OVERWIEW ON WORLD WIDE INSTALLED SOLAR COOLING SYSTEMS

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Abstract: Within this paper an overview on world wide installed solar assisted cooling systems is presented, including systems with a cooling power over 20 kW. Technical properties of the plans are listed and the dimensioning of single components is discussed.

1. *Introduction*

Within the Solar Heating and Cooling program, supported by the International Energy Agency (IEA) [1], the Task 38 [2] is carried out aiming to promote solar assisted cooling systems. In order to define the state of the art of the existing large scale solar cooling systems, relevant data have been collected.

2. *Approach*

The data about existing solar cooling plants have been collected through:

- direct contact to task 38 participants following single systems,
- contact of the institutions who own the systems,
- contact of installation firms and
- international projects like IEA-Task 25 [3], RoCoCo [4] and SACE [5].

Thanks to the collected information, a list has been draft that is aiming to count all large scale solar cooling plants existing in the world and describes the following aspects:

- system location and final use;
- type and cooling capacity of the thermally driven chillers;
- type of solar collectors and their gross area;
- capacity of energy storage on cold and / or hot side;
- type and power of back up systems;
- heat rejection technology;
- hydraulic schemes.

Within the list the state of the operation of the plants is reported and the ones which are currently monitored are highlighted. Table 1 shows the aspects which have been taken into account within the overview of installed systems. At the moment of elaboration of this document, not all requested information for each installation listed was available to the authors.

Table 1: General and technical aspects selected to describe the single solar cooling installations.

ASPECTS			DETAILS
Name of the buiding/project			
Location			country and town
Final use			
Thermally driven chiller	absorption chiller adsorption chiller		cooling capacity [kW]
	desiccant evaporative cooling system	solid liquid	cooling capacity [kW] or air volume flow [m³/hr]
Solar collectors	flat plate vacuum tube compound parabolic air heaters parabolic through		gross area [m²]
State of operation			running or not
Heat rejection system	wet coolign tower dry cooling tower		open or closed cycle and cooling capacity [kW]
Storage	solar tank cold storage		volume capacity [l]
Back up systems	heat cooling		heating capacity [kW_{th}] cooling capacity [kW_c]
Hidraulyc scheme	storages connection back up system connection		serial or parallel

3. *General overview on installed systems*

The list counts 81 installed large scale solar cooling systems, eventually including systems which are currently not in operation.73 installations are located in Europe, 7 in Asia, China in particular, and 1 in America (Mexico). 60% of these installations are dedicated to office buildings, 10% to factories, 15% to laboratories and education centers, 6% to hotels and the left percentage to buildings with different final use (hospitals, canteen, sport center, etc). Within 56 installations absorption chillers are used, within 10 adsorption chillers and within 17 DEC (Desiccant Evaporative Cooling) systems. Among the DEC installations, only 2 systems use a liquid regenerator (DEC liquid). The overall cooling capacity of the solar thermally driven chillers amounts to 9 MW 31% of it is installed in Spain, 18% in Germany and 12% in Greece (Fig. 1).

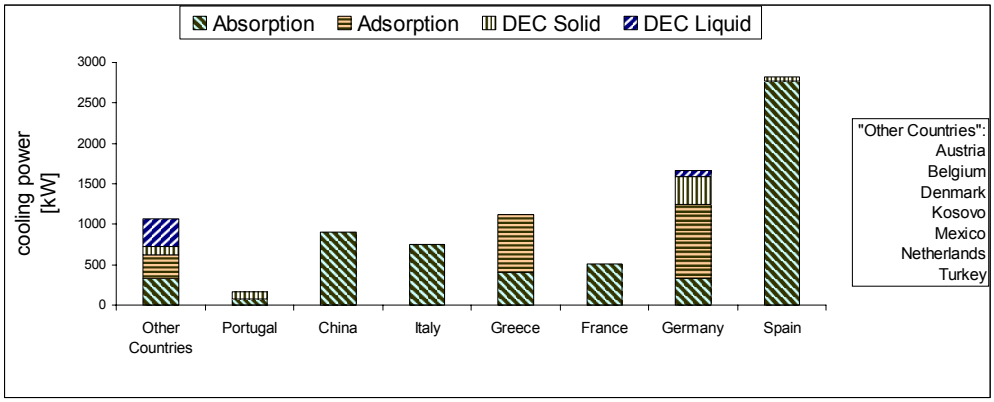

Figure 1: World wide distribution of the cooling power assisted by solar energy. The type of thermally driven chillers applied in the different countries is also highlighted.

The overall solar cooling capacity is assisted by 23'720 m² solar thermal collectors. 53% of the total gross area is made off FPC (Flat Plate Collectors), 37% of VTC (Vacuum Tube Collectors), 7.3 % of CPC (Compound Parabolic Collectors) and 2.6% of AH (Air Heaters). Only one installation, a hotel in Dalaman (TR) applies PTC (Parabolic Through Collectors) technology. The main solar thermal surfaces installed for cooling purposes are located in Spain, Germany and Greece (respectively 24%, 20% and 18% of the total surface –Fig.2).

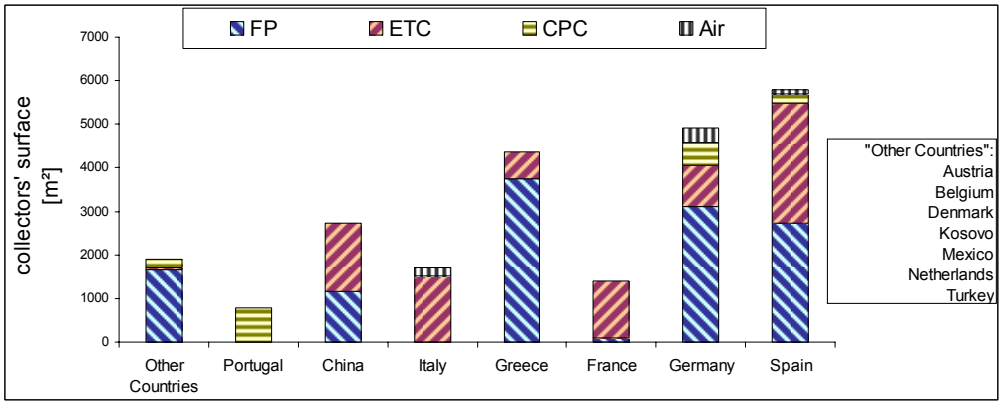

Figure 2: World wide installed solar collectors' surface for cooling purpose. The type of solar collectors used in each country is also highlighted.

The largest solar cooling plant is located in Viota (Greece). It has been realized for a cosmetic factory and it is made off 2 adsorption chillers (350 kWc each). 2'700 m² of flat plate collectors are installed delivering heat to the adsorption chillers as well as to the factory processes.

In the following, the rate between the solar collector's surface and the cooling capacity is discussed. First of all, the data collected has shown that not all the combinations "solar collectors - heat driven cooling machine" have been used (Tab.2). At the same time, 5 hybrid systems also occur, coupling different types of solar collectors or heat driven chillers. The installation of the Technology Center Cartif in Valladolid (ES) e.g. is made of 37.5 m² of FP and 40 m² of VT collectors which feed solar energy into an absorption machine of 35 kW [6]. Moreover, the collector's surface rated to the cooling power does not assume a recurrent value, even if the same technologies are applied. Table 3 illustrates some examples.

Table 2 Number of installations counted for each possible technology combination (hybrid systems are not taken into account in this table).

Devices combinations chiller type / collector type	Absorption	Adsorption	DEC solid	DEC liquid
FP	16	7	3	2
ETC	28	1	0	0
CPC	4	1	3	0
AIR	0	0	3	0

Table 3 Rate between collector surface's and cooling power installed in selected systems, corresponding to the most applied technology combinations.

country	town	final use	combination	m²/kW
Austria	Rohrbach	Office	FP/Abs	4
Denmark	Skive	Office		6,667
Kosovo	Pristina	Office		2,522
Spain	Barakaldo	Auditorium		0,655
Spain	Arteixo	Office		8,824
Germany	Remscheid	Office	FP/Ads	1,429
Germany	Augsburg	Office		5,682
Greece	Viota	Industry		3,857
Belgium	Brussels	Office	ETC/Abs	0,791
France	Banyuls	Winecellar		2,500
Germany	Berlin	Office		7,909
Italy	Bolzano	Education center		1,983
Germany	Freiburg	Office	AIR/DEC	1,786
Germany	Bückeburg	Office		3,333
Germany	Alt-Hengstett	Office		0,926

4. *System features*

For some installations, a more detailed description of the systems was available to the authors. This information concerns the hot and cold energy storages, the back up

systems and the heat rejection technology. Data about hydraulic schemes have also been considered, however at present they are not sufficient in order to draw important results.

4.1 *Energy storages*

80% of the 20 installations have one or more tanks to storage thermal energy. The collected data shows that there is not a recurrent value for the storage capacity rated to the collector's surface or to the installed cooling power, also when the same technologies are applied. Table 4 shows two examples.

Table 4 Collectors' surface, cooling power, technical data and the rates between them, of two selected systems using the most applied technology combinations.

installations	Press and Information Center of the German Government	Ott&Spiess
location	Berlin (DE)	Langenau (DE)
final use	offices	offices
cooling capacity	44 kW	35 kW
collectors' surface	348 m² of VTC	22 m² VTC
solar tank	1600 l	2000 l
storage/collectors	4.60 l/m²	90.9 l/m²
storage/cooling power	36.4 l/kW$_c$	57.1 l/kW$_c$

In 10/17 cases a cold water storage is installed. A recurrent value for the storage capacity rated to the cooling power is not registered. At the University Rovira and Virgili in Tarragona (35 kW absorption machine) there is installed a cold storage tank of 5'000l, while at the Technologic Center in Valladolid (same chiller capacity), a storage tank of 1'000 l is installed , leading to 142.8 and 28.57 cold storage liters per cooling power unit respectively. In both installations no cold back up system is present.

4.2 *Back-up systems*

A heat back up system is present in 16/19 installations. Gas boilers, cogeneration units and district heating are the main systems used for heat backup purposes. On the cooling demand side, 10/16 installations have a chilled water back up systems. These are mainly compression chillers. Only one installation, the Ministery for Traffic, Building and Housing in Berlin (DE) use two compression chillers (65 kW$_c$ and 180 kW$_c$) and an

ice storage tank of 7250 l to support a 70 kW absorption machine fed by 229 m² of flat plate collectors.

4.3 *Heat rejection*

9 plants based on absorption technology and 2 based on adsorption technology have installed a wet cooling tower as heat rejection system. 7 cases, of which 6 applying absorption technology, are driven by open cycle.

5 *Conclusions*

As detailed information were available only for single installations, statistical analysis is difficult to be carried out. The installed systems differ a lot from each other, thus leading to difficulties in comparison. The collected data show that only very limited standardization has been reached within the solar cooling systems up to now. In order to leave the scientific and prototype phase within large scale solar cooling installations drive a clear learning curve among the systems a larger standardization seems to be necessary.

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