

## **Solar Cooling Technologies for Southern Climates - A System Comparison -**

Dirk Pietruschka<sup>1</sup>, Uli Jakob<sup>2</sup>, Ursula Eicker<sup>1</sup>

<sup>1</sup> Centre of Applied Research Sustainable Energy Technology - zafh.net, Stuttgart University of Applied Sciences, Schellingstrasse 24, D-70174 Stuttgart, Germany, Phone +49 711 8926 2674, [dirk.pietruschka@hft-stuttgart.de](mailto:dirk.pietruschka@hft-stuttgart.de)

<sup>2</sup> Solem Consulting, Postfach 2127, D-71370 Weinstadt, Germany Phone +49 174 4130921, [uli.jakob@solem-consulting.com](mailto:uli.jakob@solem-consulting.com)

### **Abstract**

In the present paper different solar thermal cooling systems are compared to a PV driven and a net connected compression chiller in hot and dry southern climate. The cooling systems are considered to be applied to a planned innovative office building in Cairo, Egypt. A single effect absorption chiller with vacuum tube collectors is analysed as well as a double and a triple effect absorption chiller with higher concentrating Fresnel collectors. For the PV driven compression chiller system high efficient mono crystalline PV modules are considered together with a highly efficient compression chiller system with integrated direct dry heat rejection. Dynamic system simulations with INSEL are used to analyse the performance of the different cooling systems. To compare the overall performance of the analysed solar cooling systems, the primary energy consumption required to cover the whole cooling load of the building and the resulting primary energy ratio are calculated for each system.

### **1. Introduction**

The overall efficiency of solar driven absorption cooling machines (ACM) is mainly influenced by the thermal COP of the absorption chiller and the electricity consumption caused by the heat rejection system, the chiller and all connected system pumps. Single effect absorption chillers reach only quite low thermal COPs which are typically in the region between 0.55 and 0.75. In consequence, large solar collector areas and large heat rejection systems are required to reach high solar fractions and to remove the waste heat. This often cause high electricity consumptions which reduces the primary energy efficiency of the systems [1]. However, the main advantage of single effect absorption and adsorption chillers is the relatively low driving temperature which varies between 65°C and 95°C. Such temperatures can be provided by efficient flat plate or vacuum tube collectors. Double effect absorption chillers reach much higher thermal COPs of 1.3 and above but typically require much higher driving temperatures of around 180°C. To provide such high temperatures higher concentrating solar systems like parabolic trough or

linear Fresnel collectors are required [2]. Due to decreasing PV module prices PV driven highly efficient compression chillers become more and more attractive as a competitive solar cooling technology. In the present paper a detailed simulation based case study of a solar cooling application for an office building project in Cairo Egypt is presented. Here, four different systems are regarded: Single effect, double effect and triple effect absorption chillers and a PV driven compression chiller. The single effect absorption chiller is considered to be purely solar driven. For the double and triple effect absorption chiller backup heating with a gas boiler / integrated gas burner is considered. In case of the PV driven compression chiller additional electricity is imported from the local grid if not sufficiently provided by the PV system.

## **2. Description of the Analysed Building and its Location**

The analysed office building is located in Cairo in Egypt and has a total useful floor area of 15 100 m<sup>2</sup> with a conditioned volume of 55 116 m<sup>3</sup>. It consists of a central core and three starlike adjacent 'fingers' with four office floors each. Double glazed windows with sun protecting coating are considered for the fully glazed facades with an U-Value of 1.16 W/m<sup>2</sup>K and g-value of 0.265 with 3.8% framing fraction and an U-Value of the frames of 2.04 W/m<sup>2</sup>K. Additional shading is provided by a roof overhang of 2.5 m in the upper floors of the south, southeast and southwest facing facades. For all opaque building elements like external walls, roof and floors a insulation of 20 cm is considered resulting in U-values around 0.18 W/m<sup>2</sup>. According to dynamic building simulations performed with TRNSYS the maximum cooling load of the building is about 800 kW (52 W/m<sup>2</sup>) and the annual cooling energy demand is 1970 MWh/a (130 kWh/m<sup>2</sup>a). Due to the necessity of dehumidification in summer the temperature level of the cold water distribution system is 7°C/14°C. The local weather conditions used in the dynamic simulations are taken from METEONORM weather data base.

## **3. Analysed solar cooling systems**

The limiting factor for the size of the solar cooling systems is the available and usable roof area for the solar thermal or PV system, which is 2 000 m<sup>2</sup> only. For the system design several simulations were performed for single effect, double effect and triple effect absorption chillers. The single effect absorption chiller was combined with efficient vacuum tube collectors (Jiangsu Sunrain TZ47/1500-10U) with an optical efficiency of 0.65, a linear heat transfer coefficient of 1.585 W/m<sup>2</sup>K and a temperature dependent quadratic heat transfer coefficient of 0.002 W/m<sup>2</sup>K<sup>2</sup>. The maximum possible collector size at horizontal orientation is 2050 m<sup>2</sup> brut collector area which is equal to a collector aperture area of 1350 m<sup>2</sup> (1.500 collectors). For the double effect

absorption chiller linear concentrating Fresnel collectors of Industrial Solar are considered. The optical efficiency of the Fresnel collectors is 62% with a linear heat transfer coefficient of 0.1 W/m<sup>2</sup>K and a temperature dependent quadratic heat transfer coefficient of 0.00043 W/m<sup>2</sup>K<sup>2</sup>. For the linear Fresnel collectors the maximum collector aperture area is 1320 m<sup>2</sup> (60 collectors; length 4 m; width 8 m). To evaluate the optimum system configuration the size of the hot water storage and the capacity of the absorption chillers were varied. For the comparison of single, double and triple effect absorption chillers the optimum system design found for each of the solar thermal cooling systems was selected. For the PV driven compression chiller the available and useful roof area of 2000 m<sup>2</sup> allows the installation of 1200 m<sup>2</sup> mono crystalline PV modules with an optimum inclination of 25° towards south. The following four system configurations are analysed:

- Case 1: Single effect ACM (LiBr)** 422 kW (THERMAX, ProChill LT12C), 7°C/12.2°C cold water, wet cooling tower (29.4 °C/36.6°C), **vacuum tube collector field** for hot water supply. 2025 m<sup>2</sup> brut collector area, 1350 m<sup>2</sup> collector aperture area, 3.3 kW electricity consumption solar pump, 20 m<sup>3</sup> hot water storage and 10 m<sup>3</sup> cold water storage
- Case 2: Double effect ACM (LiBr)** 500 kW (**Shuangliang 500 KW**) 7°C/12°C cold water, wet cooling tower (37°C/42°C), **linear concentrating Fresnel collectors** (Industrial Solar) for hot water supply. 2 050 m<sup>2</sup> brut collector area including spaces between the rows, 1 320 m<sup>2</sup> collector aperture area, 3.2 kW electricity consumption solar pump, 20 m<sup>3</sup> pressurised hot water storage (max. 200°C) and 10 m<sup>3</sup> cold water storage.
- Case 3: Triple effect ACM (LiBr)** 563 kW vapour driven (250°C) (Kawasaki Sigma Ace CF01-10-0001), 7°C/15°C cold water, wet cooling tower (32°C/36.6°C), **linear concentrating Fresnel collectors** (Industrial Solar) for water steam supply (max. 250°C at 3.9 MPa) 1280 m<sup>2</sup> brut collector area including spaces between the rows, 880 m<sup>2</sup> Collector aperture area, 1.8 kW electricity consumption solar pump, no hot water storage and 10 m<sup>3</sup> cold water storage.
- Case 4: Compression Chiller** 795 kW (Quantum A090 3C12 with R-134a as refrigerant), 7°C/12°C cold water, with integrated direct dry heat rejection for refrigerant condensation (power given at 35°C ambient air temperature), the electrical COP is 2.9 at 100%, 3.9 at 75%, 4.9 at 50% and 6.5 at 25% cooling capacity. A 10 m<sup>3</sup> cold water storage is considered

#### PV modules

875 Aleo S17 modules of ALEO Solar GmbH with 180 W per module at maximum power point (I<sub>SC</sub> = 8.42 A, U<sub>OC</sub> = 30.4 V). 25° Inclination towards south, 1206 m<sup>2</sup> total module area, 156 kW<sub>peak</sub> total installed power at maximum power point.

#### Inverter:

Sunny Central SC 150 of SMA, 150 kW nominal power, U<sub>max,DC</sub> = 900 V; I<sub>max,DC</sub> = 354 A (Grid connected without battery)

For the thermal cooling systems additional cooling is considered to be provided by an efficient compression chiller with an average electrical COP of 2.8 including the electricity consumption of the compression chiller, of the dry heat rejection system and of all connected pumps. For heat rejection of the thermally driven LiBr chillers wet cooling towers are considered with frequency inverters for fan speed control at part load conditions. The single effect and triple effect absorption chillers are

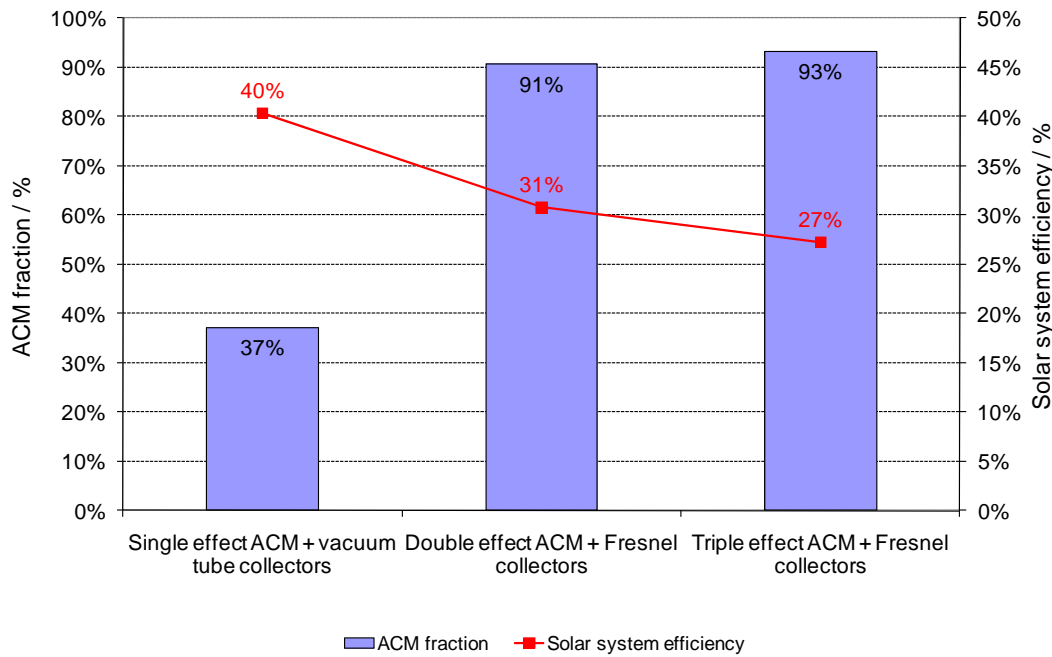
combined with an AXIMA EWK 680/9 and the double effect chiller with an AXIMA EWK 450/9 cooling tower. Compared to the single effect absorption chiller, the required heat rejection energy is much lower for the triple effect chiller but due to the high mass flow rate in the absorber/condenser circuit the bigger cooling tower is required.

#### **4. Results and Discussion**

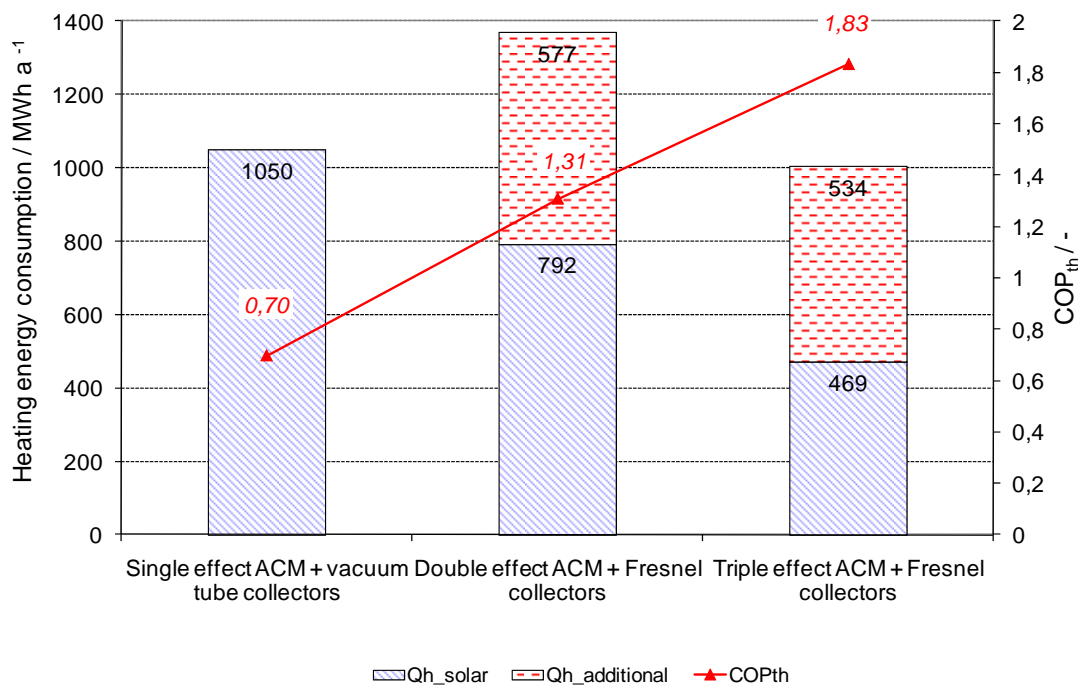
The main simulation results found for the analysed solar cooling systems are shown in Figure 1 to Figure 3. The fraction of the thermally driven absorption chillers on the overall cooling energy demand of the building is shown in Figure 1 together with the solar system efficiency. The lowest absorption chiller fraction of 37% is reached for the single effect absorption chiller, since no backup heating is used in this case. This system reaches compared to the higher concentrating systems the highest overall solar thermal system efficiency of 40%. The much lower solar system efficiency of the systems with higher concentrating collector results mainly from the fact, that these collectors can only use the direct solar radiation and not the diffuse part of it. In the annual average the direct beam radiation part is in Cairo only 60% of the total solar radiation. The system with the double effect absorption chiller and higher concentrating collector reach 91% ACM fraction on the cooling load, since only the peak loads above 500 kW need to be covered by the compression chiller. The triple effect absorption chiller reaches a higher maximum cooling power of 563 kW and is therefore able to cover 93% of the annual cooling load of the building.

The solar heating energy and the additional heating energy provided to the absorption chillers is shown in Figure 2 together with the average thermal COP of the chillers which are 0.7 for the single effect, 1.31 for the double effect and 1.83 for the triple effect chiller. Due to the higher thermal COP the double and triple effect chillers require much lower heating energy than the single effect system.

Figure 3 shows the primary energy consumption of the four analysed solar cooling systems compared to the primary energy consumption of the reference system with efficient compression chiller. The resulting average primary energy ratio of all analysed systems is also shown in this graph. From this graph it becomes clearly obvious, that the primary energy ratio of the single effect absorption chiller with vacuum tube collectors and additional cooling is with 1.43 only slightly lower than that the double effect absorption chiller with Fresnel collectors, additional heating and additional cooling which reaches a value of 1.50. The overall best energetic performance is reached for the triple effect absorption chiller which reaches a primary energy ratio of 1.6 which is 12 % higher than in case of the single effect system.



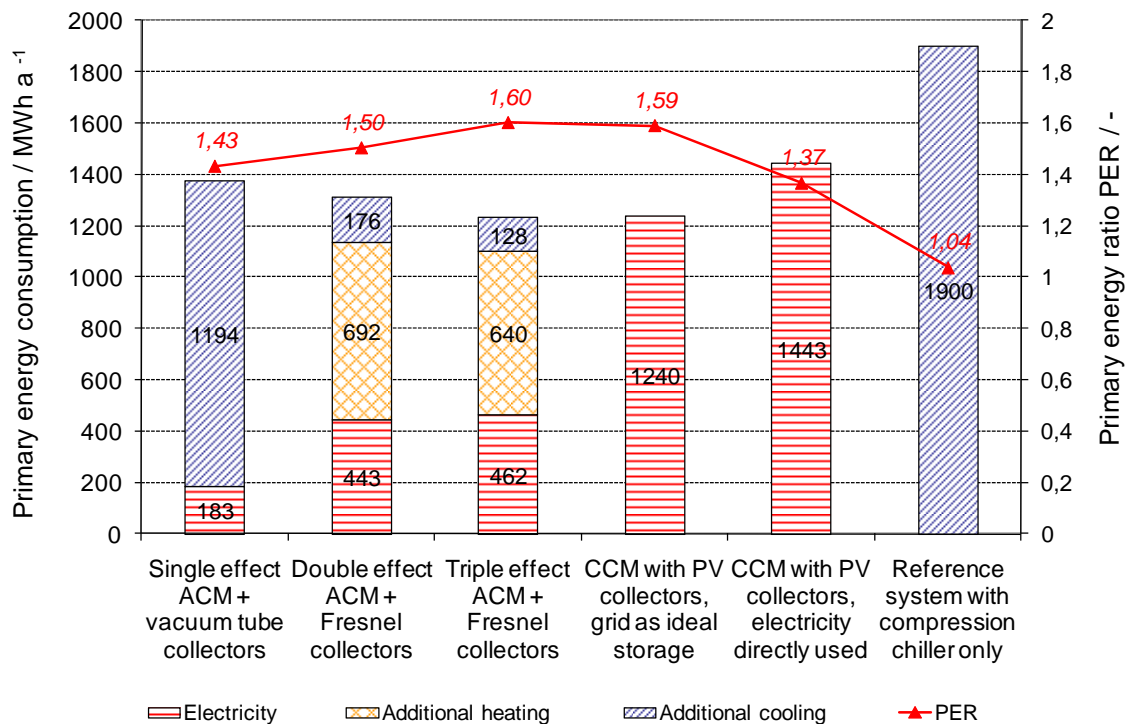
**Figure 1: Fraction of the ACM on the cooling load and solar system efficiency**



**Figure 2: Solar heating, additional heating and average thermal COP**

If the local electricity grid is considered as ideal storage the PER of the PV driven compression chiller is with 1.59 only slightly lower than the best thermal cooling system (33% PV contribution). If only the produced electricity is considered, which can be directly used by the chiller (22% PV contribution), the PER decreases to 1.37 which is even worse than the single effect absorption cooling system. Compared to an efficient standard compression cooling system only fed by the local grid, all analysed solar cooling systems reach significantly higher primary energy ratios of

+38% in case of the single effect absorption chiller up to +54% in case of the triple effect chiller with Fresnel collectors. This highlights the main advantage of efficient designed and controlled solar cooling systems.



**Figure 3: Primary energy consumption and average primary energy ratio (PER)**

## 5. Conclusions

The results found in this paper clearly demonstrated that double effect absorption chillers with backup heating (1st choice) and backup cooling (2nd choice) are from the primary energy point of few not necessarily better than single effect absorption chillers with backup cooling only. The overall best performance with a primary energy ratio of 1.6 was reached for a triple effect chiller with backup heating (1st choice) and backup cooling (2nd choice). The analysed highly efficient PV driven compression chiller reaches a comparable primary energy ratio, if the local electricity grid is considered as ideal storage. Otherwise, the primary energy ratio of this system is lower than that of the analysed thermal cooling systems. However, it could be shown that all analysed solar cooling systems reach significantly higher primary energy efficiencies than standard systems with compression chillers only. Further analyses will focus on the comparison of the economic performance of all analysed systems.

### References:

- [1] Albers, J., Kemmer, H., Ziegler, F. "Solar driven absorption chiller controlled by hot and cooling water temperature", 3rd International Conference Solar Air-Conditioning, 30th September – 2nd October, Palermo, Sicily, Italy, proceedings pp 338-343, 2009
- [2] Rubio, H., 'Solar cooling systems and natural gas; experiences and results', in proceedings of the 7<sup>th</sup> European Forum Gas, Madrid, Spain, 2009