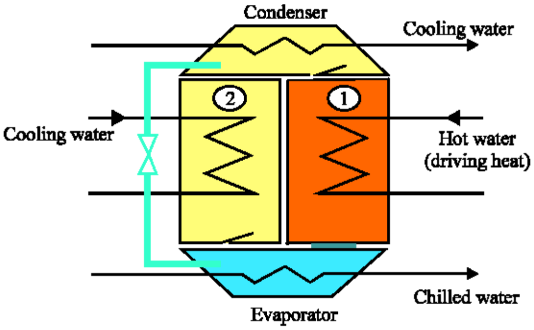

Fig. 3: Principle of an a dsorption chiller. Coroyannakis *et al.* (2009)

electric power consumption of a mechanical compressor. For chilled water above 0°C, as is used in air conditioning, a liquid H_2O/LiBr solution is typically applied with water as a refrigerant. Most systems use an internal solution pump, but consume only little electric power (Samen, 2006). In the operation of an H_2O/LiBr absorption chiller, the cooling effect is based on the evaporation of the refrigerant (water) in the evaporator at very low pressure. The vaporized refrigerant is absorbed in the absorber, thereby diluting the H_2O/LiBr solution. To make the absorption process efficient, the process has to be cooled. The solution is continuously pumped into the generator, where the regeneration of the solution is achieved by applying driving heat (e.g., hot water). The refrigerant leaves the generator by this process, condenses through the application of cooling water in the condenser and circulating by means of an expansion valve again into the evaporator.

Adsorption chillers: Here, instead of a liquid solution, solid sorption materials are applied. Market available systems use water as a refrigerant and silica gel as a sorbent. The machines consist of two sorbent compartments, one evaporator and one condenser as shown in Fig. 3.

While the sorbent in the first compartment is regenerated using hot water from the external heat source, e.g., the solar collector, the sorbent in the compartment 2 (adsorber) adsorbs the water vapour entering from the evaporator; this compartment has to be cooled in order to enable a continuous adsorption. The water in the evaporator is transferred into the gas phase being heated by the external water cycle; here useful cooling is actually produced. If the cooling capacity reduces to a certain value due to the loading of the sorbent in the adsorber, the functions of the chambers are switched over. To date, only a few Asian manufacturers produce adsorption chillers.

Under typical operation conditions, with a driving heat temperature of about 80°C, the systems achieve a COP of about 0.6, but operation is possible even at heat source temperatures of approx. 60°C. The capacity of the chillers ranges from 50 to 500 kW chilling power (Wuppertal Institute, 2007). The simple mechanical construction of adsorption chillers and their expected robustness is an advantage. There is no danger of crystallization and thus no limitations in the heat rejection temperatures. An internal solution pump does not exist and hence only a minimum of electricity is consumed. A disadvantage is that they are much heavier. Furthermore, due to the small number of items produced, the price of adsorption chillers is currently high. A large potential for improvements of the heat exchangers in the adsorber compartments is expected; thus, a considerable decrease in volume and weight can be expected in future generations of adsorption chillers.

Desiccant cooling: Desiccant cooling systems are basically open cycle systems, using water as a refrigerant in direct contact with air. The thermally driven cooling cycle is a combination of evaporative cooling with air dehumidification by a desiccant, i.e., a hygroscopic material. For this purpose, liquid or solid materials can be employed. The term open is used to indicate that the refrigerant is discarded from the system after providing the cooling effect and new refrigerant is supplied in its place in an open-ended loop. Therefore, only water is possible as a refrigerant since a direct contact to the atmosphere exists. The common technology applied today uses rotating desiccant wheels, equipped either with silica gel or lithium-chloride as sorption material. Solar assisted desiccant cooling uses solar thermal energy to dry out or regenerate the desiccant. It is both a new and clean technology, which can be used to cool the inside of a home or commercial building without using any harmful refrigerants, such as those used in conventional air conditioning systems. According to Torrey and Westerman (2000), the major benefits of desiccant cooling by dehumidification include increased comfort (since temperature and humidity are controlled independently), lower operating costs, heat recovery options, improved indoor air quality and reduced building maintenance as a result of high humidity levels (Marano *et al.*, 2009). In addition, they do not utilize CFCs for moisture removal. Commercially available desiccant systems are based on five technical configurations namely; liquid spray towers, solid packed tower, rotating horizontal bed, multiple vertical bed or rotating desiccant wheel (Harriman, 1990). The materials used in desiccant systems include silica gel, LiCl or LiBr, activated alumina, titanium silicate or molecular sieve. Desiccant cooling can also be used when coupled with a conventional air conditioning system in that the desiccant removes the humidity from the air as the AC unit cools the air. Residential use of desiccant cooling is being explored in conjunction with energy recovery ventilators or ERV.

Solid desiccant cooling with rotating wheels: The main components of a solar assisted desiccant cooling system are shown in Fig. 4. Warm and humid ambient air enters the slowly rotating desiccant wheel and is dehumidified by adsorption of water (1-2). Since, the air is heated up by the adsorption heat, a heat recovery wheel is passed (2-3), resulting in a significant pre-cooling of the supply air stream. Subsequently, the air is humidified and further cooled by a controlled humidifier (3-4), according to the desired temperature and humidity of the supply air stream. The exhaust air stream of the rooms is humidified (6-7) close to the saturation point to exploit the full cooling potential in order to allow an effective heat recovery (7-8). Finally, the

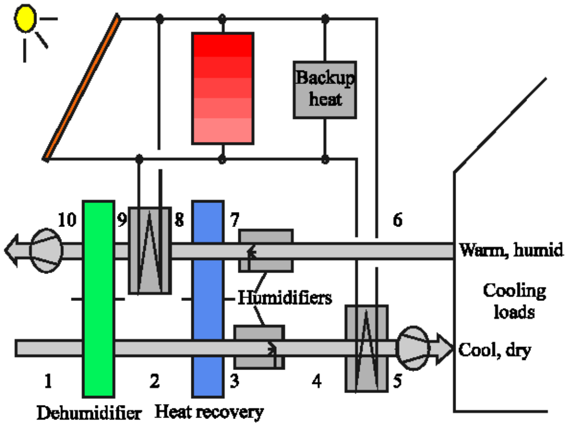

Fig. 4: Main components of a solar assisted desiccant cooling system. ESTIF (2006)

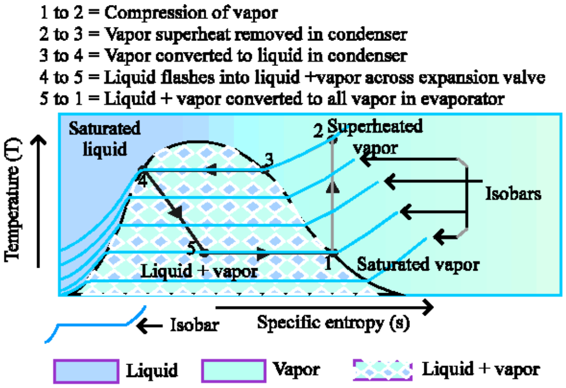

Fig. 5: Typical Vapour Compression Cycle. Anonymous (2010)

sorption wheel has to be regenerated (9-10) by applying heat in a comparatively low temperature range from 50-75°C, to allow a continuous operation of the dehumidification process.

Special design of the desiccant cycle is needed in case of extreme outdoor conditions such as coastal areas of the Mediterranean region and African islands. Here, due to the high humidity of ambient air, a standard configuration of the desiccant cooling cycle is not able to reduce the humidity down to a level that is low enough to employ direct evaporative cooling. More complex designs of the desiccant air handling unit, employing for instance another enthalpy wheel or additional air coolers supplied by chilled water, can overcome this problem.

Liquid desiccant cooling: A new development, close to market introduction, are desiccant cooling systems using a liquid Water/Lithium-Chloride solution as sorption material. This type of system shows several advantages such as higher air dehumidification at the same driving temperature range as solid desiccant cooling systems and the possibility of high energy storage by storing the concentrated solution. This technology is a promising future option for further increasing the exploitation of solar thermal systems for air-conditioning.

Vapour compression cooling: Vapor-compression refrigeration is one of the many refrigeration cycles available for use. It has been and still is the most widely used method for air-conditioning of large public buildings, private residences, hotels, hospitals, theaters, restaurants and automobiles. It is also used in domestic and commercial refrigerators, large-scale warehouses for storage of foods and meats, refrigerated trucks and railroad cars and a host of other commercial and industrial services, which use solar thermal energy to power a rankine-cycle heat engine (Anonymous, 2010; Manning, 2001). A typical vapour compression cycle is shown in Fig. 5.

The major advantage of vapour compression cooling systems is their high efficiency of up to 60% of the Canot theoretical efficiency, but a serious demerit of such systems is the fact that the more efficient vapour compression systems still make use of HCFCs, which deplete the ozone layer. A few new systems now utilize HFCs but these are generally less efficient.

Evaporative cooling: This type of technology is used in heat pumps and air conditioners, which are powered by solar photovoltaic systems. It is a physical phenomenon in which evaporation of a liquid, typically into surrounding air, cools an object or a liquid in contact with it as the latent heat is released. An evaporative cooler, sometimes called swamp, desert or wet air cooler is a device that cools air through the evaporation of water. When considering water evaporating into air, the wet-bulb temperature, as compared to the air's dry-bulb temperature, is a measure of the potential for evaporative cooling. The greater the difference between the two temperatures, the greater the evaporative cooling effect. Evaporative cooling is especially well suited for climates where the air is hot and humidity is low. In dry, arid climates, the installation and operating cost of an evaporative cooler can be much lower than refrigerative air conditioning, often by up to 80%. However, evaporative cooling and vapor-compression air conditioning are sometimes used in combination to yield optimal cooling results. Some evaporative coolers may also serve as humidifiers in the heating season.

Evaporative cooling was in vogue for aircraft engines in the 1930s, but is now more commonly used in cryogenic applications. The vapor above a reservoir of cryogenic liquid is pumped away and the liquid continuously evaporates as long as the liquid's vapor pressure is significant. Evaporative cooling of ordinary helium forms a 1-K pot, which can cool to at least 1.2 K. Evaporative cooling of helium-3 can provide temperatures below 300 mK. Each of these techniques can be used to make cryo-coolers, or as components of lower-temperature cryostats such as dilution refrigerators. As the temperature decreases, the vapor pressure of the liquid also falls and cooling becomes less effective. This sets a lower limit to the temperature attainable with a given liquid.

Evaporative cooling is very convenient for cooling buildings for thermal comfort since it is relatively cheap and requires less energy than many other forms of cooling. However, evaporative cooling requires an abundant water source and is only efficient when the relative humidity is low, restricting its effective use to dry climates. This makes the system suitable for arid and semi-arid regions of Africa.

POTENTIAL APPLICATIONS OF SOLAR COOLING

There are four main product market combinations where renewable energy cooling may be commercialized: agriculture and fisheries, convenience and tourism, health and production of refrigerators and other renewable energy cooling appliances (Verschelling and Sluijs, 2000).

Agriculture: The unique feature of a controlled environment agricultural system designed for year-round production of lettuce and other vegetable crops in hot, arid climates is that all the energy needs of the system, including ventilation and cooling in the summer months and heating in the winter, are supplied by solar energy. The system uses solar energy in three ways: directly for vegetable growth, as electrical energy from photovoltaic arrays and as thermal energy for heating or cooling via absorption chillers (Stickford *et al.*, 2000). Solar greenhouses are designed to collect and store heats gained during the day and are insulated to retain heat at night or during periods of cloudy weather (Montana, 2009). Solar chimneys are passive solar collectors attached to the highest point on the greenhouse and are combined with vents or openings on either end of the greenhouse (Bellows and Adam, 2008).

Hotels: For this commercial sector, solar air-conditioning offers an interesting marketing opportunity, especially in many parts of Africa as it makes the hotels more attractive to the rising share of environmentally-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 and per night are expected to be low compared to the average accommodation cost. A further advantage is that existing, medium cooling capacity systems can be employed which are already on the market. Since the maximum required cooling demand is often seen in hotels in the afternoon and evening, appropriate measures in building construction and system design are necessary to optimize the solar system utilization and to minimize the use of backup cooling systems (e.g., high thermal inertia of the building, night ventilation, etc.).

Private buildings: Private houses can be equipped with solar thermal systems for combined domestic hot water production and heating support in transition periods (Combi Systems). The systems consist of a comparatively large solar thermal collector system and use either selectively coated flat plate collectors or evacuated tube collectors. These installations uncover an interesting option to considerably increase the utilization of the large systems for solar air-conditioning in summer.

Despite rising energy efficiency standards in the private building sector, rising comfort habits also cause an increasing interest in active cooling systems. A market niche for small solar cooling systems could be seen in the near future if the additional costs for cooling installation are low (e.g., using reversible heat pumps for heating and cooling and no additional cooling backup) or small units of thermally driven air-conditioning units with sufficient low driving temperatures (e.g., adsorption heat pumps) are market-available. Thus, the market potential would be limited more to countries with moderate climates, where cooling in summer is an additional comfort, but is not critical if the system does not work in case of low radiation availability.

SOLAR COOLING FOR GHG ABATEMENT IN AFRICA

The use of solar energy instead of conventional energy to run air conditioning offers several benefits: On a global scale, the reduction in CO_2 emissions is the most significant advantage. Solar cooling systems offer high CO_2 saving potentials and, on an average, up to 15 tons of CO_2 per year per system can be saved by using the technology (Wuppertal Institute, 2007). On a regional level, the increased use of solar energy for cooling lessens the demand on grid electricity and helps to avoid power failures during peak usage periods in the summer. Furthermore, the fact that solar energy systems do not depend on grid electricity allows for the development of solar projects in regions where the usage of grid electricity is at its maximum, or where there is no access to grid electricity such as remote communities in rural Africa. Compared to a conventional system, the solar system runs silently creating no pollution and using no refrigerants. As the pool is used as a heat sink no extra cooling tower is necessary, which reduces the need for maintenance. In addition, the pool heating is free of charge because it simply uses the surplus energy from the solar system.

CONCLUSIONS

Despite the cost factors, there is great potential for solar cooling technologies considering their inherent benefits, especially in Africa. Most of the installed solar cooling systems are for office use in mild climatic conditions, notably in southern Europe and Germany. Among the established technical approaches, adsorption cooling systems-the most widely deployed in the world so far-are associated with lower power consumption, although the individual units are heavy and expensive. Vapour compression systems possess high efficiency but often utilize CFCs. As such they are not recommended unless there is a major improvement in the systems based on HFCs. Evaporative cooling systems are cheap and convenient and although they require a lot of water, there is great potential for their integration within existing energy systems in Africa. Desiccant cooling systems hold a great promise since they have low operating costs, lead to improved indoor air quality and do not utilize CFCs.

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