SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Task 38
Solar Air-Conditioning and Refrigeration

State of the art on existing solar heating and cooling systems

A technical report of subtask B

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1. Introduction

Within the subtask B of the "Task 38 - Solar Air Conditioning and Refrigeration", an overview has been carried out on thermally driven chillers and solar thermal technologies used in realized systems. The aim of this overview is to collect information on existing solar heating and cooling systems in order to derive a first identification of proven design solutions in terms of selection of technologies and dimensioning in relationship with location, final use and size of the building. The analysis of existing design solutions can help planners in the first steps of the decision making by addressing them towards the identification of optimal design solutions for solar heating and cooling applications.

Such activity has been carried out in the work package B1 in the framework of subtask B about solar cooling systems with overall thermal driven cooling power largely higher than 20 kW.

Collection of data on existing solar cooling systems has also been carried out in the work package A 5 of the subtask A concerning small solar cooling applications (overall thermal driven cooling power below 20 kW).

The present report summarizes the results derived from both the activities and working teams but goes in detail with special features of large scale systems as they are custom made systems, hence they are not as standard as package solutions for small applications and much more information could be found.

2. Research approach

Two lists of existing solar heating and cooling systems have been created, one for small scale systems and one for large scale systems.

For each system the following general data have been collected:

- name of the building project,
- location,
- final use,
- status (working, monitored,…).

Concerning technical aspects the following data have been collected:

- type and cooling capacity of the thermally driven chillers;
- type of solar collectors and their gross area;
- the capacity of energy storage on cold and hot side;
- the type and the power of heat and cold back up systems.

The data about existing solar cooling plants have been collected through a survey intended for:

- task 38 participants responsible for single systems,
- owner institutions and
- design and installation companies.

Table 1 summarizes the content of the survey.

Tab. 1 General and technical aspects selected to describe single solar cooling installations.

Survey On Existing Solar Heating And Cooling Installations							
General data	Name of the building/project						
	Location						
	Final use						
	Status of the SHC system						
	Components	**Technologies**					**Unit**
Technical data	Thermal Driven chiller (TDC)	Absorption		Adsorption	DEC solid	DEC liquid	kW or m³/hr
	Solar Thermal Collectors (STC)	Flat Plate (FP)	Evacuate Tube (ETC)	Compound Parabolic (CPC)	Air (Air)	Parabolic Through (PTC)	m² (gross area)
	Storage	Water, PCM, ICE…					l
	Heat back up	Gas boilers, heat pumps, district heating…					kW
	Cold back up	Compression chiller, heat pump…					kW

A first amount of data has been derived from other international projects like IEA-Task 25 [1], RoCoCo [2] and SACE [3].

In spite of the effort spent in collecting information, detailed data are still missing, especially for the small installations which are often private residential installations where acquiring data is difficult. In fact, for small scale systems most data have been collected thanks to manufacturers which counts the chillers sold per year. For this reason, quite complete information is available on the type and size of installed thermal driven chillers but most left required data are missing.

3. General overview on installed systems

To the knowledge of the authors, 113 large scale solar cooling systems and 163 small scale systems have been installed worldwide, eventually including systems which are currently not in operation. 254 installations are located in Europe, 13 in Asia, mostly in China and Japan, 4 in America (3 in USA and 1 in Mexico), 3 in Australia and 2 in Africa (Egypt and South Africa). Figure 3.1 shows the distribution of the worldwide number of installations on Countries, classified in small or large scale.

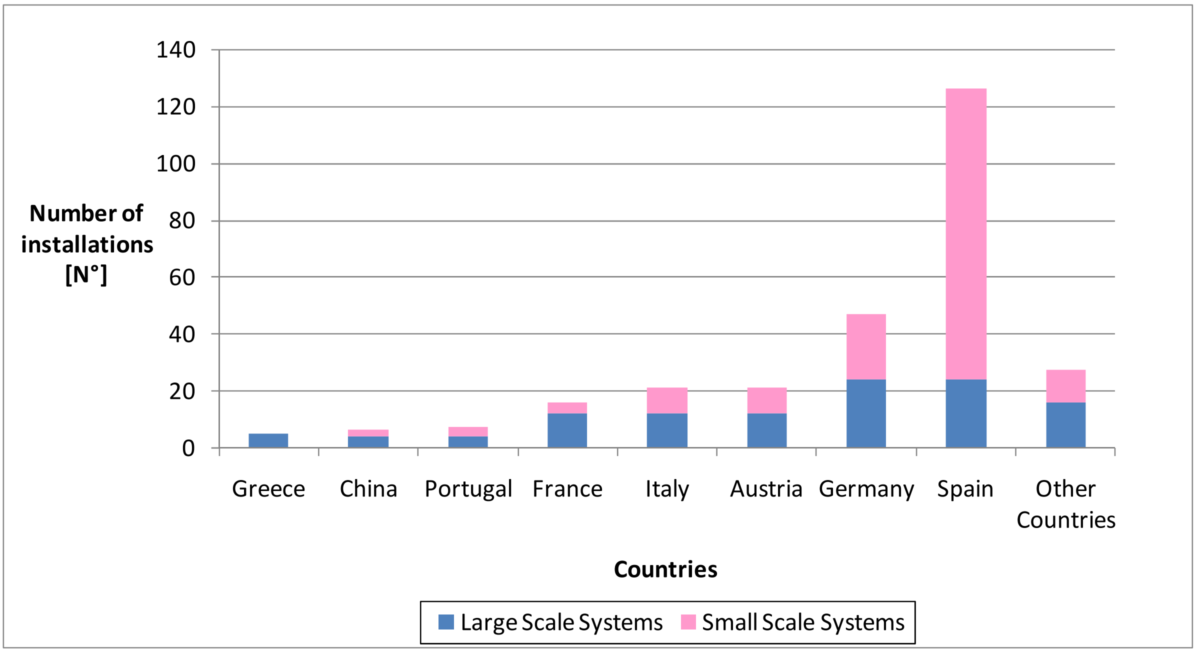

Figure 3.1 Total number of solar heating and cooling systems installed in different countries and classified in small or large scale systems. "Other Countries" include: Armenia, Australia, Belgium, Denmark, Egypt, Japan, Kosovo, Lichtenstein, Malta, Mexico, Netherlands, Singapore, South Africa, Switzerland, Syria, Turkey, UK, United Arab Emirates and USA.

Most installations are dedicated to office buildings as shown in Figure 3.2 and Figure 3.3, but 28% of the overall small scale installations serve residential buildings.

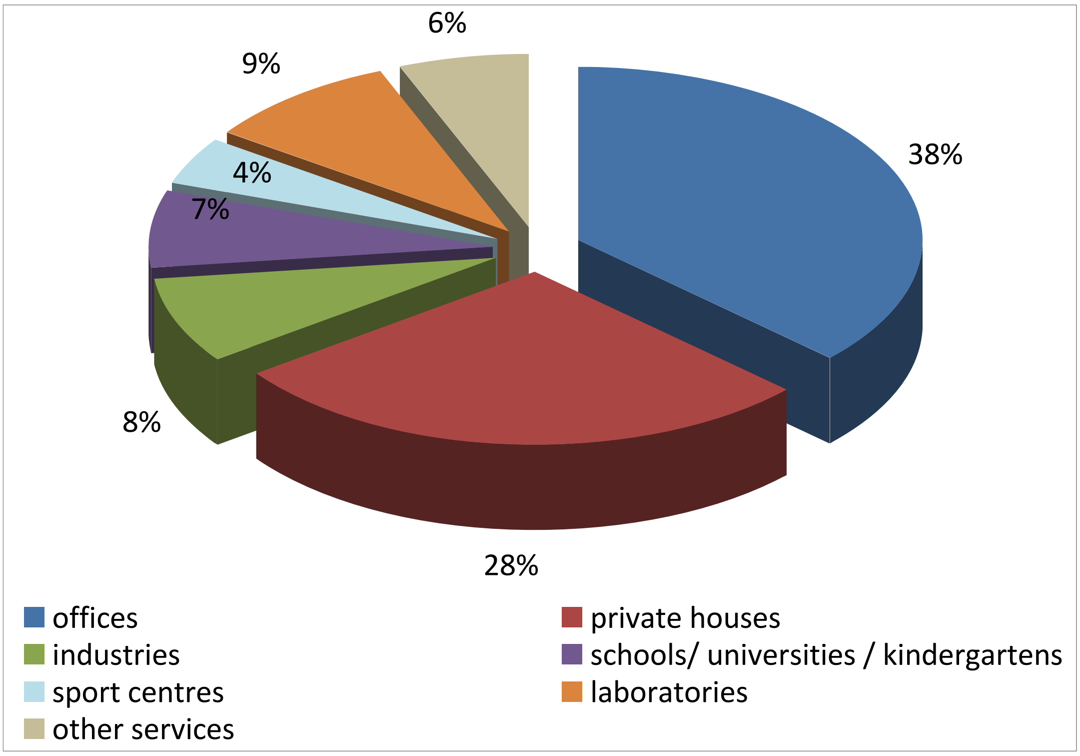

Figure 3.2 Use of small scale solar heating and cooling installations. ("Other services" include: schools, show rooms, hotels, etc)

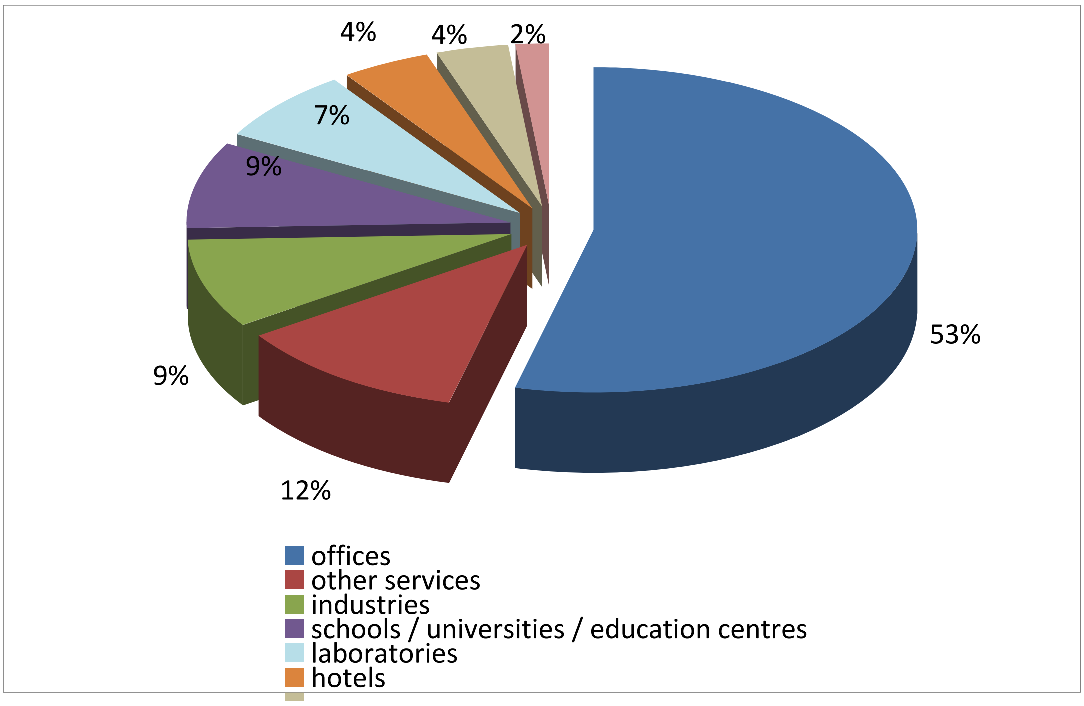

Figure 3.3 Use of large scale solar heating and cooling installations. ("Other services" include: hospitals, canteen, sport center, etc)

The overall cooling capacity of thermally driven chillers assisted by solar energy calculated on 268 systems amounts to 15.7 MW: 24.4% of it is installed in Spain, 19,5% in Germany and 17.4% in Italy 7 (Figure 3.4). 14.1 MW of such cooling capacity goes to large scale systems and 1.6 MW to small scale systems.

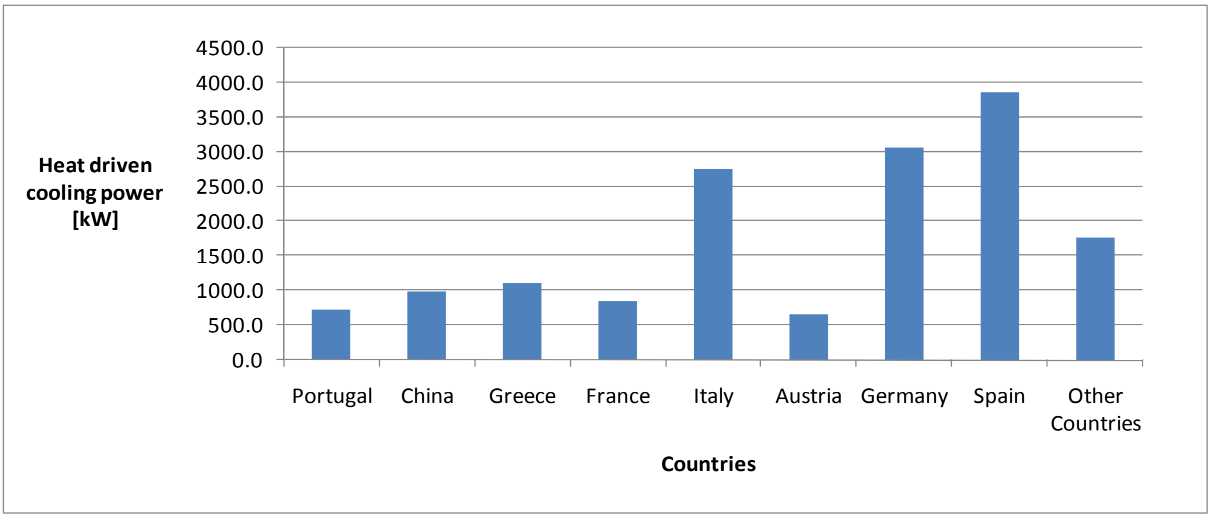

Figure 3.4 Cooling power of thermally driven chillers assisted by solar energy installed in different world Countries. "Other Countries" include the cooling power installed in Australia, Belgium, Denmark, Egypt, Kosovo, Lichtenstein, Malta, Mexico, Netherlands, Singapore, Switzerland, Syria, Turkey, UK, United Arab Emirates and in one US plant. As the cooling capacity of DEC systems is often expressed in m³/hr, information on kW installed in 5 DEC based systems (2 Austrian, 2 Italian and one Armenian) is missing.

Within 269 installations, the technology of thermally driven chillers most used is based on absorption principle (Figure 3.5 and Figure 3.6) whereas DEC systems are only used in large applications.

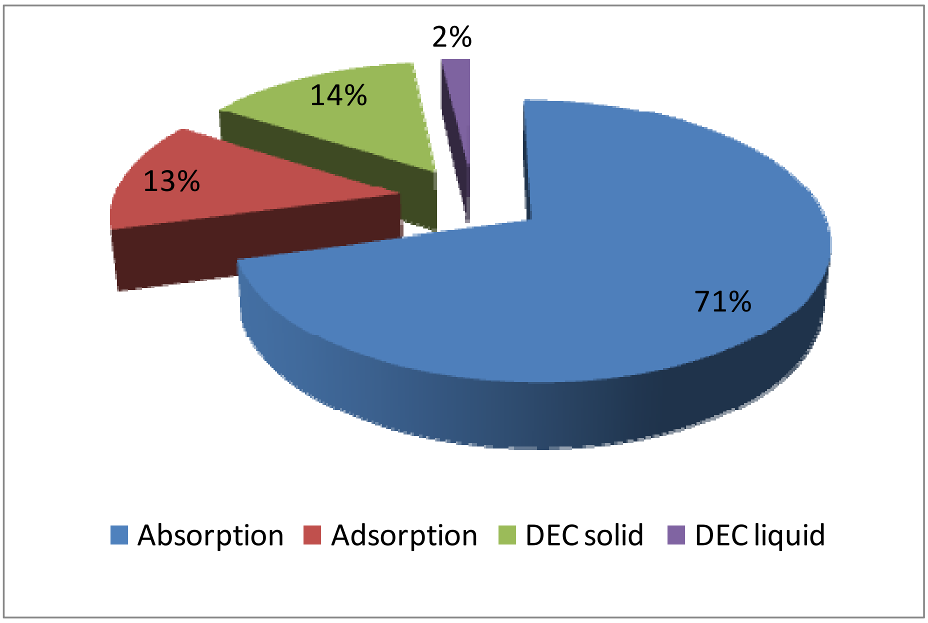

Figure 3.5 Percentage of use of different technologies for thermally driven chillers within 113 large scale systems.

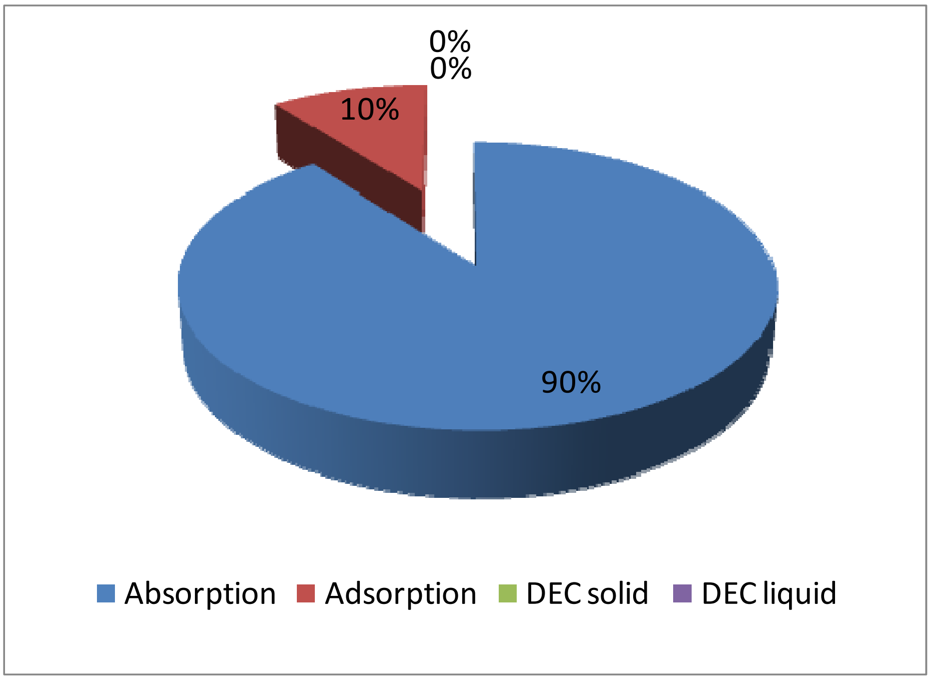

Figure 3.6 Percentage of use of different technologies for thermally driven chillers within 156 small scale systems.

Within around 105 small scale solar cooling systems based on absorption, the chillers manufactured by Rotartica with 4.5 kW are present in 50% of the installations, whereas Sorthech is the only manufacturer providing adsorption chillers in 16 systems.

For large scale systems no data of manufacturers are available and the nominal cooling capacities installed are so different within the existing installations that it is not possible recognizing special manufacturers, except one: 18 large scale installations are probably equipped with Yazaki chillers with a power of 35 kW.

4. Technical data and statistics on large scale systems

Solar thermal collectors and thermally driven cooling systems

A focus on large scale solar cooling systems shows that the technology selected for thermally driven cooling systems can vary country by country. For instance, adsorption chillers are largely used in Germany whereas Italy and Spain feature a large adoption of absorption chillers as shown in Figure 4.1.

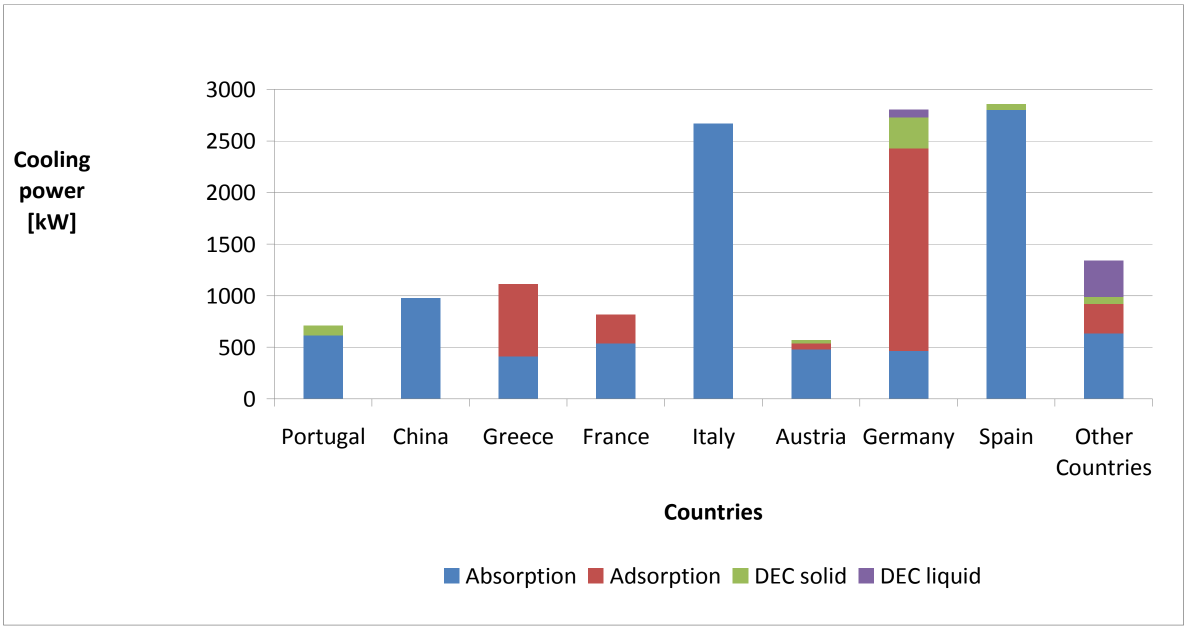

Figure 4.1 World wide distribution of the cooling power are assisted by solar energy. The type of thermally driven chillers applied in the different countries is highlighted. "Other Countries" include:, Australia, Belgium, Denmark, Kosovo, Mexico, Netherlands, Singapore, South Africa, Switzerland, Turkey and one US installations. Data on kW installed in 2 "DEC solid" systems in Austria and two in Italy are missing.

Flat Plate (FP) collectors and Evacuated Tube Collectors (ETC) are the technology mostly used in large scale solar cooling assisted systems, as shown in
Figure 4.2, whereas Compound Parabolic Collectors (CPC), Air Collectors (Air) and Parabolic Through Collectors (PTC) are respectively present in 9, 5 and 3 installations (PTC are used in Australia, in Turkey and in USA).

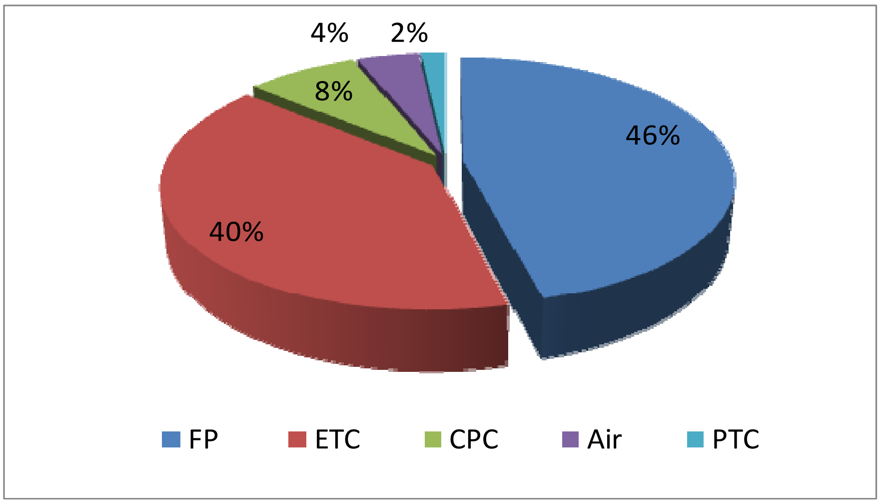

Figure 4.2 Percentage of use of different technologies for solar thermal collectors within 112 large scale systems.

The overall solar surface installed in 108 systems amounts to 35,530 m². The largest surfaces installed for cooling purposes are located in Germany, Italy and Spain as shown in Figure 4.3.

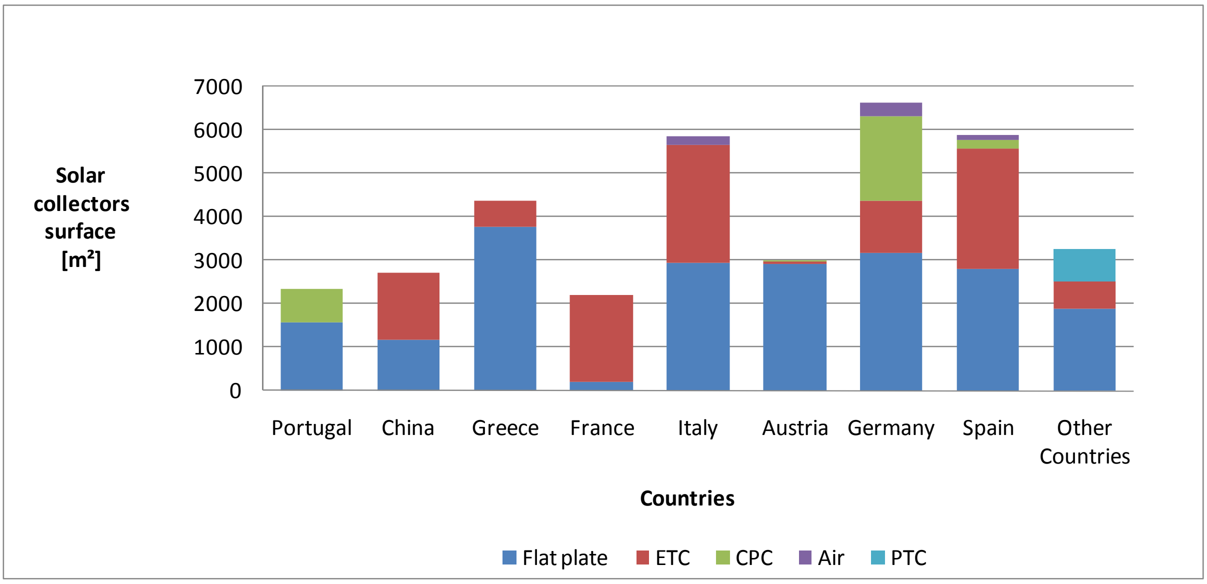

Figure 4.3: World wide installed solar collectors' surface for cooling purpose. The type of solar collectors used in each country is highlighted.

According to Figure 4.3, the technologies used for solar collectors can vary country by country. For instance, 20% of the total solar surface installed in Germany is made of CPC collectors even though they mostly belong to one installation, i.e. the FESTO Company with over 1,200 m² solar collector's surface. Still Italy and Spain feature similar characteristics as their solar surfaces for cooling purposes are nearly 50% made of FP and 50% of ETC. However, 9/12 Italian installations feature ETC fields and the surface distribution similar to the Spanish one is only due to the largest solar cooling plant which has been built in Rome on the roof of the METRO Cash & Carry building (2700 m² driving 700 kW absorption chiller).

Correlating the different technologies of solar collectors used per installed thermal driven technology in 112 installations, it results that not all possible combinations (20) are used (Tab. 2).

Tab. 2 Number of installations counted for each possible technology combination (hybrid systems are not included in this table).

Devices combinations	Absorption	Adsorption	DEC solid	DEC liquid
FP	32	8	6	2
ECT	35	5	1	0
CPC	4	2	3	0
AIR	0	0	5	0
PTC	3	0	0	0

At the same time, 6 hybrid systems also occur, coupling different types of solar collectors or heat driven chillers. E.g. the first installation of the Technology Center Cartiff in Valladolid (ES) 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. Moreover, the collector's surface rated to the cooling power does not assume a recurrent value, even if the same technologies are applied.

The average rates used within 95 large scale installations for different combinations of solar thermal surface (STC) and thermally driven chillers (TDC) are shown in Figure 4.4. Actually, such average values are the results of largely different rates used in the examined installations, as represented in Figure 4.5.

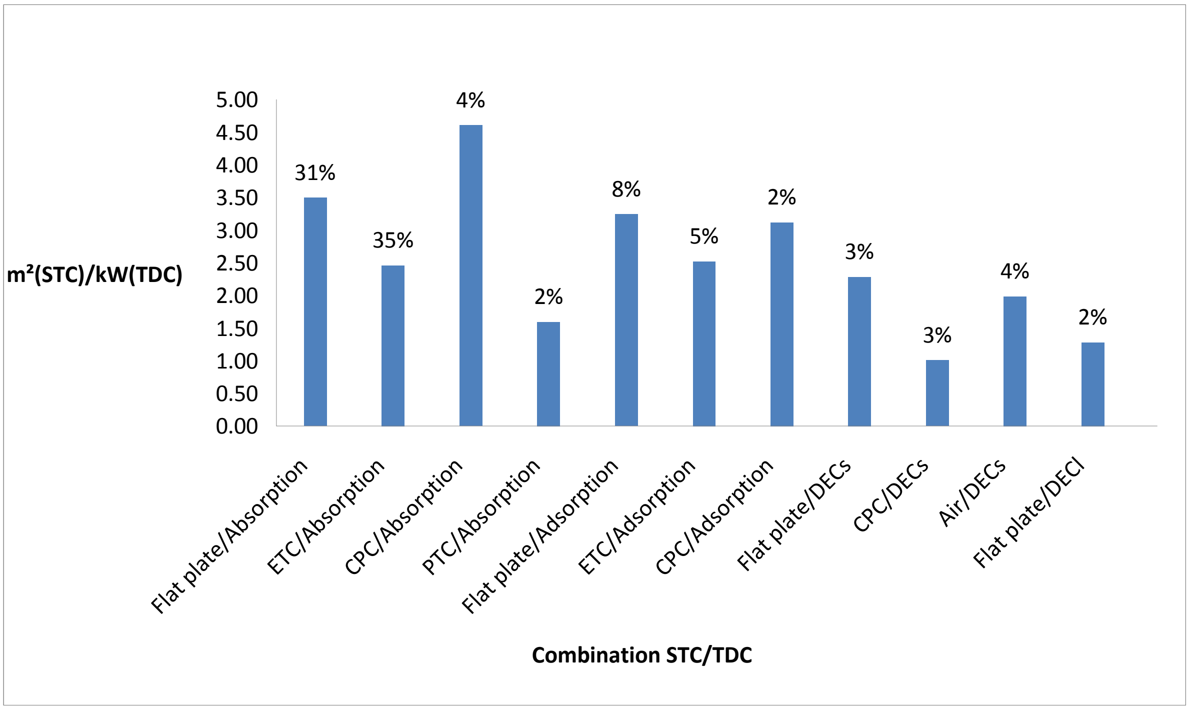

Figure 4.4 Mean of the rates used for each combination taking into account the rate between the used combination and the overall number of cases (95)

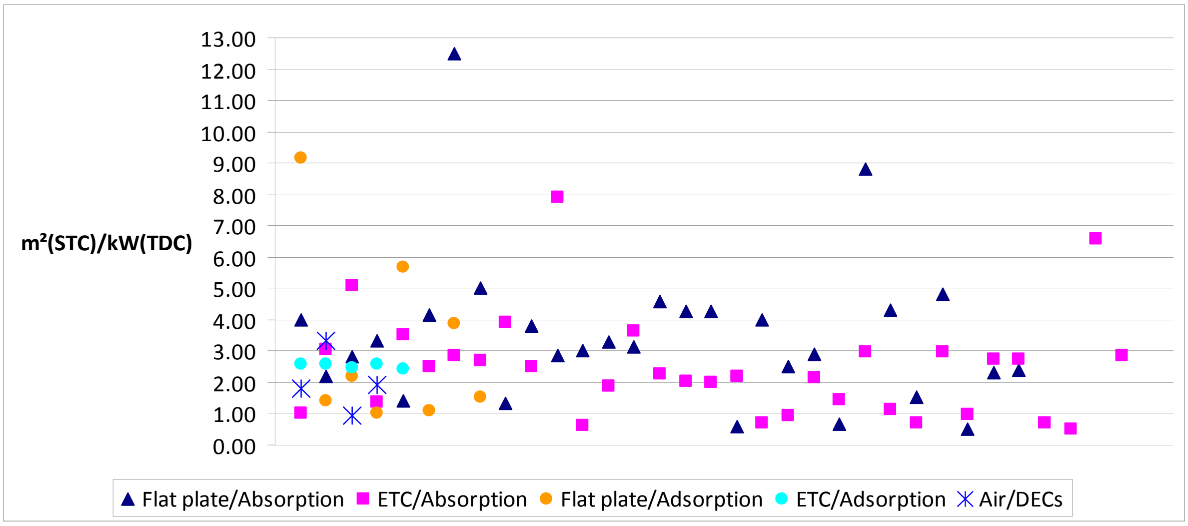

Figure 4.5 Rates between the solar surface collectors installed per kW of cooling capacity for the most used technologies combinations

Heat and cold storage tanks

43 large scale installations are equipped with hot water storage tanks. The rates between the volumes of the tanks and the installed solar surfaces vary case by case, even for those ones which appear similar as shown in Tab. 3.

Tab. 3 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 Centre of the German Government**	**Ott & Spiess Headquarter**
Locations	Berlin (DE)	Langenau (DE)
Final Use	Offices	Offices
Cooling capacity	44 kW	35 kW
Collectors' surface	348 m² of ETC	22 m² of ETC
Solar Tank	1,600 l	2,000 l hot water
Storage/collectors	4.60 l/m²	90.9 l/m²

Figure 4.6 shows an average calculated on 40 cases (hybrid systems are excluded). Nevertheless, such average values are still based on quite different rates as shown in Figure 4.7. In these cases, any average could not reflect the reality.

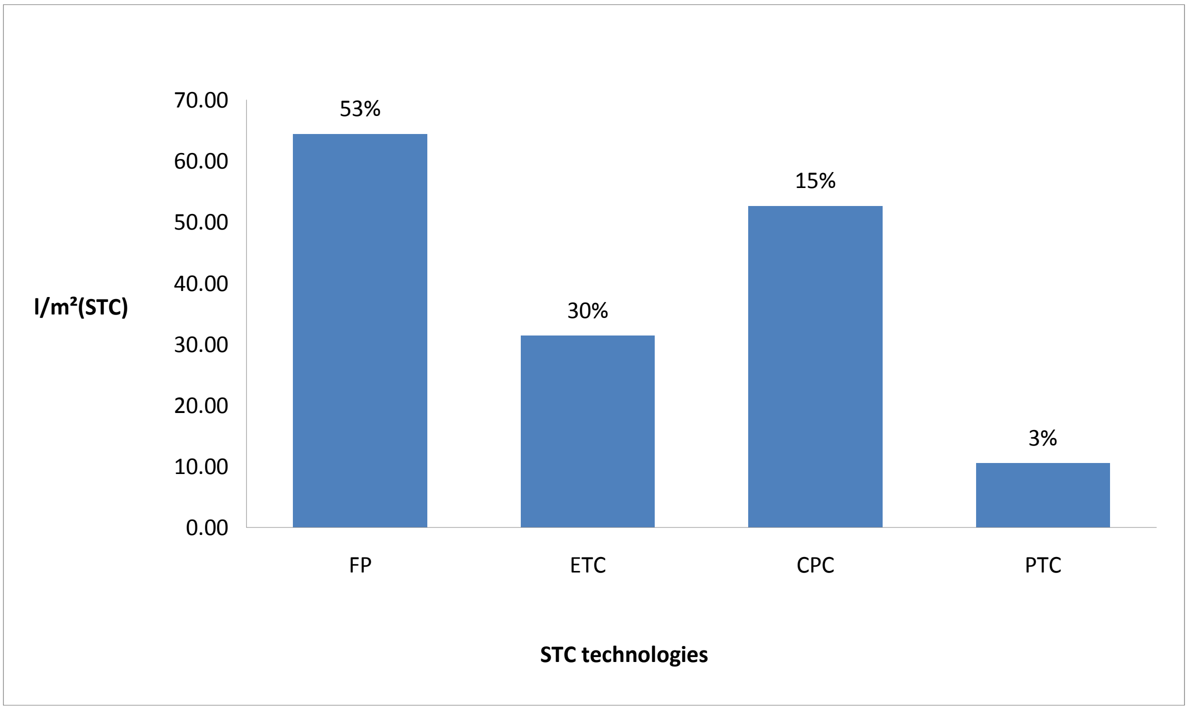

Figure 4.6 Mean of the litres of solar tanks used for different technologies of solar collectors taking into account the rate between the used combination and the overall number of examined cases (40)

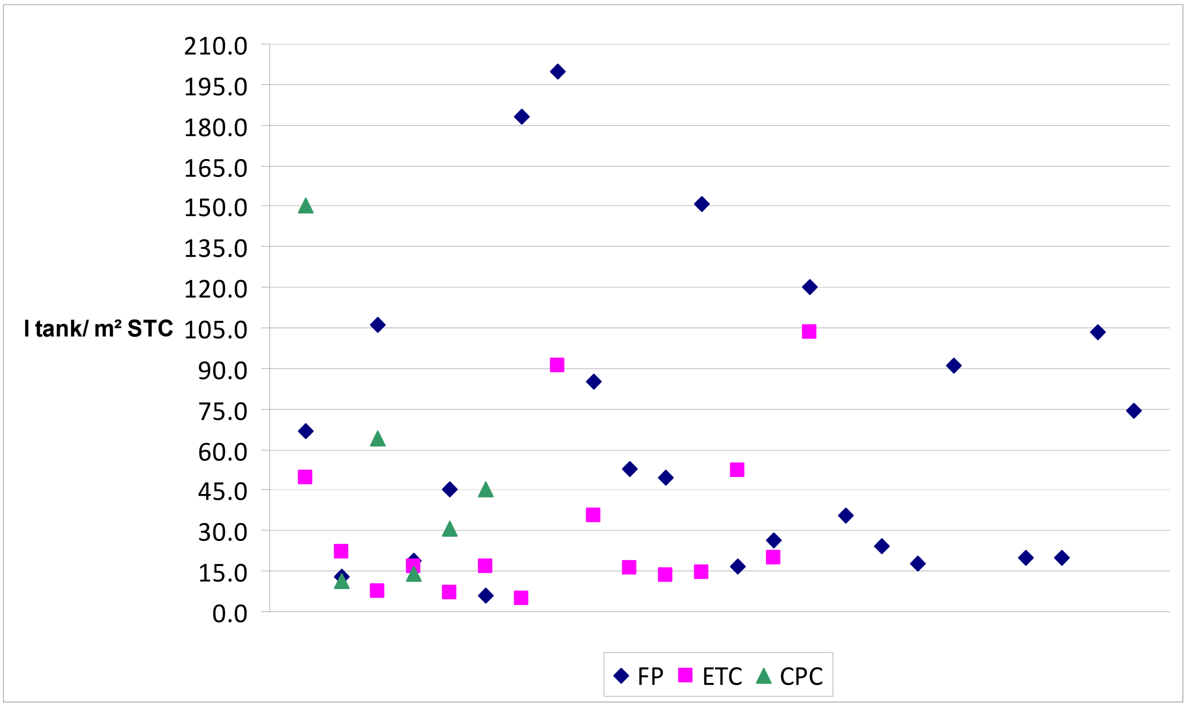

Figure 4.7 Rate between the litres of hot water storage tanks used in each of 46 installations and classified according to the technology used for solar thermal collectors

Cold water storage tanks are not spread as the hot water ones: within 33 installations, 19 have a cold water tank whereas the rest do not (especially DEC systems). Also in this case the rate between the volume of the tank and the kW of cooling installed varies case by case as shown in Figure 4.8.

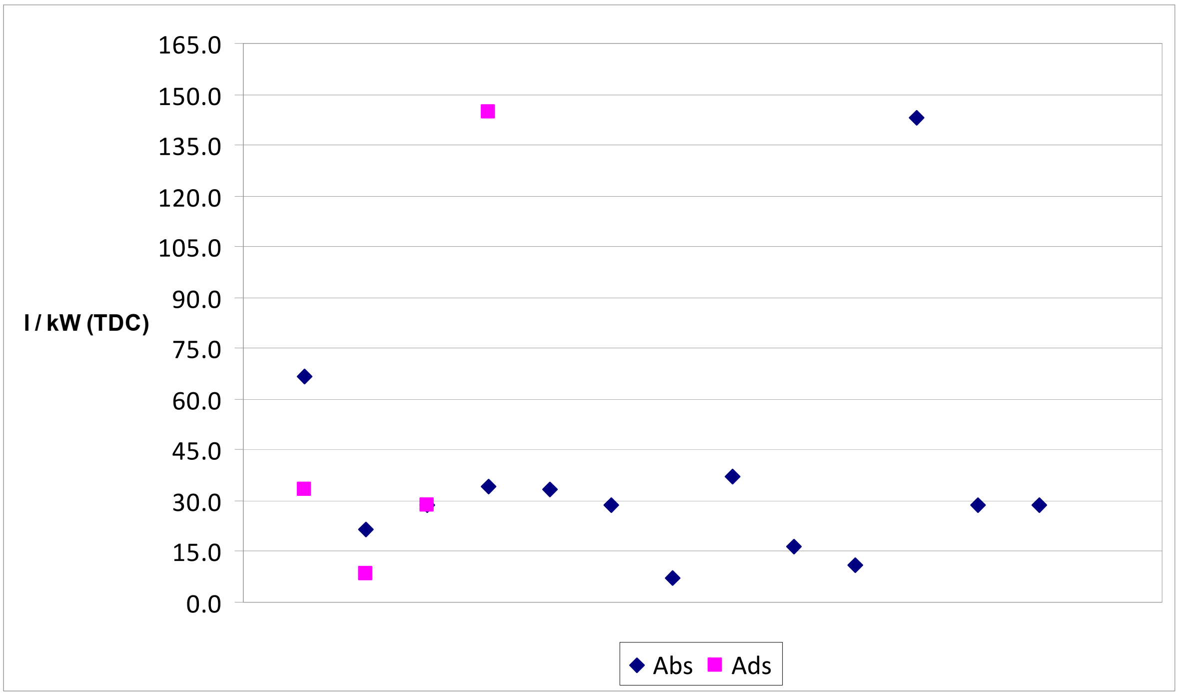

Figure 4.8 Rate between the volume of cold water tanks and the corresponding installed cooling capacity

Heat and cold back up systems

Within 45 systems, 40 are equipped with heat back up systems, based on gas/oil boilers, or heat recovery from cogeneration unit, district heating and heat pumps as shown in Figure 4.9.

Within 36 installations, 25 do not have any cold backup. Within the left systems, 58% employs vapor compression chillers whereas 32% employs heat pumps (NB, systems for which data are available can be different from the ones where data on heat backup systems are available).

As example of solar cooling systems with no heat neither cold backup system is the plant installed in La Reunion (F), where 30 kW absorption chiller is exclusively driven by the heat deriving from 90 m² flat plate solar collectors and thanks to the management of two storage tanks, one for solar heat of 1,500 l tank and one for cold water (1,000 l).

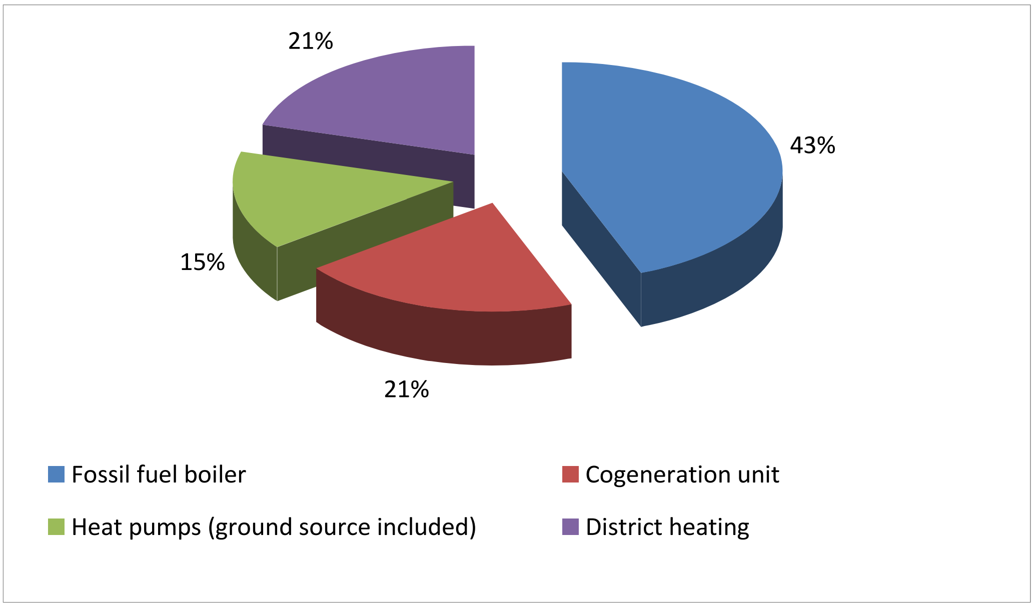

Figure 4.9 Used heat back up in 34 installations

5. Conclusions

Considering the total number of existing solar cooling installations known to the authors in 2009, 10% growth in the market has been registered with respect to 2007, as shown in Figure 5.1

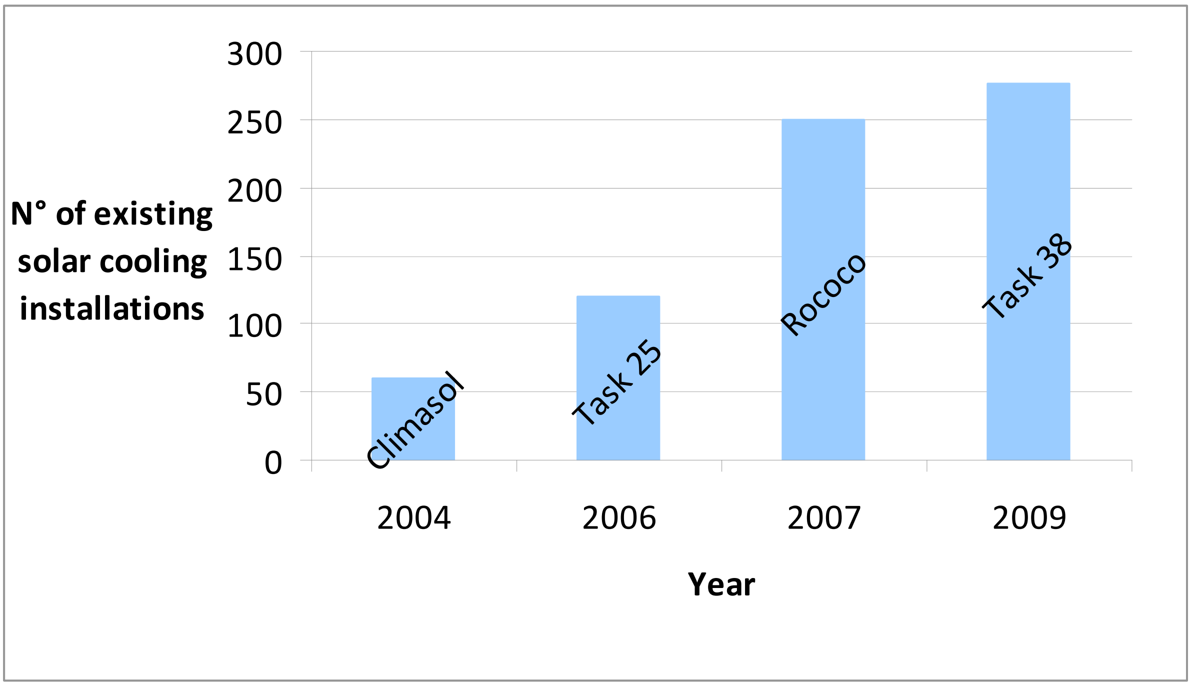

Figure 5.1 Number of total solar cooling installations per year according to different sources as collected by SolarNext

Such growth has been more significant in some Countries, as Spain, Italy and France leading to an overturning of the situation registered in 2005 as shown in Figure 5.2 and Figure 5.3.

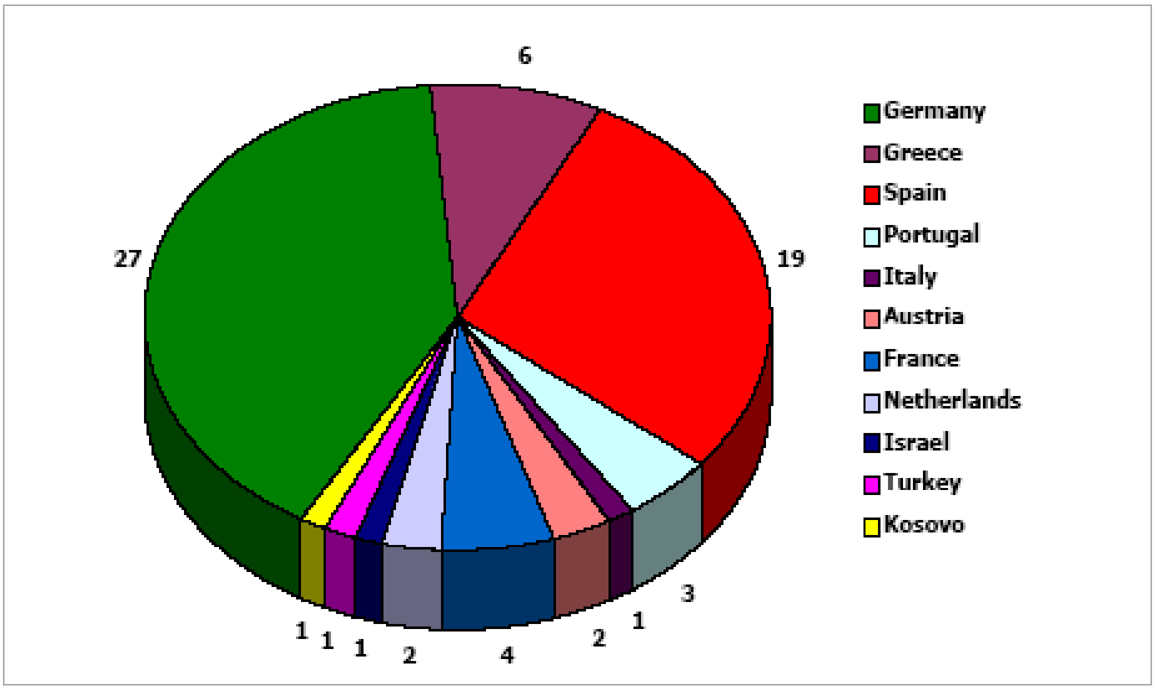

Figure 5.2 Distribution of existing solar cooling installations listed in 2005 in the final report of the IEA Task 25 [1] within different Countries.

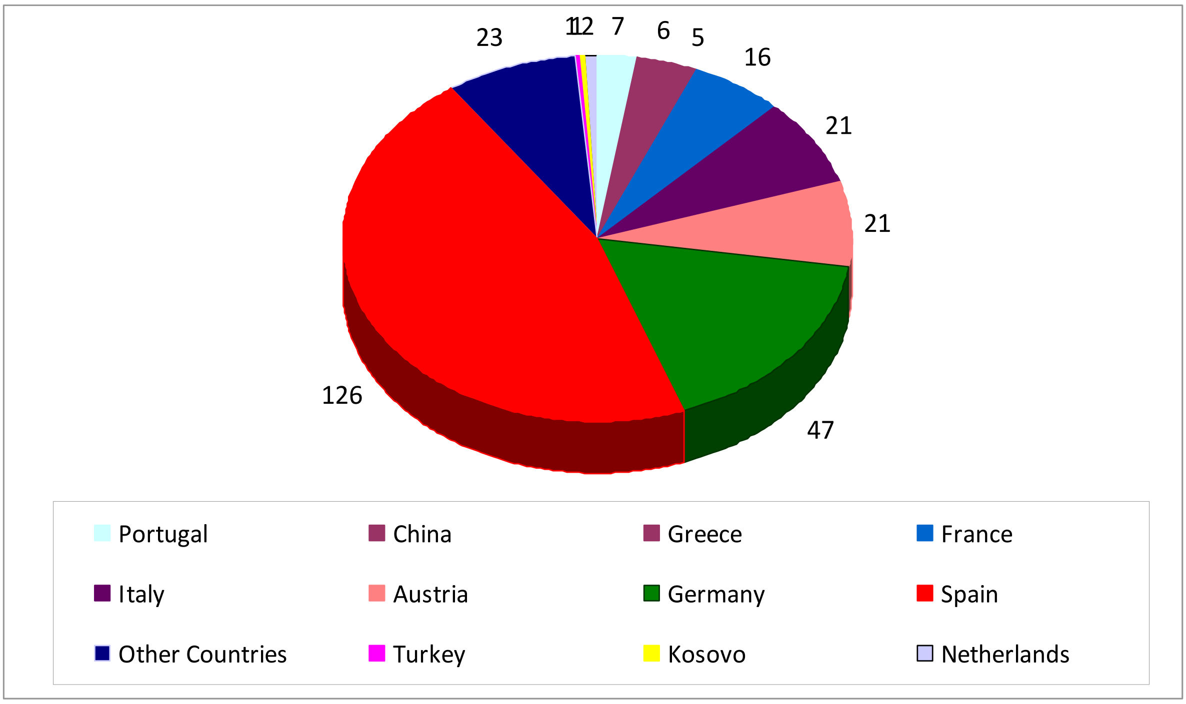

Figure 5.3 Distribution of existing plants listed in 2009 in Task 38 within different Countries. "Other Countries" include: Armenia, Australia, Belgium, Denmark, Egypt, Japan, Lichtenstein, Malta, Mexico, Singapore, South Africa, Switzerland, Syria, UK, United Arab Emirates and USA

Absorption chillers are the thermally driven chillers most present on the market in both small and large applications. Their combination with solar flat plates or evacuated tube collectors is quite well experienced in large systems.

DEC systems have not penetrated the market as absorption and adsorption chiller, especially the DEC liquid technology. To the knowledge of the authors, only 2 DEC liquid systems exist, one in Germany (75 kW) and another one in China (350 kW). Nevertheless, the combination of DEC solid systems with air collectors seems to be competitive with respect to other kind of combinations (mostly DEC solid plus flat plate collectors).

Concerning the solar thermal technology, PTC are present in only 3 solar cooling installation over 113, wherever flat plates and evacuated tubes are the most used technologies.

Whereas the selection of components and their combinations clearly outline the solar cooling market, sizing criteria for the solar thermal surface compared to the installed cooling power, or of the heat and cold storage respectively compared to the installed solar surface and cooling capacity can not be easily derived. In fact, first of all, detailed and reliable statistical analysis is difficult to be carried out as information is not available for all the systems listed. Then, well known installed systems differ so much that possible average values cannot be considered representative of the sample. Finally, the large difference between existing and documented plants do not enable for comparing different design solutions and for deriving any criteria.

To address planners towards optimal design, monitoring results showing advantages and disadvantages of single solutions seem to be necessary. On the other hand, a detailed investigation on the approach used by planners to size components in analyzed projects could be useful to understand the reason the rates between the solar surface and the cooling capacity installed or between the storage capacity and the solar surface or the cooling power installed are so different.

At the current state of the art, the large difference between the systems highlights that solar cooling is still in an early phase of technology development. By addressing planners towards selected configurations and sizes, a clear learning curve could be defined and standardization could be achieved.

REFERENCES

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