Solar Cooling: A sustainable air conditioning and refrigerating system

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The air-conditioning as well as the solar thermal market in Europe and world-wide shows annual growth rates of several percent. In the first case initiated by the growing demand for air-conditioning in residential houses as well as office and hotel buildings and in the second case by increasing environmental awareness or political guidelines.

If the thermal loads can't be dissipated with passive cooling methods, active cooling machines have to be used. Due to the large number of manufactured compressor chillers, these systems are produced and offered at very low prices, however, such systems increase the adverse effects on local environments as a result of using primary energy such as electricity. The high current demand of common compressor chillers abut the national electric networks in summertime more and more on their capacity limits. Simultaneously, in many southern countries, these units have been the main reason for the bottleneck in the electric networks in recent years. Therefore, it is important to search for alternative air-conditioning units that are driven by either waste heat or solar thermal energy and to develop combined solar cooling and heating systems.

Market situation of Solar Cooling

The first solar cooling systems for air-conditioning were developed in the seventies of the 20th century, e.g. by the company Dornier-Prinz Solartechnik GmbH, Germany (Schubert et al., 1977) or Arkla Industries Inc., USA (today Robur SpA, Italy) (Grossmann, 2002). Due to the lack of demand on the market for solar cooling, the production of these solar cooling systems was stopped.

The market of solar cooling is still small: today in Europe approximately 8 to 9 MW of cooling capacity are installed. These are about 100 up to 120 solar cooling systems, which use solar thermal collectors for the solar air-conditioning of buildings. Most of the systems are realized in Germany and Spain. The total installed collector surface is nearly 20,000 m². Approximately 60% of the closed cycle systems are absorption chillers and around 11% adsorption chillers. The DEC systems

with sorption wheels dominate the open sorption air-conditioning systems by 25% and only 4% liquid sorption systems exist. However the potential is very high – in Germany 40,000 GWh of current consumption are accumulated alone for the air conditioning of office buildings (Nick-Leptin, 2005). The technologies for the solar cooling units in the medium and big performance range are fully developed, only the small-scale performance range below 20 kW will continue to be developed and investigated.

Technologies

Solar cooling technology has been used for several years, but there are not a lot of complete solar cooling systems commercially available. In principal absorption chillers and DEC systems (Desiccant and Evaporative Cooling) and occasional adsorption chillers are used for the air-conditioning of buildings. Against it liquid sorption systems are mainly in prototype or field test stage.

The technology of heat driven solar cooling systems is mainly divided into closed systems to produce cold water and open systems for air-conditioning.

Table 1 shows the working pairs and the cooling medium as well as the different temperature ranges for cooling, heating and cooling water, the cooling capacity per unit and the COP of the presented marketable solar cooling technologies.

	Absorption			Adsorption	DEC
	Single-Effect	Double-Effect	Double-Effect		
Refrigerant	water	water	ammonia	water	–
Sorbent	lithium bromide	lithium bromide	water	silica gel	silica gel or lithium chloride
Cooling Medium	water	water	water glycol	water	air
Cooling Temperature	6 – 20°C	6 – 20°C	-20 – +20°C	6 – 20°C	16 – 20°C
Heating Temperature	75 – 100°C	130 – 160°C	80 – 160°C	55 – 100°C	55 – 100°C
Cooling Water Temperature	30 – 50°C	30 – 50°C	30 – 50°C	25 – 35°C	not required
Cooling Capacity Range (per unit)	10 – 20.500 kW	170 – 23.300 kW	5 – 1.000 kW	70 – 350 kW	6 – 300 kW
Coefficient of Performance (COP)	0,6 – 0,7	1,1 – 1,4	0,5 – 0,6	0,6 – 0,7	0,5 – 1,0

Table 1. Solar thermal driven or assisted cooling and air-conditioning technologies

Absorption / Adsorption chillers

The heat driven closed absorption (Fig. 2) or adsorption chillers most closely resemble common vapour compression chillers in terms of their integration into buildings. The chillers provide cold water at temperature between 6°C and 20°C. They can also be used for central air conditioners as well as cooling systems with decentralised air treatment, such as fan coils and cooled ceilings.

The ammonia/water absorption chillers could generate evaporator temperatures down to -20°C, which are useful for cold processes.

In absorption chillers the refrigerant (water or ammonia) is absorbed by a liquid sorbent (lithium bromide or water). In the directly or indirectly solar powered generator with high heating temperatures, the refrigerant is desorbed from the solution. This generates a high refrigerant vapour pressure, which is sufficient to condense the refrigerant in the condenser. After evaporation, the refrigerant vapour is absorbed in the solution which is cooled in the absorber. The solution is pumped to the generator by a solution pump where it is regenerated and throttled back to the absorber.

The heating temperatures for desorption are between 75 and 160°C according to the technology.

At adsorption chillers the refrigerant water is adsorbed on a solid sorbent like silica gel among disposal of latent heat on the surface. The latent heat decreases to zero with increasing addition of water molecules, then only evaporation heat has to be dissipated. The desorption of the stored water and the pressure generation for the condensation is already caused by low heating temperatures of 60 to 70°C.

Fig. 2

Novel ammonia/water absorption chiller "chillii PSC" with 5, 10 or 20 kW cooling capacity of the company SolarNext (source: SolarNext)

Open sorption assisted air-conditioning

Open systems normally employ a combination of sorptive air dehumidification and evaporative cooling, which is used in ventilation systems for treating air. Sorption assisted air-conditioning is in effect a well-engineered technology. In DEC systems (Fig. 3), both the humidified exhaust air and supply air serve as coolants. The supply air is blown directly into the room through heat recovery process.

The minimum supply air temperature is about 16°C. The physical adsorption of water on silica gel or lithium chloride serves the air drying in this process. Afterwards the air will be cooled by direct evaporative humidification of the dried and through a heat exchanger precooled air. The thermal heat input is required for the regeneration of the sorbent, this means the desorption of the adsorbed water. The heating temperatures could be chosen very low between 60 and 70°C as well.

Fig. 3

Ventilated PV facade and solar air collectors of a solar assisted DEC system (Jakob et al., 2007) of a library in Mataró, Spain (source: zafh.net)

Reference values of realised projects

The average value of the specific collector surface of all systems in Europe is about 2.9 m²/kW. A value of 3.0-3.5 m²/kW could be valid as reference value for thermal driven cooling machines. Usually for open systems the reference value is related to the air quantity, a value between 8 and 10 m² per 1,000 m³/h installed volume flow has been carried out as useful value (Henning, 2005). These values are only rough reference values.

The specific total costs of installed solar cooling systems using absorption chillers (35 to 170 kW) is in range between 2,515 and 6,000 EUR/kW. The costs could be reduced to 1,258 to 3,400 EUR/kW with subsidies.

If adsorption chillers are used (700 to 70 kW) total costs of 1,866 to 5,029 EUR/kW without and 933 to 1,286 EUR/kW with subsidies were resulted. At open systems with sorption wheels (36-108 kW) specific total costs of 2,066 to 3,500 EUR/kW are determined.

If subsidises are included total costs of 1,119 EUR/kW were achieved.

Conclusion

In Germany, Europe and worldwide the energy consumption for air-conditioning increases. In Germany 14% of the total current consumption is used for cooling (77,000 GWhel), which corresponds to 5.8% of the primary energy demand.

Thermal cooling by solar or district heating or biomass could be lead to a clear reduction of the energy consumption and the CO2 emissions. An assumption for single-effect thermal chillers is above all a very high solar fraction or better a complete solar heating system, because low COPs lead rapidly to higher primary energy consumptions, if an additional heating system has to be used. For an economical operation of solar cooling system the additional investment costs for the thermal cooling technology have to be further reduced, which is expected at higher piece numbers. At very low heat prices e.g. with an existing solar thermal plant with heating support, thermal solar cooling systems can almost compete with todays common electrical compressor chillers. As a general trend to larger solar thermal plants, small-scale thermal chillers offer a good possibility to use the summer heat efficiently.

Many concepts of absorption, adsorption and liquid sorption technology are being turned from simply prototypes into field test stage or into small serial production. In the next few years further projects are expected for the small scale cooling capacity range.

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