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166 - Development and Investigation of Solar Cooling Systems Based on Small-Scale Sorption Heat Pumps

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Abstract

This paper presents the development and investigation of solar cooling systems based on small-scale sorption heat pumps and chillers, respectively. An ammonia/water absorption chiller with a cooling capacity of 12 kW, the chillii® PSC12, a 17.5 kW water/lithium bromide absorber, the chillii® WFC18 and two water/silica-gel adsorption chillers with cooling capacities of 7.5 and 15 kW, the chillii® STC8 and chillii® STC15, all single effect, are specified as core components of solar cooling systems. Up to now over twenty chillii® Cooling and Solar Cooling Systems respectively are in installed in Germany, Austria, Spain, Italy, Malta, Romania, Syria, Canada, China and Australia. Different kind of applications are realised like for residential buildings, retirement home, office buildings, bank, bakery, greenhouse and institutes. The first experiences and experimental results of the installed solar cooling systems showed that the chillers and the solar cooling system work very well.

Keywords: Solar cooling, absorption, adsorption, heat pump, chiller

1. Introduction

Active air-conditioning of buildings is also necessary at European climate conditions, especially in Southern Europe. Therefore the energy consumption for cold and air-conditioning is rising rapidly. Usual electrically driven compressor chillers (split-units) have maximal energy consumptions in peak-load period during the summer. In the last few years even in Europe this regularly leads to overloaded electricity grids. The refrigerants that are currently used in the split-units do not have an ozone depletion potential (ODP) anymore, but they have a considerable global warming potential (GWP), because of leakages of the chiller in the area of 5 to 15 % per year. However, solar cooling systems provide a sustainable active air-conditioning possibility. The sorption heat pumps or chillers use environmentally friendly refrigerants and have only very low electricity demand. Therefore the operating costs of these chillers are very low and the CO_2 balance compared to split-units is considerably better. The main advantage of solar cooling is the coincidence of solar irradiation and cooling demand. Particularly the sale figures of split-units with a cooling capacity range up to 5 kW are rising rapidly. In Europe the number of sold units has risen about 53% from 5.3 million in 2004 to predicted 8.1 million in 2007 [1]. The Japan Refrigeration and Air Conditioning Industry Association (JRAIA) has expected a worldwide sales of 74.4 million units in 2007. The market potential for solar cooling systems with small-scale capacity is very large, so that different companies are developing solar cooling systems/kits for the product business [2]. In case active cooling being necessary, the long running times of the chillers are the key for economic efficiency of solar cooling systems. For residential buildings in Central Europe only about 50 to 200 cooling hours occur, whereas in the southern Mediterranean area as well as for some industrial and office buildings approximately 1,000 full load hours are necessary. An all-season use of renewable energy sources for hot water, space heating and solar cooling is here indispensable.

2. Small-scale sorption chillers

2.1. Technology

The mainly used technologies for solar cooling systems with small-scale cooling capacity (< 30 kW) are absorption and adsorption cooling. Single-effect absorption chillers with the working pair water/lithium bromide and ammonia/water respectively are generating cold over a closed, continuous cycle. The ammonia/water absorption chillers could generate evaporator temperatures down to -60°C, which are useful for industrial cold processes. Using water as refrigerant the evaporator temperature is limited to temperatures above the freezing point. In absorption chillers the refrigerant (water or ammonia) is absorbed by a liquid sorbent (lithium bromide or water) as shown in Fig. 1. 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 70 and 120°C according to the technology. Basically absorption chillers are used as central air-conditioning systems with decentralised fan coils or cooled ceilings.

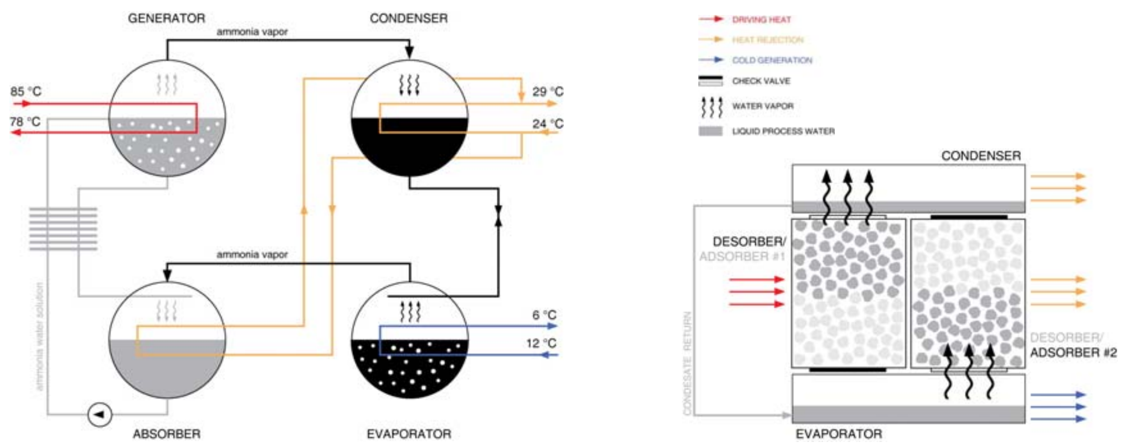

Fig. 1. Absorption (left) and adsorption (right) principle (sources: SolarNext).

At adsorption chillers the refrigerant water is adsorbed on a solid sorbent like silica gel among disposal of latent heat on the surface (Fig. 1.). 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 55 to 70°C, so that this technology is especially appropriate to the application of solar energy. The closed adsorption chillers are generating cold water of minimal 5 to 6°C through the periodical cycle. These chillers can also be used as central air conditioning systems with decentralised fan coils or cooled ceilings.

2.2. Market availability

During the last few years especially in Europe many new small-scale sorption chillers have been developed. Many of these absorption and adsorption chillers have now passed from the prototype phase to field tests and into the production. Today absorption chillers with capacities from 4.5 kW to 30 kW and adsorption chillers with capacities from 7.5 kW to 15 kW cooling capacity are available [3]. Table 1 shows the different applications for the different chillers, the adsorber chillii® STC8 with a cooling capacity of 7.5 kW is mainly for residential buildings, the 12 kW ammonia/water absorption chiller chillii® PSC12 is for office buildings or process cooling like e.g. milk cooling and the 15 kW water/silica gel adsorber chillii® STC15 as well as the water/lithium bromide absorber chillii® WFC18 (17.5 kW cooling capacity) are for air-conditioning e.g. of office buildings, hotels, banks, bakeries, public and administration buildings.

Table 1. Small-scale sorption chillers for solar cooling systems.

Company	SorTech	SolarNext	SorTech	Yazaki
Product name	chillii® STC8, (ACS 08)	chillii® PSC12	chillii® STC15, (ACS 15)	chillii® WFC 18 (WFC-SC5)
Technology	adsorption	absorption	adsorption	absorption
Working pair	water/silica gel	ammonia/water	water/silica gel	water/lithium bromide
	 (source: SorTech)	 (source: Pink)	 (source: SorTech)	 (source: Yazaki)
Cooling capacity	7.5 kW	12 kW	15 kW	17.5 kW
Heating temperature	75 / 68°C	85 / 78	75 / 69	88 / 83°C
Recooling temperature	27 / 32°C	24 / 29°C	27 / 32 °C	31 / 35°C
Cold water temperature	18 / 15°C	12 / 6°C	18 / 15°C	12.5 / 7°C
COP	0.56	0.62	0.56	0.70
Dimensions (LxDxH)	0.79 x 1.06 x 0.94 m^3	0.80 x 0.60 x 2.20 m^3	0.79 x 1.35 x 1.45 m^3	0.60 x 0.80 x 1.77 m^3
Weight	260 kg	350 kg	510 kg	420 kg
Electrical power	20 W	300 W	30 W	72 W

3. System Controller

For the development of standardized solar cooling systems it is indispensable to use a system controller for the complete system. The previous solar cooling demonstration and pilot projects are using several single controllers e.g. for the solar thermal system, for the chiller, for the recooler and for the cold or heat distribution, which are together cost intensive and are not always operating optimal together. The alternative was until now an expensive SPS controller which had to be programmed for each single case. Because of that the SolarNext has decided in the year 2007 to develop an own system controller for the whole system (Fig. 2.), which has an influence from the automotive sector and is cheap and system oriented.

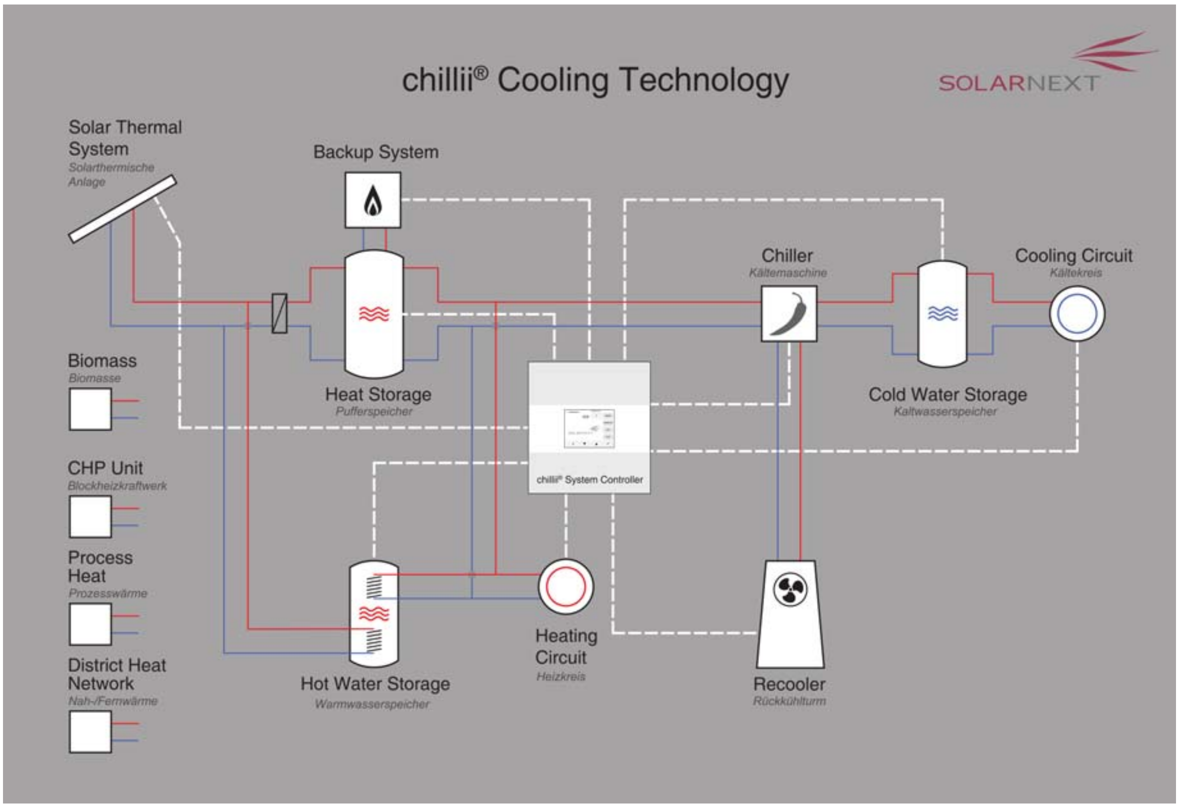

Fig. 2. chillii® Solar Cooling System scheme (source: SolarNext).

The functional range of the chillii® System Controller (Fig. 3.) contains the control of different heat sources (e.g. solar heat, CHP waste heat, district heat, etc.), the back-up system (e.g. controllable oil/gas boiler or not controllable wood boiler or exhaust gas heat recovery), the storage management (heat and cold storage), the hot water, the chiller (e.g. chillii® STC8, PSC12, STC15, WFC18, EAW SE15, Yazaki WFC-SC10, etc.) and the re-cooling (e.g. wet, dry, and hybrid cooler) as well as heating and cooling circuits. The chillii® System Controller is the first system controller for thermal cooling and heating systems that controls many large hydraulic variables with one device. So the highest system efficiency is reached with the needed energy generation with priority in regenerative energy sources, optimized running of chillers as well as the re-cooling with speed control of the pumps and the re-cooling ventilator.

Fig. 3. chillii® System Controller (source: SolarNext).

4. Solar Cooling Systems

During the last few years a few companies in the solar business have positioned on the market as system providers for solar cooling. In the small scale capacity range up to 30kW there is for example the company SolarNext with its chillii® Solar Cooling Kits and Systems respectively based on the chillii® STC8, chillii® PSC12, chillii® STC 15, chillii® WFC18 and absorption chillers from the company EAW and Yazaki. Further companies like e.g. Enus, Phönix, Schüco and Solution also offer solar cooling systems with the different chillers. The solar cooling systems basically contain solar thermal collectors with attachment, hot water storage, pump-sets, a chiller, a re-cooler, partly cold water storage and a control unit. Fig. 4. shows as an example the chillii® Cooling Kit 18, which can be supplemented by a solar package, a cold storage package, a cold distribution package, etc. The cooling kits are developed for the European market, whereas other re-coolers can be offered according to the country (e.g. in Spain a dry re-cooler).

Fig. 4. chillii® Cooling Kit 18 (source: SolarNext).

The average value of the specific collector surface of all until the year 2006 installed solar cooling systems in Europe is about 3 m²/kW. A value from 3.5 to 4.5 m²/kW can be considered as a reference value for thermal driven absorption and adsorption chillers. But these values are only rough reference values and can never replace the detailed design and simulation of a system. The specific total costs of installed solar cooling systems in Europe are so far between 5,000 and 8,000 EUR/kW. For 2008 system prices of 4,500 EUR/kW are reached, in the future 3,000 EUR/kW are expected.

5. Solar cooling projects

In May 2008 the worldwide first installation of a chillii® Cooling Kit 8 for a two family house in Alzenau, Germany based on a chillii® STC8 (Fig. 5.) was successfully put into operation. The necessary heat for driving the machine is provided by 24 m² flat collectors and a biomass back-up. As a buffer 2.000 litre hot water storage is used. An electrically high efficient dry re-cooler with water spraying is used for an effective re-cooling of the 22 kW waste heat of the adsorption chiller. The cold distribution is effected by fan coils.

Fig. 5. Flat plate collectors on the roof of the two-family-house as well as the chillii® STC8 adsorption chiller and the dry re-cooler (sources: SolarNext).

The chillii® Cooling Kit 8 is until now besides others installed in residential or office buildings in the following countries: Germany, Austria, Italy and China.

For the new training centre and office building of Bachler Austria, Austria a complete solar cooling system with biomass back-up has been installed between winter 2006 and spring 2007. The chiller that is used is a chillii® PSC10 (Fig.6.) for a required cooling load of 9 kW and as recooler a 26 kW wet cooling tower as well as in addition a swimming pool. The wet cooling tower is operated with very low re-cooling temperatures of 24/29°C for the Middle-European application. The requested solar heat is delivered by 40 m² flat plate collectors, which are mounted at the façade and on the ground and is stored in three hot water storages with 1.5 m³ each. The cold distribution is done by concrete core activation (cooled ceilings) with cold water temperatures of 16/19°C and a dew point thimble for cooling of the training and office rooms.

Fig. 6. Flat plate collectors on the facade and the ground as well as absorption chiller chillii® PSC10 at the training center and office building of the company BachlerAustria (sources: SolarNext).

Further chillii® PSC10 absorption chillers are installed in different thermally driven systems worldwide, e.g. three in Germany, one in Canada and two in Malta. The current chillii® PSC12 is installed for the first time together with a chillii® Solar Cooling Kit 12 in Italy. A second chiller is now running in Spain.

With the chillii® WFC18 water/lithium bromide absorption chiller four chillii® Cooling Kits 18 for air-conditioning applications have been realized until now, one in Germany (bakery), one in Syria (residential building), one in Romania (university) and one in Australia (office building).

6. Conclusion

The energy demand for air-conditioning is rising rapidly in Europe and worldwide. Thermal cooling with solar thermal heat, district heat, process waste heat, CHP waste heat or biomass can reduce the energy consumption and the CO_2 emissions considerably. But if a backup system is used, which is not based on renewable energy sources; the primary energy consumption rises again. Basically the solar fraction of solar cooling kits should be higher than 70% or an existent complete solar heating system would even be better. In the small-scale capacity range with up to 30 kW several water/lithium bromide absorption chillers; one ammonia/water absorbers as well as two water/silica gel adsorption chillers are recently available on the European market. For an economical operation of solar cooling systems the additional investment costs for the sorption chillers have to be further reduced, which is absolutely expected at higher sales numbers. At very low heat prices, for example at existing solar thermal plant for the heating support, thermal solar cooling systems can nearly compete today with common electrical compressor chillers. Because of the general trend in Europe to larger solar thermal plants for the heating support, small-scale sorption chillers offer good opportunities to use efficiently the summery heat.

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