Durability issues, maintenance and costs of solar cooling systems

Task Report 5.3.2

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Quality Assurance in solar thermal heating and cooling technology – keeping track with recent and upcoming developments

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1. Introduction

Several factors are driving the market for solar cooling solutions. On the one hand the exploding demand for cooling and consequently also the demand for electricity to drive the conventional cooling machines is becoming not only very expensive but also endangers the stability of whole electricity grids. In several European countries the peak electricity demand has already shifted from winter to summer and the demand for more comfort and cooling is rapidly increasing even in more moderate climates. Furthermore, the trend to larger solar thermal systems and higher solar fractions lead to more available solar heat output in summer than what is actually needed. These factors make solar thermal cooling a more and more attractive option. The number of installed systems has increased tremendously in the past few years and several new thermally driven cooling machines – especially designed for smaller capacities and lower driving temperatures - have entered the market. As this is a very new market, there are hardly any standards regarding the durability of solar thermal cooling systems so far. To ensure a good quality and to avoid any backlashes from low – or nonperforming systems, quality requirements need to be developed soon, as solar cooling technology is developing very fast and high expectations are put in it. Solar cooling systems require rather high investments and therefore any kind of guarantees on life expectancy, performance or durability are welcome to convince or reassure customers and investors.

The objective of this task is to develop a basis of requirements and test methods with a focus on the solar thermal part of a solar cooling system.

Previous work has already been taken out on this issue within the IEA SHC Task 38 – Solar Air-Conditioning and Refrigeration and the project NEGST. The potential and assessment of most promising technologies has been conducted in NEGST. Nevertheless, requirements for durability and performance of solar cooling systems have not been defined and test methods have not been developed accordingly for such applications.

2. Report on durability issues, maintenance and cost

Surveys on existing solar cooling installations have been performed in the past by other working groups e.g. Task 25 and Task 38 of the Solar Heating & Cooling Programme (SHC) of the International Energy Agency (IEA), project Solar Air-Conditioning in Europe (SACE), project Promoting Solar Air-Conditioning (CLIMASOL) and the SOLAIR project.

Within the QAiST project a survey on existing solar cooling installations has been carried out with a focus on durability issues, maintenance and costs. For this purpose a questionnaire has been elaborated and distributed by the project members. In the following the main structure of the questionnaire is introduced and the results gathered from the survey using this questionnaire are presented and discussed. The complete questionnaire as it was distributed can be found in the Annex of this document.

2.1. Questionnaire

The questionnaire was prepared in a way to be able to include data from previous surveys of other projects. The most comprehensive questionnaire of previous working groups is the one distributed by the Solair project. For this reason the questionnaire elaborated for QAiST is based on the Solair questionnaire and extended. The questionnaire is divided into the following sections:

- Project data
  General information on the person who filled out the questionnaire and general information on the location of the related plant.
- Building
  Information on the building characteristics, heating and cooling loads, the distribution system and the cooling strategy
- Heat sources
  Data on the solar system including the heat storages and the back-up heating
- Cooling equipment
  Data on the chiller or desiccant evaporative cooling system (DEC), the cold storages, the heat rejection and the back-up cooling
- Investment costs
  Financial accounting of the investment costs for the whole system and the costs split up by component costs, installation costs, etc.
- Running costs
  Accounting of the running costs of the system split up by maintenance expenses and operation expenses
- Qualitative assessment
  Reasons for choice of the system, user reactions, performance, reliability and problems
- Schematic
- Pictures

2.2. Analysis of the QAiST questionnaire for solar thermal cooling

The data base of QAiST includes 57 installations for solar thermal cooling. As shown in **Error! Not a valid bookmark self-reference.** these systems are located in different European countries, most of them in Greece, Spain, Austria and Germany.

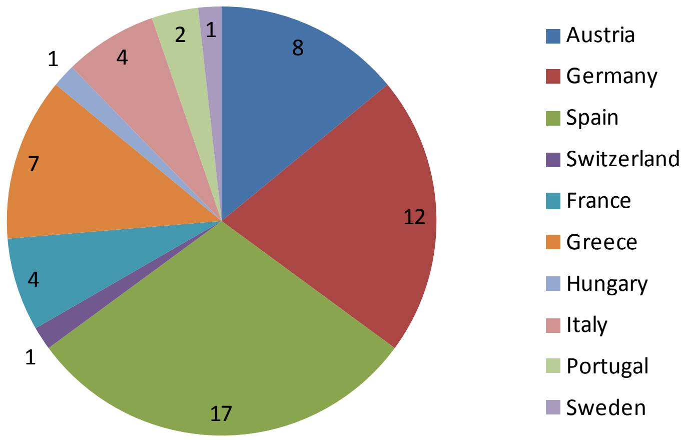


Figure 1: Locations of the solar cooling plants

2.2.1. Building

In this section the building category, heating and cooling requirements as well as the cold distribution system and the cooling strategy has been sampled.

All the systems in the QAiST database are used for space cooling. 44 of them are also used for space heating. 28 are used for hot water preparation, 4 for heating a swimming pool. **Error! Not a valid bookmark self-reference.** shows the distribution of the different building types that are equipped with solar cooling systems. Most frequently solar cooling is used in offices, followed by commercial buildings and hotels.

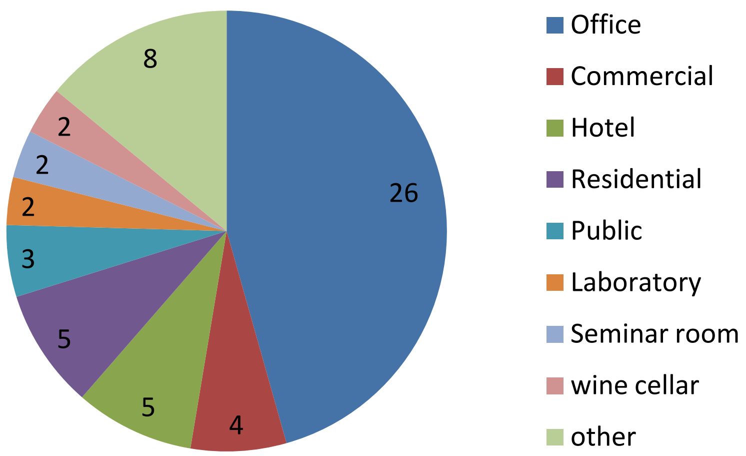
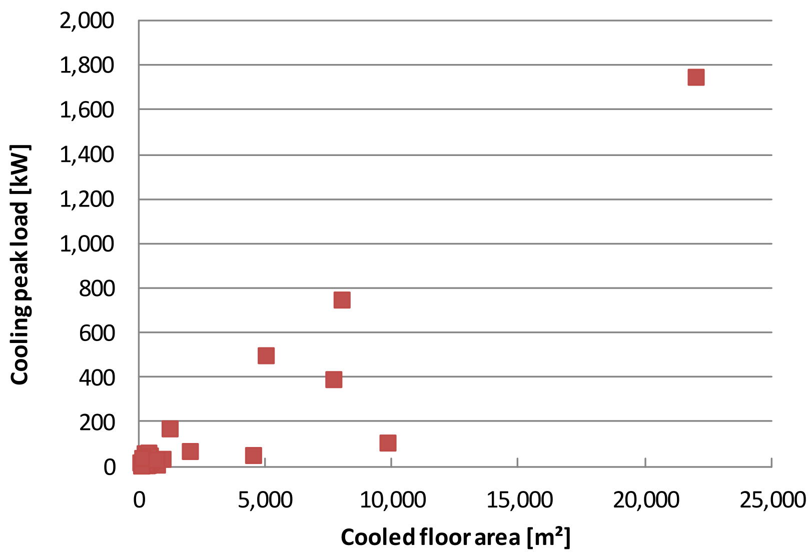


Figure 2: Building types

The cooled floor area of the different systems varies very much and ranges from 42 m² to 35130 m² with a cooling peak load between 4.8 kW and 1,750 kW. The cooling peak load depends on the cooled floor area as



shown in

Figure 4 and

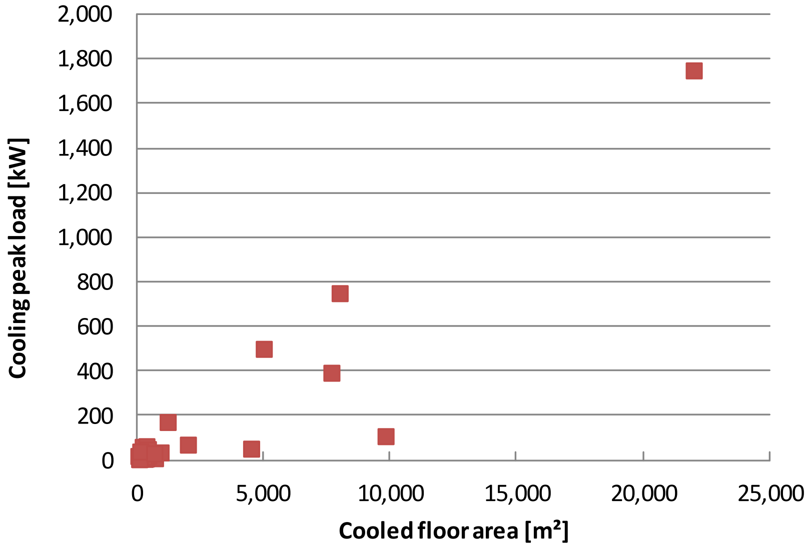


Figure 4. So the specific cooling peak load varies between 0.011 and 0.452 kW/m². But this specific cooling load shows no dependency on the size of the cooling system.

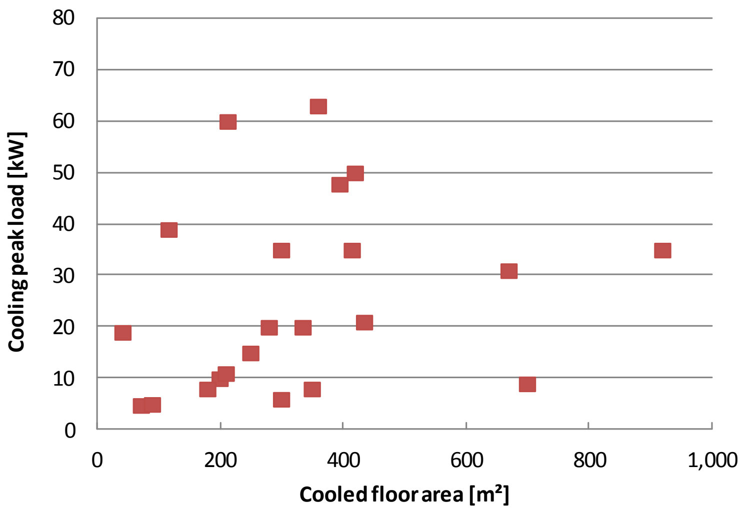


Figure 3: Cooling peak load for installations with up to 1,000 m² of cooled floor area

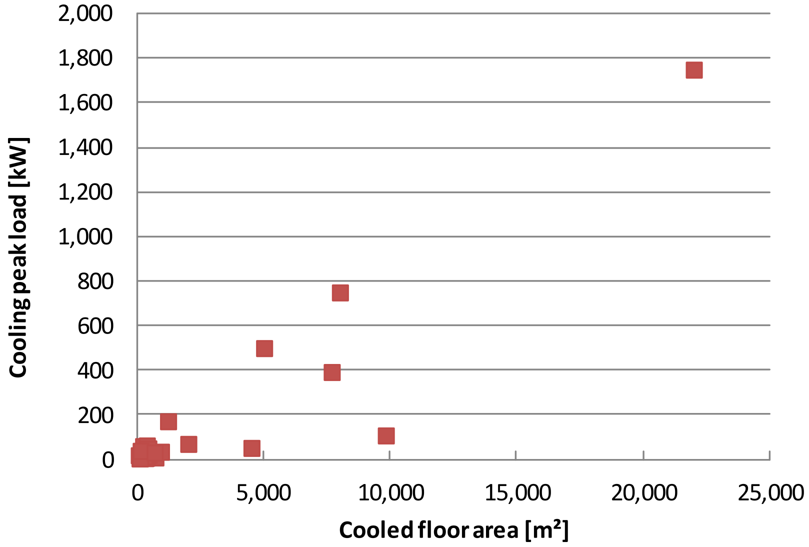


Figure 4: Cooling peak load of all installations

Apart from two plants in Mid European countries like Austria, France and Germany the installations are designed to meet specific peak cooling loads of 0.01 to 0.09 kW/m². In South European countries installations are designed to meet higher peak cooling loads. For example Spain and Greece show higher specific peak cooling loads in the range of 0.05 to 0.18 kW/m². Figure 5 shows the specific peak cooling loads for different European countries.

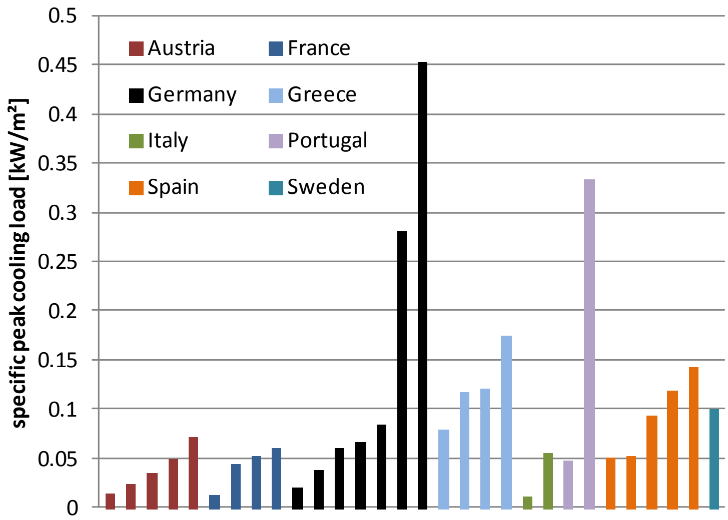


Figure 5: Specific peak cooling loads of installations across Europe

A dependency of the specific peak cooling load and the building type cannot be stated. Offices show a large range of specific peak cooling loads. The largest specific peak cooling load was found in the kitchen of a cafeteria. This may be caused by the strong internal heat sources. Figure 6 shows the specific peak cooling load for different building types.

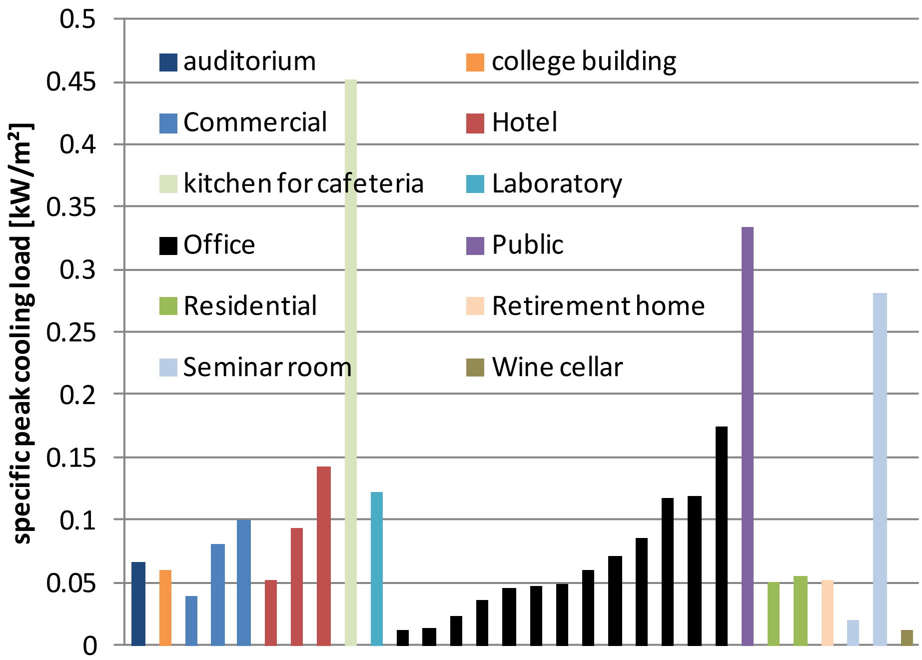


Figure 6: Specific peak cooling loads of different building types

Building ventilation is performed by a mechanical centralized ventilation system in 17 of the plants. 17 of the plants use natural ventilation. In about half of the systems cold distribution is performed by fan coils. 16 plants use air ducts, eight systems use a cooling ceiling and nine systems use floor cooling. As shown in Figure 7 the supply temperatures for the cold distribution system vary between 6 °C and 19 °C with a temperature spread of 1.5 to 7 K. Most common is a supply temperature of 9 to 10 °C with a temperature spread of 5 K. The water flow rate of the cold distribution system shows a dependency on the cooled floor area. It is in the range of 0.002 to 0.039 m²/h/m². The absolute values of the water flow rate vary between 0.8 m³/h and 240 m³/h.

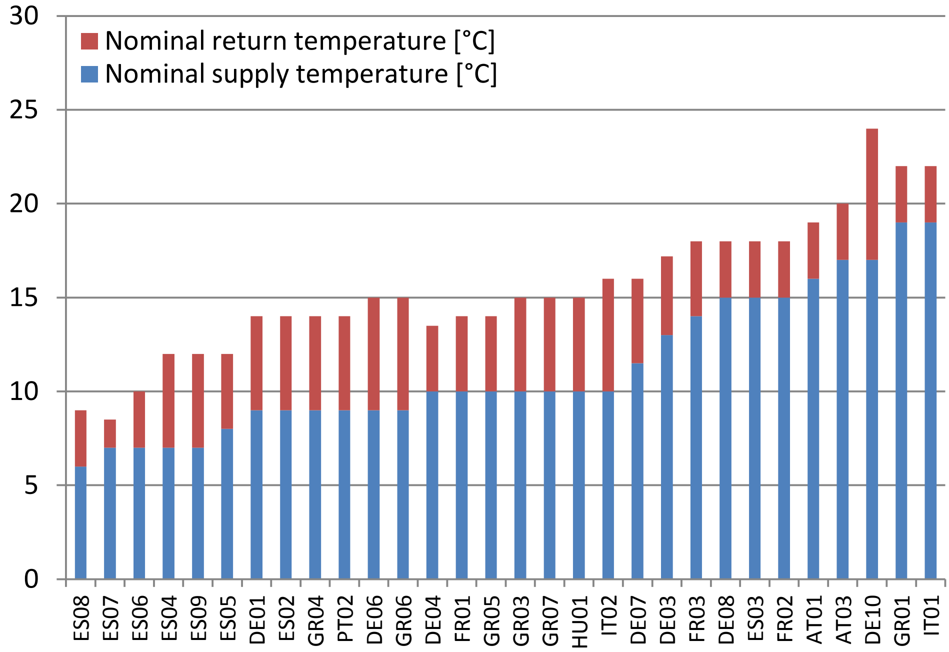


Figure 7: Supply and return temperatures of the cold distribution systems

Table 1 shows the outdoor conditions that were used during the design phase of the system broken down by country.

	Temperature [°C]	Humidity [%]
Austria	32	40
France	30	60
Germany	32 … 35	40
Greece	35 … 38	40 … 50
Hungary	35	50
Italy	32	n.a.
Portugal	32 … 33	40
Spain	31	65
Sweden	n.a.	n.a.

Table 1: Design outdoor conditions

2.2.2. Heat sources

In order to provide thermal energy, for the majority of the systems in the QAiST database flat plate collectors are used. As shown in Figure 8 about a quarter of the plants is equipped with concentrating collectors.

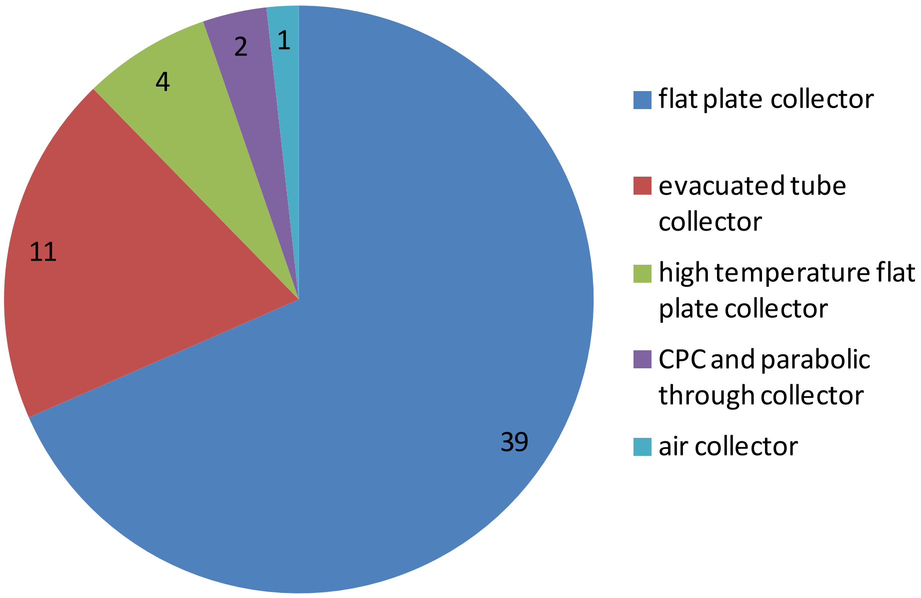


Figure 8: Types of collectors used

The total collector area varies between 10 m² and 2,700 m². The specific aperture collector area per cooling capacity is 0.9 to 4.4 m²/kW with an average of 2.5 m²/kW for evacuated tube collectors and 1.2 to 14.7 m²/kW with an average of 4.6 m²/kW for flat plate collectors.

Most (32) of the solar collector fields are installed on flat roofs, ten on tilt roofs. Five collector fields are installed on ground and three are wall-mounted. The tilt angle of the collectors lies between 0° and 70°. Most installations use a tilt angle of 30°. Apart from four installations the orientation is south.

In 19 of the solar systems water is used as fluid, in 22 systems a combination of water and glycol is used and in 2 systems air is used as heat transfer fluid. The use of high, variable or low flow control is equally distributed.

For storing heat, water is used in one up to twelve stores per system. The size of the total storage volume varies between 0.3 m³ and 60 m³. The heat storage volume per kW cooling capacity varies very much. The average is 0.2 m³/kW.

Apart from ten systems all have an auxiliary heating system. Figure 9 shows the type of auxiliary heating used in the systems of the QAiST database. Five systems use heat from district heating or waste heat. For backup heating electrical heaters are only used up to about 50 kW. Fossil fuel burners are used burning oil, gas or biomass in a range of 9 to 2,400 kW.

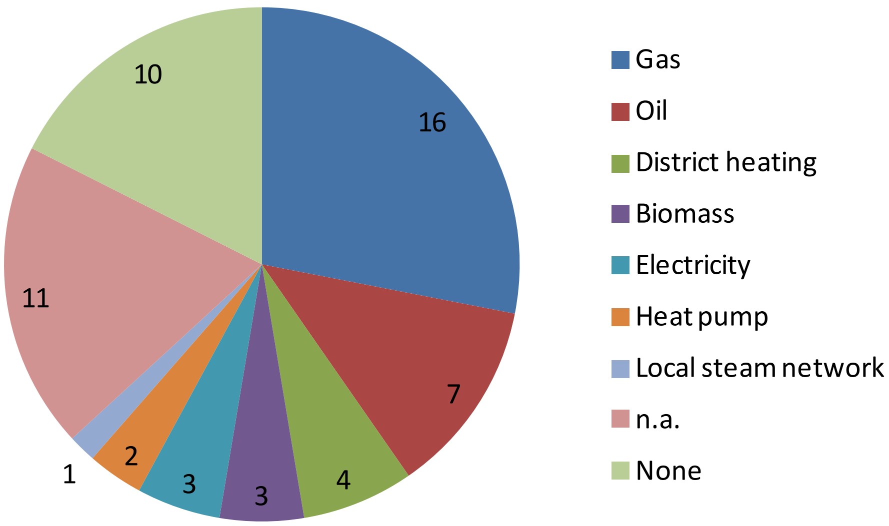


Figure 9: Distribution of auxiliary heating systems

2.2.3. Cooling equipment

The QAiST database contains systems with sorption chillers as well as desiccant evaporative cooling plants (DEC). Eight systems use open cycle DEC with a liquid (4) or solid (4) sorption material. All the other systems use closed cycle sorption chillers. Figure 10 shows the sorption mechanism and the substance combinations used in the closed cycle chillers of the requested installations.

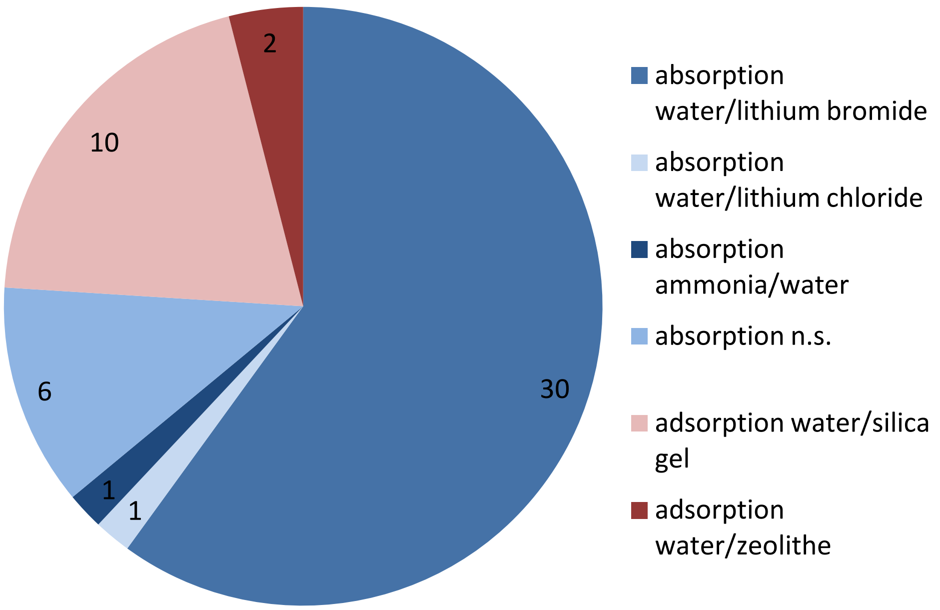


Figure 10: Distribution of sorption mechanism and substance combination

Most systems use the working pair water / lithium bromide in an absorption process. Manufacturers of these systems are Yazaki (Japan), EAW (Germany), Sonnenklima (Germany), Rotartica (Spain), Carrier, GBU (Germany), LG (Korea), Sole SA (Greece) and Thermax (India). The chilling capacities of these machines lie within 4.5 kW and 250 kW. Nine systems work on adsorption – two with water / zeolithe, manufactured by InvenSor (Germany) and the other seven with water / silica gel, manufactured by Nishyodo (Japan), Mayekawa (Japan), GBU (Germany) and SorTech (Germany). In the QAiST database adsorption chillers represent on the one hand some of the smallest units with 5.5 to 10 kW (InvenSor and SorTech) as well as the largest units with 350 kW (GBU and Mayekawa).

A common characterisation is the coefficient of performance (COP), a performance indicator describing the momentary efficiency of the energy conversion of the chiller. It is calculated according to Eq. 1:

$$COP = \frac{\dot{Q}_{cooling}}{\dot{Q}_{driving}} \qquad (1)$$

With:

COP = coefficient of performance [-]

$\dot{Q}_{driving}$ = driving capacity [kW]

$\dot{Q}_{cooling}$ = cooling capacity [kW]

The nominal COP of the chillers is given in a range of 0.5 to 0.75. As illustrated in Figure 11 the COP of the chiller shows a dependency of the driving temperatures. Chillers with higher driving temperatures tend to have higher COPs.

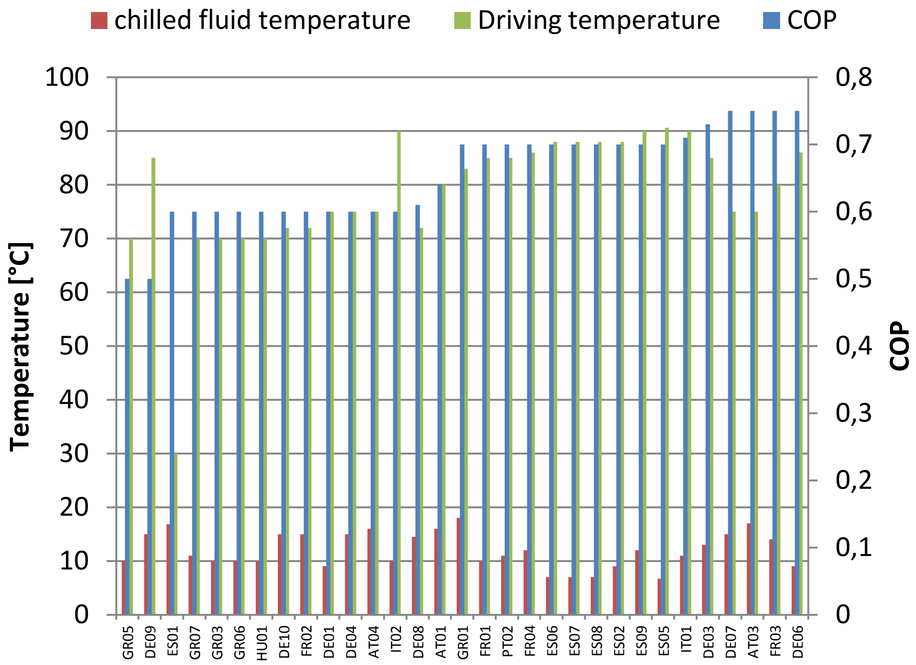


Figure 11: Driving temperatures, chilled fluid temperatures and COP

Storages for cold water are used in one third of the systems. For most of the plants the volume lies in a range between 0.1 m^3 and 1.95 m^3. But also some very large cold water stores with 60 m^3 and 180 m^3 are used.

Figure 12 shows the distribution of different types of heat rejection units used in the reviewed installations. Most systems are equipped with wet heat rejection units, so-called cooling towers. Although four plants are also used for heating a swimming pool, none of the systems uses the swimming pool for heat rejection.

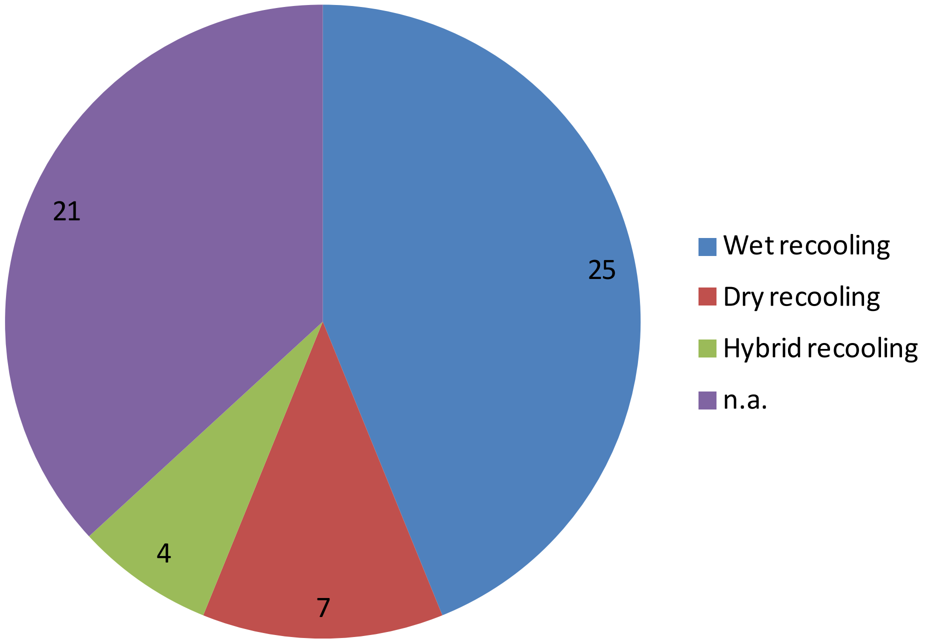


Figure 12: Types of heat rejection units

With given COP and given cooling capacity at nominal conditions it is possible to calculate the heat rejection capacity needed at nominal conditions according to the following equation:

$$\dot{Q}_{rejection} = \dot{Q}_{cooling} \cdot \left(1 + \frac{1}{COP}\right) \quad (2)$$

With:

$\dot{Q}_{rejection}$ = heat rejection capacity [kW]

$\dot{Q}_{cooling}$ = cooling capacity [kW]

COP = coefficient of performance [-]

In Figure 13 and Figure 14 the stated heat rejection capacities are compared with calculated heat rejection capacities. For nominal operation conditions most systems are designed well regarding the combination of chiller and heat rejection unit. Some heat rejection units are rather oversized. Few heat rejection units are too small regarding the required capacity. It is stated in the questionnaire of System ES08 that the chiller has problems with the output temperatures of the heat rejection unit. Figure 14 indicates that the heat rejection unit is undersized with regard to capacity. For System GR05 there is no problem stated with the slightly undervalued heat rejection.

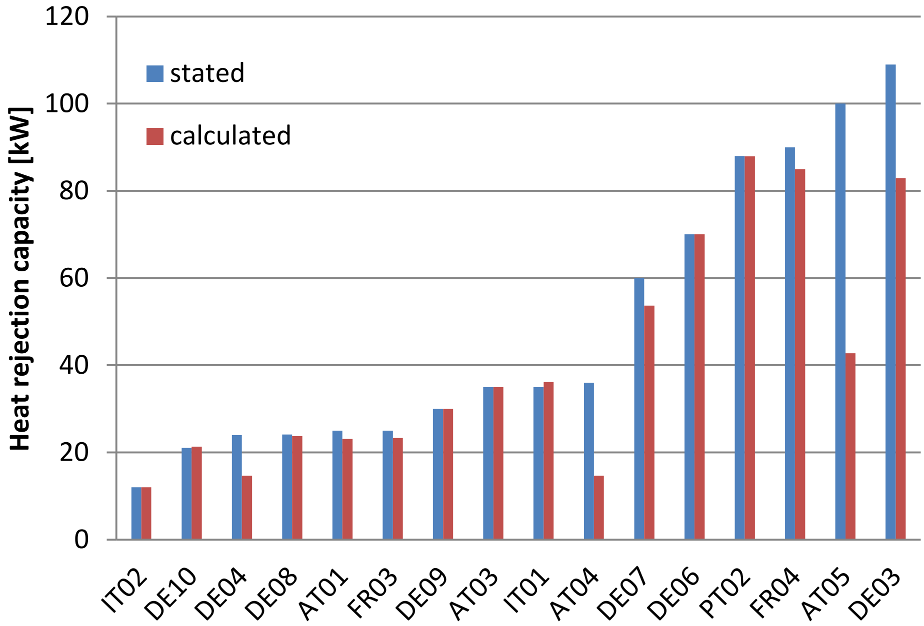


Figure 13: Heat rejection capacity stated and calculated (1 of 2)

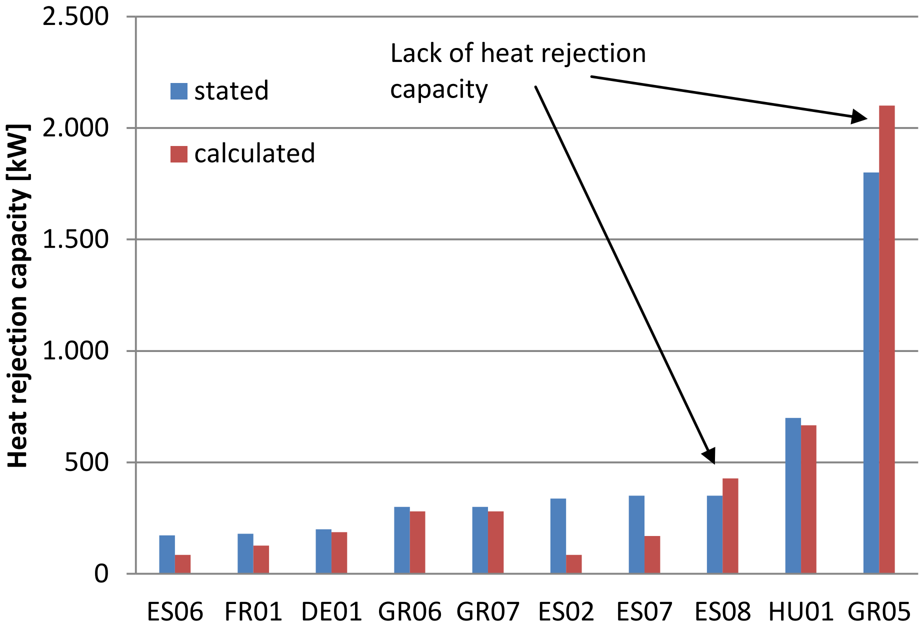


Figure 14: Heat rejection capacity stated and calculated (2 of 2)

The specific nominal electricity consumption of the heat rejection unit varies between 0.0125 kW and 0.426 kW per kW heat rejection capacity. The average is 0.078.

In 17 of the systems an electrically driven vapour compression backup chiller is included. To provide comfortable conditions all the time the sum of the capacities of the sorption chiller and the backup chiller should be as large as the cooling peak load. In Figure 15 and Figure 16 these two values are compared for all systems with available information. A lack of cooling capacity as shown in the figures is most cases also represented in the questionnaires by statements on inadequate performance of the systems: For system DE04 it is mentioned in the questionnaire that the chiller is undersized and cannot provide enough chilling capacity. This statement coincides with the given figures. For system AT06 the ceiling used for cooling is considered to be too small. The lack of cooling capacity can also be the result of the fact that the total installed cooling capacity of the chiller and the backup chiller is too small. For plant DE06 no performance problems are stated. It was only installed recently. Hence, no operational performance was evaluated. For AT05 it is stated that the room temperatures quite often exceed the set point temperature. As shown in Figure 16 the total installed cooling capacity is smaller than the peak cooling load. The chilling capacity of the chiller at plant DE01 is below expectations. For the system ES07 it is stated in the questionnaire that the output of the chiller is frequently poor and that the performance of the system should be improved.

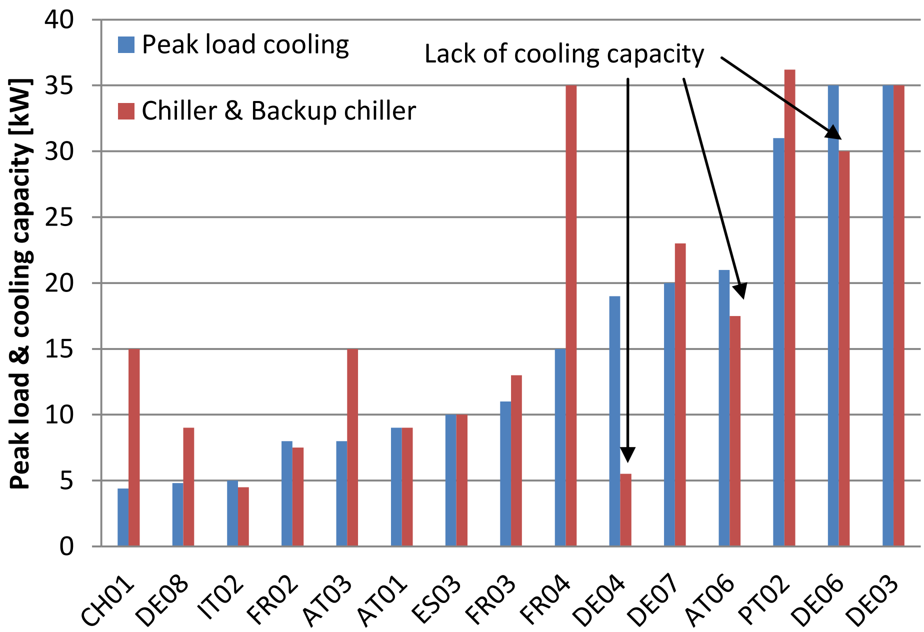


Figure 15: Peak load and cooling capacity (1 of 2)

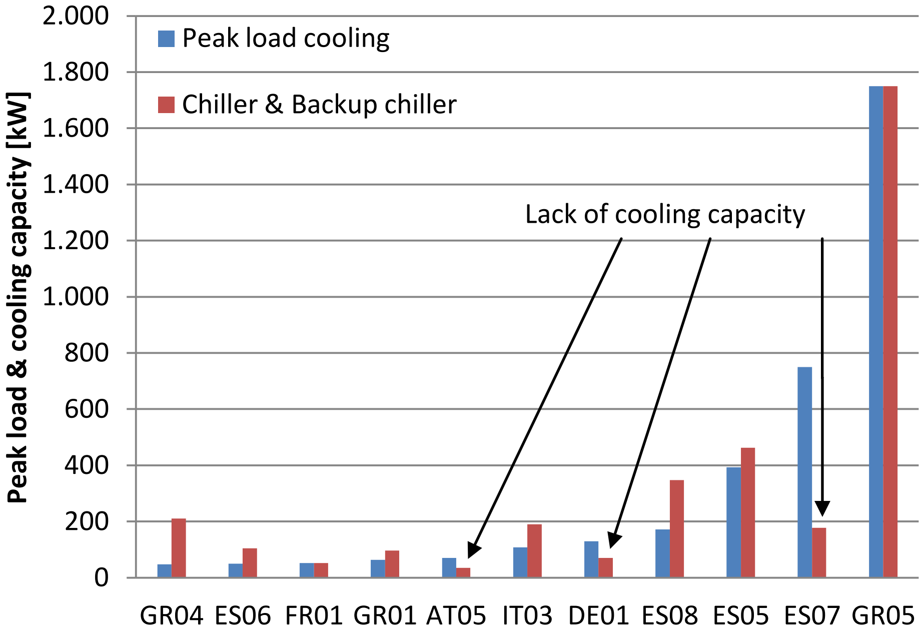


Figure 16: Peak load and cooling capacity (2 of 2)

Taking into account the given figures the problems mentioned for these plants can be explained by a mismatch of installed cooling capacity and peak cooling load. Apart from these systems also for the systems ES05 and ES08 performance problems are stated. Regarding the performance problem of plant ES05 no explanation could be determined from the questionnaire. For system ES08 it is mentioned, that the set point temperatures are not reached. This problem might also be caused by the insufficient heat rejection shown in Figure 14.

2.2.4. Investment costs

The investment costs of the solar thermal cooling plants of the QAiST database vary very much. The cheapest installation afforded 12,000 Euro, the most expensive one 1.4 Mio Euro. This of course depends on the size of the installation. Figure 17 shows the specific costs per cooling capacity. The specific costs decrease for very large plants. A closer look on the smaller plants in Figure 18 reveals no explicit dependency of the specific costs on the system size. Investment costs of systems with a maximum cooling capacity of 20 kW vary between 1,200 €/kW and 27,000 €/kW.

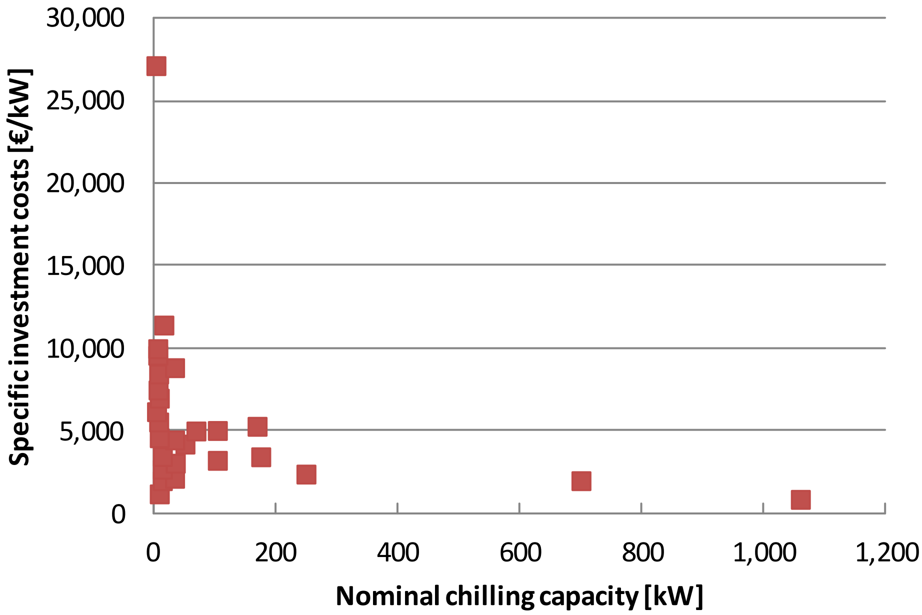


Figure 17: Specific investment costs per chilling capacity

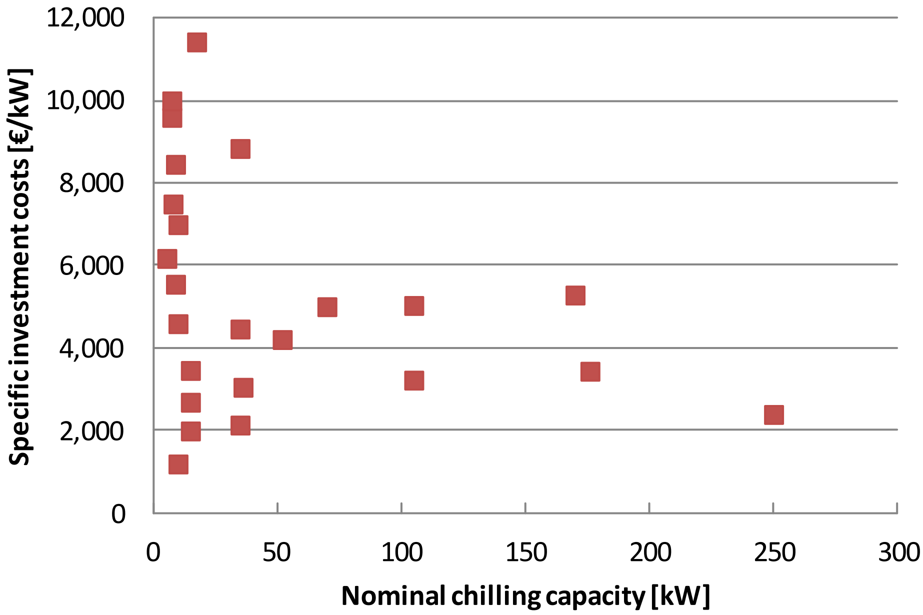


Figure 18: Specific investment costs per chilling capacity below 300 kW

2.2.5. Qualitative assessment

Figure 19 shows the distribution of satisfied and dissatisfied users of the solar cooling installations in the QAiST database.

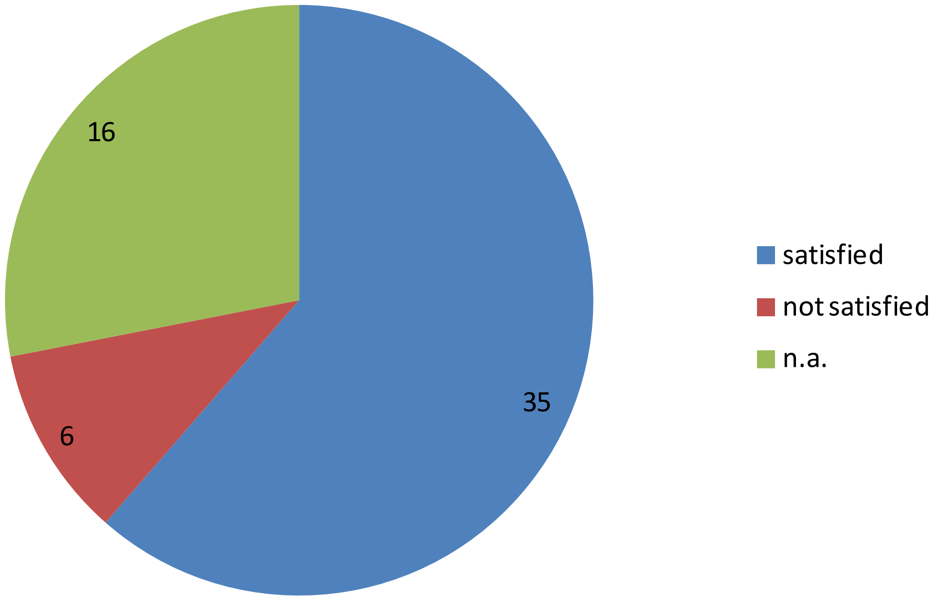


Figure 19: overall qualitative assessment

Mostly companies that are active in the solar thermal market use their solar thermal cooling systems as demonstration plants for marketing purpose. Like the majority of the operators of solar cooling plants in the QAiST database those companies are totally satisfied with their solar cooling plants. But four hotels in Spain are rather dissatisfied with the performance of their systems. They stopped using their solar cooling plants in marketing campaigns. A company in Austria and a winery in Switzerland are unsatisfied due to the fact that their systems are out of order for most of the time. In Table 2 the problems that were stated in questionnaires are listed and the frequency is shown.

Problem	
Inadequate temperatures for chiller, chiller stops or works with very low performance	9
Control system is not reliable, not configured optimally	9
Operation of a cooling tower is problematic, maintenance of a cooling tower is expensive	4
System is too big and complex	3
Equipment and maintenance is too expensive, system is not profitable	2

Sensors failed	2
There was no commissioning	2
Solidification of the lithium chloride solution	1

Table 2: Described problems

As mentioned above a lack of performance may be caused by inadequate dimensioning of system components like the chiller, the backup chiller or the heat rejection unit. Apart from this, wrong control strategies and controller configuration as well as maintenance problems of cooling towers cause problems within the whole solar cooling systems.

3. More in depth durability questionnaires

In order to get more information regarding to durability and life-expectancy of solar cooling systems already installed, some selected installations from the QAiST database were again surveyed to outline the current state and to know the technical problems detected during periods in which the installation has been working. A second questionnaire regarding to durability issues was elaborated and distributed by the project members. This questionnaire is included in the annex of this document.

3.1. Questionnaire structure

With the technical information about the solar assisted cooling systems already available, the second questionnaire was focused on durability issues and divided in four sections:

- Project data
  General information on the person who filled out the questionnaire and general information on the location of the solar cooling system
- General
  General information regarding the user/owner's knowledge about its system and the access to performance data
- Planning and Installation
  Consumed time and companies involved during planning and installation. Location of main components and detected problems during these phases
- Operation
  Maintenance tasks, cost and detected problems during the period in which the solar cooling system has been in operation

3.2. Analysis of the QAiST durability survey

From the QAiST database, 15 solar cooling systems were selected in order to ask for more information about durability issues and life-expectancy.
They were selected to include all different cooling technologies: absorption, adsorption and desiccant evaporative cooling, different heat rejection systems, different solar collector technology and were located in different countries.

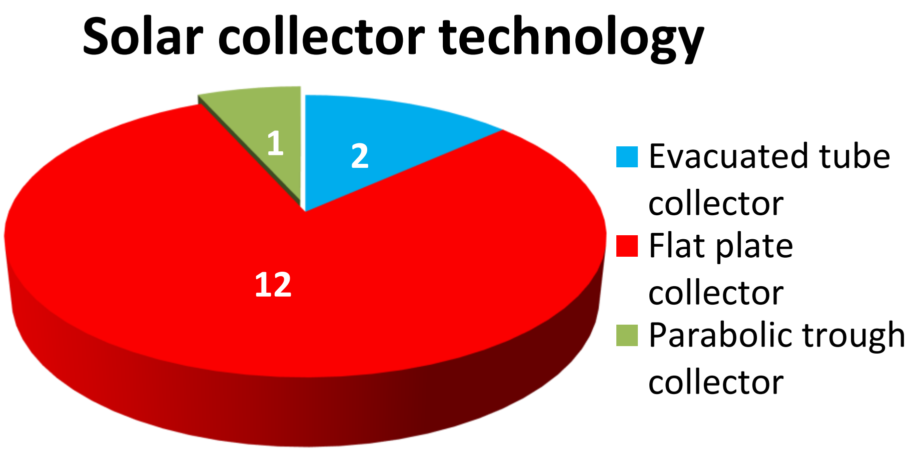


Figure 20: Solar collector technology

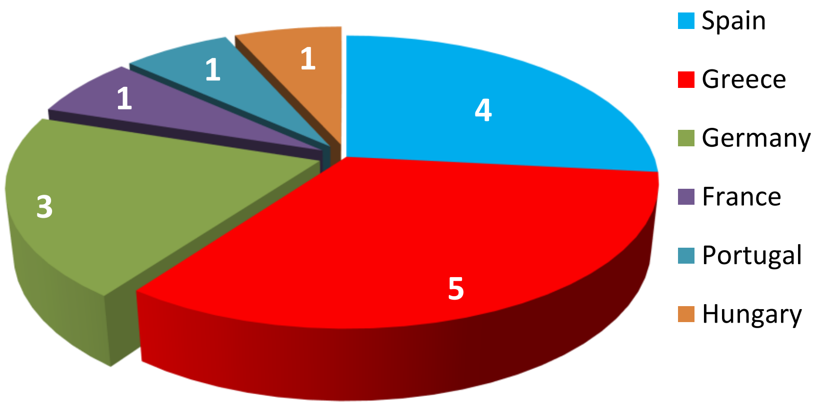


Figure 21: Locations of the solar cooling plants

3.2.1. General

Most of the surveyed owners/users state to know the cooling technology used in their solar cooling system and the system operation is clear to them. They have also information to separate working periods with solar operation or with backup operation.

Most of the solar cooling systems have been equipped with temperature sensors, flowmeters, pyranometers and others measurement equipment to register real system operation and its performance but in three cases there is not access to the registered data because of data acquisition system failure.

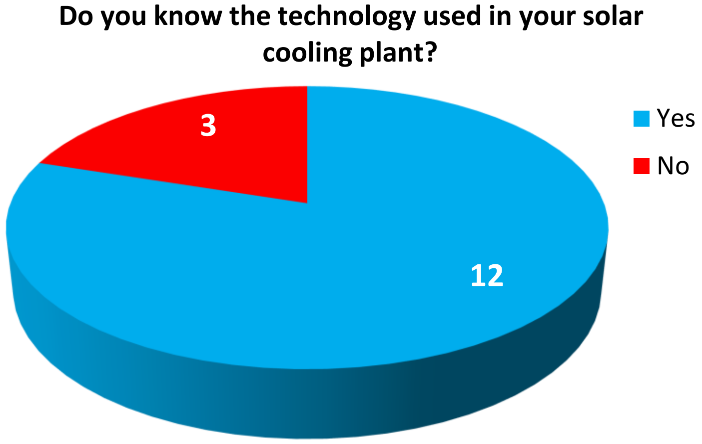


Figure 22: Cooling technology knowledge

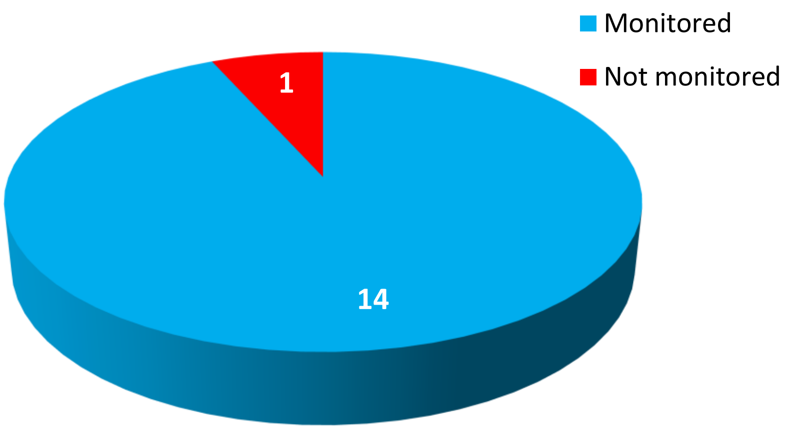


Figure 23: Solar cooling system monitoring

Usually the access to registered data is made possible by a local controller inside the technical room, in some cases there is also on-line connection via internet.

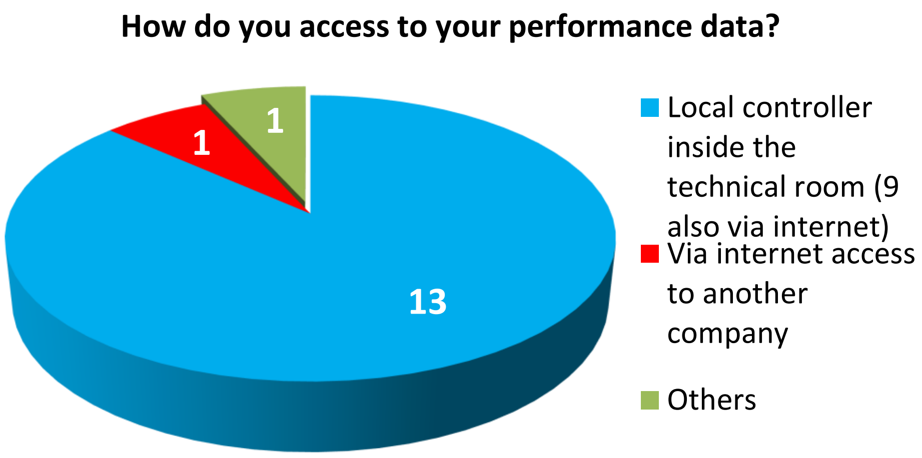


Figure 24: Access to registered data

Additionally owners/users were asked for the information delivered during the system commissioning.
In general, maintenance instructions and technical characteristics of the main elements were delivered. In nine cases, a guide with general operations is also available and in only four cases they have owner/user guides.

Since solar assisted cooling systems are more complex than solar thermal systems for heating support due to additional elements such as cooling equipment and a heat rejection system, more effort should be taken to describe the system operation, regular maintenance and system checks to detect possible failures.

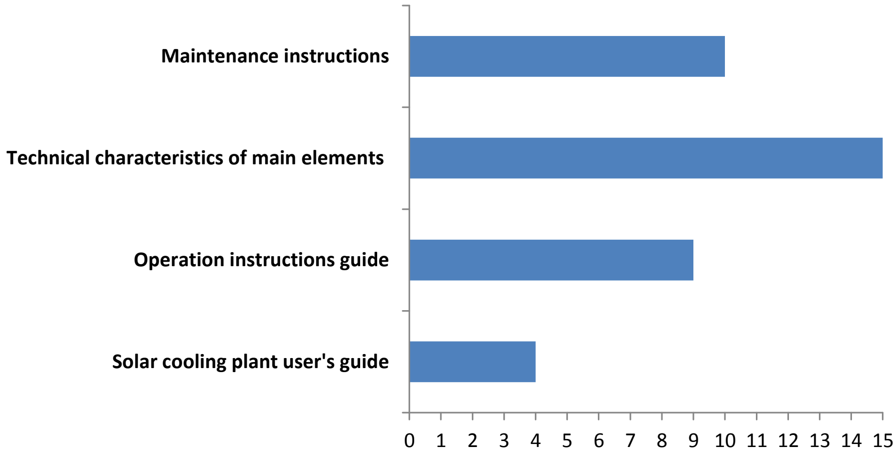


Figure 25: Available technical information

3.2.2. Planning and Installation

Only two surveyed solar cooling systems were planned and installed by the same company. In most cases, planning and installation were made by several companies. Furthermore between two and four companies were involved during the installation works except for one case in which the system owner was the installer company.

In 85 % of studied cases the heat storage and the solar collectors are distanced at less than 20 meters. The values range among 4 mand 40 m. On the other hand, heat storage and chiller/s are located closer to each other than heat storage and solar collectors; in 13 of 15 analysed systems this distance is lower than 10 m. Nevertheless there was one case in which heat storage was 25 m away from the associated chiller.

It was not possible to find a relation on the number of required days to install the solar cooling systems and their chilling capacity or collector field in square meters. In all cases except one the installation process took less than 100 days. There was only one case in which some technical problems delayed this phase and extended it to 270 days.

During planning and installation phases, some problems outlined by owners/users were:

EQUIPMENT	PROBLEM DESCRIPTION
Chiller	Loss of vacuum. Vacuum pump was undersized
	Heat source temperature sensor was installed in a wrong position
	Flow rates (in the driving circuit, the heat rejection circuit and the cooling circuit) have not been properly regulated
	Connections of the driving circuit were inverted
	Lack of trained technicians to prepare the chiller commissioning
	Insufficient system pressure (membrane expansion vessel)
Solar collector field	Not enough heat production and collectors had to be added
	Leakages due to stagnation. Seals and air release valves were damaged and antifreeze fluid had to be removed
	Damages in the heat storage due to the trapped air and high temperatures
	Return flow rate from the heat source too high causing buffer tank stratification breakage
	Insufficient flow rate
Heat rejection system	Heat rejection unit equipped with non-modulating fans
	There is no membrane expansion vessel in the heat rejection circuit
Monitoring and control system	There is no internet access
	Control strategy was not able to regulate the system, so the absorption chiller stopped operation and the solar loop reached high temperatures
	Control temperature sensors are not located in right positions

Table 3: Outlined problems during planning and installation phases

3.2.3. Operation

Usually more than one company is in charge of maintenance works and it makes the system management more complex. Maintenance tasks are mainly related to the overall hydraulic circuit, the cooling equipment and the heat rejection unit. The costs are quite different, depending on cooling system, heat rejection technology and solar cooling system location.

Where wet cooling towers are used, water treatment and chemical analysis are required to avoid the presence of legionella bacterium. This leads to higher maintenance costs.

Some technical problems outlined by owners/users during system operation were:

EQUIPMENT	PROBLEM DESCRIPTION
Chiller	COP less than expected: system does not reach steady state operation due to the fluctuation of the heat source temperature
	COP less than expected: performance is lower than manufacturer specifications
	COP less than expected: system does not reach steady state operation due to the cold load being smaller than foreseen
	Flow rates are too low (quoted twice)
	Anti-freeze protection was not working correctly
Solar collector field	Damaged air vents, leakages and collector degradation (thermal insulation) due to stagnation (quoted 4 times)
	Loss of vacuum in evacuated tube collector field
	Absorbers (flat plate collectors) show decoloured areas and selective surface is damaged
	Heat exchanger with serious fouling problems due to high temperature
	Electrical resistance (heat backup) damaged due to a short circuit
	Corrosion in the hydraulic circuitsdue to the use of different metals
	Solar pump failure
Heat rejection system	Dirty coating inside the heat rejection unit (quoted 3 times)
	Flow rate too low (quoted twice)
	Chemical treatment failure (dosage pump does not work)
	Overflow control system failure
	Corrosion inside/outside of cooling tower

EQUIPMENT	PROBLEM DESCRIPTION
	Fan speed control is not suitable
Monitoring and control system	Data acquisition system failure and there is no access to the control system (system does not work) (quoted 3 times)
	There is no cooling demand signal (chiller in standby)
	Loss of control software due to failure of the internal batteries
Cold distribution technology	Performance of the floor cooling system too low

Table 4: Outlined problems during operation phase

Most of solar cooling owners/users have been checking the performance of their system during its lifetime.

In one surveyed case, the owner complains about the performance being lower than that declared by the chiller manufacturer. In another case such a lack of performance could be repaired by modifying the control software to adapt the control strategy to the real cold demand. This increased the COP of the system from ranges of 0.2-0.4 to ranges of 0.6-0.7.

Finally, they were asked about the solar cooling operation during last summer. Two solar systems were not in operation because of several technical problems, the other ones have been in operation although three of them needed to be stopped for some time to solve technical problems.

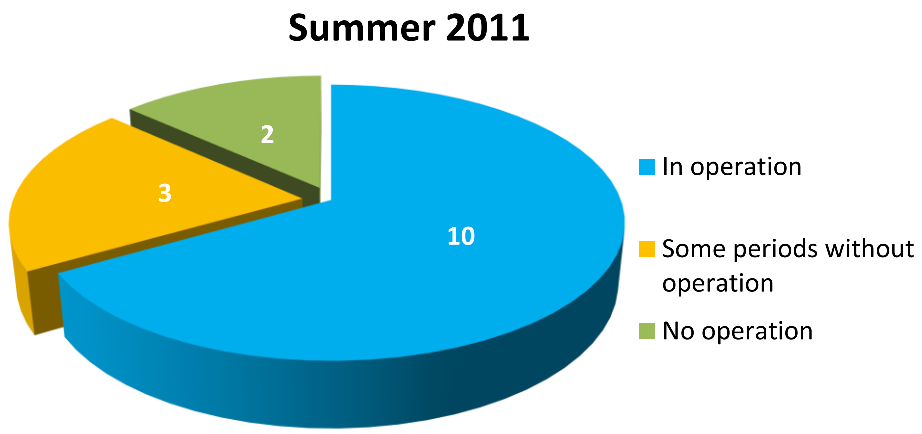


Figure 26: Operation during summer 2011

4. Solar cooling experts consultation

In the context of the QAiST project, a document with opened questions regarding to durability issues in solar cooling systems was distributed among solar cooling experts close to QAiST partners. Their answers provided useful information and emphasized technical key problems with respect to the life-expectancy of solar assisted cooling systems. They were also asked about aspects to promote solar cooling installations.

The following solar cooling experts have participated in this consultation:

Dr. Constantinos A. Balaras, Institute for Environmental Research & Sustainable Development, National Observatory of Athens, Greece.

Dr. Giorgos Panaras, Solar & other Energy Systems Laboratory, NCSR DEMOKRITOS, Greece.

Mr. Francés Padrós Corominas, Absorsystem, Barcelona, Spain

Ms. Laura Sisó Miró, Mira Energia, Barcelona, Spain

Mr. Tim Selke, Austrian Institute of Technology, AIT, Wien, Austria

Mr. Moritz Hummel, InvenSor, Berlin, Germany.

Mr. Patrick Frey, Institute for thermodynamics and Thermal Engineering, University of Stuttgart, Stuttgart, Germany.

Mr. Francois Boudéhenn, Institut National de l'energie solaire, CEA INES RDI, Le Bourget du Lac, France.

We would like to thank their valuable collaboration and their comments, which gave us useful information to define key aspects regarding the durability of solar cooling systems.

5. Guideline regarding durability and reliability of solar cooling systems

5.1. Key aspects regarding durability and life expectancy of solar cooling systems

Regarding solar cooling systems global questionnaires, durability questionnaires and the consultation of solar cooling experts, gave important feedback and valuable information to define some key aspects regarding durability and life expectancy of this technology. They are summarized in the following.

Common technical problems:
Some of the frequently detected technical problems which have been emphasized are:

- Solar collectors overheating due to insufficient thermal energy demand or difficulties to match solar energy availability and energy demand with the result of serious damages in solar collector field: leakages, degradation of the thermal insulation and absorbers, etc…
- Control and regulation sensors located in not suitable positions causing control failures and low system performance.
- Heat storage higher than necessary causing delay to start up the solar assisted cooling system and reduction of operating hours in “solar cooling” mode.
- Lack of suitable technical maintenance. Risk points are basically the solar collector field and the heat rejection system.
- Difficulties to combine the control of the conventional cooling system with that of the solar cooling system.
- System performance deviations against predicted performance due to failures in operation of the control system and the heat rejection system, resulting in an insufficient cooling capacity.

Seasonal operation of solar assisted cooling systems:
Chiller manufacturers state that seasonal operation of solar assisted cooling systems does not produce technical problems if during each commissioning, suitable regulation of all internal parameters is made according to the instructions provided by the manufacturer, although there is evidence that this could have influence on the switching valves.

On the other hand it is also unlikely that the medium and large chiller can be operated as a heat pump for heating, due to its low coefficient of performance (COP).
In terms of cost-effectiveness of solar cooling systems, seasonal operation leads to less operation hours per year and makes it more difficult to get the investment recovery. Anyway regarding to cost-effectiveness, seasonal operation is only an additional issue because the main problem is the actual high investment costs of the systems.

In case of long-term shutdown of absorption chillers, some manufacturers recommend to pressure the vapour space with nitrogen above atmospheric pressure so that oxygen cannot enter the equipment through any possible leakage caused by corrosion. Usually, chiller parameters are controlled during each annual commissioning at the beginning of operation, but they are not taken into account during idle operation.

Maintenance requirements:
Depending on the system, solar cooling systems can require exhaustive technical maintenance. Because different elements (solar thermal circuit, heat rejection circuit, chiller circuit and distribution circuit) need to be combined, , the complexity of the hydraulic connections is higher for a solar cooling system than for a solar thermal systems to produce heat. Maintenance must be periodic and it cannot be neglected because the consequences are complex to solve afterwards.

The maintenance effort for chillers is usually low. Absorption machines, for example, are robust and inherently stable, its solution concentration adjusts to the imposed temperatures according to its thermodynamic properties to provide trouble free operation for the user and no active controls are required with the exception of controls to deal with crystallization issues. However their maintenance, in most of the cases, requires technicians trained by the own chiller manufacturer. As a result it is usually expensive and the access to this maintenance uses to be difficult to get in some regional markets where chiller manufacturers have few products or there is no presence at all. After-sales management should be guaranteed.

Corrosion is usually the ultimate failure of absorption chillers. Because the life of the chiller is limited by corrosion, for long life, great attention must be paid to avoid introduction of air into the equipment and to ensure the corrosion inhibition regime is strictly followed. Maintenance of absorption chillers usually includes: purging of non-condensable gases, addition of octyl alcohol (if it is used), addition of corrosion inhibitor and addition of pH buffer. The frequency of these tasks depends on variables such as the size of the chiller or the purging system and is specified by the chiller manufacturer.

Heat rejection systems such as cooling towers require exhaustive maintenance and in the case of wet cooling towers, periodic controls, regular water treatment and periodic water analysis depending on the national regulations are required. On the other hand, heat rejection systems such as geothermal probes, basically require the checking of hydraulic pressure in the pipes.

The solar collector field imposes an annual basic maintenance load. Air vents should be installed and periodically checked.

Critical elements regarding system durability

Elements which need special attention regarding system durability are the heat rejection system at the top, the chiller and controls.

Many technical problems with chillers are associated with improper maintenance on the heat rejection system. Insufficient heat rejection air flow due to dirt accumulation in the filters is frequently reported. Hence, the heat transfer capacity of the heat rejection system decreases and the return temperature of the chiller rises resulting in a decrease of the performance of the chiller.

In such situations, a safety control should be active to protect absorption chillers against crystallization. It is absolutely necessary to avoid or minimize the accidental introduction of oxygen during maintenance procedure. If vacuum must be broken for any reason, the vapour space should be filled with nitrogen or other inert gas to avoid introduction of oxygen.

Regarding adsorption chillers using silica gel, the return temperature provided by the heat rejection shall be above the temperature of the cooling circuit. Otherwise condensation may occur in the absorber. Critical components are the vacuum chamber and switching valves which have to switch every 5-10 minutes.

For desiccant systems, the air filters have to be cleaned or changed regularly, in order not to have accumulation of dust in the passages of the desiccant wheel resulting in performance degradation. Potential air leakage between the supply and exhaust air stream in the desiccant wheel has to be checked and prevented.

Additional to the maintenance procedures, it is strongly recommended to carry out a periodic assessment of performance against the values declared by the manufacturer in order to detect potential technical problems.

Overheating during periods without cooling demand (weekends, holidays, etc.…) produces a great degradation of the solar collector field. Special caution has to be paid to release trapped air inside the circuits and collectors.

Since solar cooling systems are more complex than e.g. solar thermal systems for heating support, more effort has to be made for regular maintenance and system checks. Some aspects which should be tested/checked to improve the durability of solar cooling systems are:

Chillers:

- Modulation of the cooling capacity for different cooling load ranges: Part load operation is crucial due to high inefficiencies caused by non-variable operation of periphery units like pumps, fans, etc…
- High temperature resistance and influence of variable generator inlet temperature. Chillers connected to solar collector fields have to operate at variable and varying generator temperatures. The internal protection against high temperature should be checked and the chiller should be tested under various dynamic operating conditions.
- Protection against low inlet cooling temperature. Depending on technology, the failure of this protection can produce very complex technical problems. If cooling towers are used, there must be a continuous or stepwise control of the cooling tower fan. This solution is also an effective measure to reduce parasitic electricity consumption. A mixing valve in the cooling circuit is another safety equipment to avoid the inlet of low temperatures inside the chiller circuits. In any case the function of the different protection mechanisms should be checked during each commissioning.
- Protection against high inlet cooling temperature: If H_2O/LiBr technology is used, the failure of this protection can cause corrosion inhibitor degradation. In other cases it causes a performance reduction due to the impossibility of rejecting heat. The function of the protection mechanisms should be checked during each commissioning.
- Control of non-condensable gas generated in absorption chillers during operation, in order to maintain suitable level of vacuum in the shell. It should be checked during each commissioning and for the future it should be tested according to an accelerated aging test method.
- Pressure resistance: This test is made by chiller manufacturers before delivery, for the future it should be tested according to an accelerated aging test method.
- Freeze resistance: The internal anti-freeze protection should be checked during each commissioning.

Heat rejection:

- In case of wet cooling towers, chemical treatment against scaling and corrosion should be checked before commissioning. Check the bleed-off valve and its function (a malfunction can result in very high water consumption).

- The state and the flow rate of the cooling tower pump should be checked before each commissioning. An insufficient flow rate can result in a rise in temperature of inlet cooling circuit.
- The water filter to remove sediments and trash should be checked periodically because its malfunction can increase the inlet cooling temperature by about 1.5 – 2 ºC.
- Freeze resistance: The internal anti-freeze protection should be checked where the risk of freezing is possible.

Controls:

- The function of the control unit should be checked before commissioning. For the future solar assisted cooling systems controls should be standardized to reduce configuration time, costs and they should include automated error detection.

High quality solar assisted cooling systems:
To ensure customer's satisfaction, almost the entire life cycle of the system has to be taken into consideration: feasibility study, design, installation, commissioning and operation.
In some reported cases feasibility studies were unrealistic and not accounting the operational costs in order to pretend these investments to be more attractive, causing customer's disappointment. Compared to conventional cooling systems, solar assisted cooling systems are still expensive and the comparison with other competitors as micro-generation and biomass makes it clearly unfavourable in terms of cost-effectiveness. As a result, it is quite difficult to promote solar cooling systems outside the public sector and projects should be focused on the environmental benefits of using solar energy more than cost-effectiveness.

The main problem in the design phase is the estimation of the cold demand. In many occasions, the hourly energy demand is not taken into account or there is not enough information available to make a good estimation. The most common result of this is the system being over dimensioned, which causes overheating of the solar collector field and less operational hours than were foreseen to calculate the project cost-effectiveness. A monitoring of the cold demand, previous to the design, is strongly recommended. The lack of standardized methodologies and tools to support a sensitivity analysis for the optimization of the final selection is another outlined problem related to the design phase.

Special care must be taken during installation in order to guarantee the predicted energy savings. Potential simplification of the hydraulic connection is also required.

Commissioning is an important phase although sometimes it is overlooked. The complexity of the various components which are integrated in the overall solar cooling system requires several companies working together in the majority of the cases. Furthermore, parameters regulation has to consider the special operation conditions due to the intermittent characteristics of the solar heating source.

Operation is the most important phase to ensure the customer's satisfaction. Information about the system operation should be available to the customers, including technical description of components, periodic maintenance, a user's guide with potential failures and possible solutions, etc...

The survey on durability of solar cooling systems carried out in the context of the project showed that less than half of the polled owners had a solar cooling plant user's guide and in the majority of the cases, the available information only comprehended the technical characteristics of the main components and an operation instruction manual. Both documents are not easy to understand for users.

Solar cooling technology requires exhaustive monitoring to detect potential failures and to calculate energy savings. Half of the polled owners could not access this information because of the failures of their control/acquisition system. Among the owners with access to operating performance data, many of them complained about the costs to process the registered information and the lack of automated data management (basically error detection and energy savings calculator). As a result in many occasions, owners do not know the real energy savings of the solar cooling system and they only have information about the reduction of conventional energy consumption. In this procedure, the energy savings can also be caused by other/different installations.

Aspects to promote solar cooling installations:

Even though the level of technological solutions of solar assisted cooling systems can be considered as quite mature, their penetration is mainly limited to demonstration and research installations.

At present the costs of solar assisted cooling systems are high compared to other cooling technologies. The low degree of standardization and the lack of know-how in system design and of trained installers, technicians and designers are additional obstacles. Training of the installers, planners, etc… should be part of a quality assurance system.

Further research is also required to improve chiller efficiency and to get an important cost reduction.

For these reasons, economic support and incentives are still required to improve the market penetration of the technology. More demonstration projects for practical use with high quality should be installed. Their operating performance and energy savings should be analysed. Such information should be easily accessible by interested people. Monitoring and data analysis of at least two operation years should be asked in order to obtain financial support.

5.2. Common failures in planning, installation and operation of solar cooling systems

Common failures in the planning, installation and operation of solar cooling systems have been outlined. Hence, solutions to prevent or solve these failures are required. In the following, solutions to the identified problems are outlined. For this purpose the solar cooling system has been divided into its main components: solar collector field, cooling system, heat rejection unit and monitoring and control devices.

5.2.1. Solar collector field

	PROBLEM	POSSIBLE SOLUTION
Planning	Not enough information to estimate heat demand	Cold demand monitoring, previously to the design, taking into account hourly energy demand
	Lack of standardized methodologies and tools to support a sensitivity analysis for the optimization of the final selection	More efforts should be made to have available standardized methodologies and design tools
Installation	Leakages, seals and air release valves damaged, anti-freeze fluid degradation, etc… as a consequence of stagnation conditions	Solar collectors should be shielded from solar radiation until the overall system commissioning
	Damages to the heat storage and its insulation due to the trapped air and high temperatures in the solar collectors' hydraulic circuit	Solar collectors should be shielded from solar radiation until the overall system commissioning
	Insufficient flow rate	Check solar circuit pump. Check solar array flow distribution
Operation	Damaged air vents, leakages and trapped air inside the circuit due to stagnation conditions	Solar field should be shielded during periods without cold demand (holidays, week-ends,….) or heat dissipation strategy should be included in system control

	PROBLEM	POSSIBLE SOLUTION
	Solar collector damages: loss of vacuum (evacuated tube collectors), thermal insulation degradation, selective surfaces degradation, absorbers with decoloured areas, etc…	Avoid stagnation conditions during periods without cold demand (holidays, week-ends,….): solar field should be shielded or heat dissipation strategy should be included in system control
	Return flow rate too high causing heat storage stratification breakage	Install diffuser elements at the inlet to conserve the stratification
	Not enough heat production or over-heating due to non-suitable system dimensioning	More effort should be made to have available standardized methodologies and design tools. Increase solar collector array or shield to adapt the heat production to the cold demand
	Solar collector damages due to the entrance of little animals during periods without operation (months without cold demand)	During periods without operation, collectors should be checked, shielded and ventilation holes should be protected
	Solar pump failure	Check if there is trapped air and if there are closed valves downstream. Check the range of working temperatures. Substitute if there is no other option
	Corrosion and insulation degradation in hydraulic circuits	Remove and substitute the joints between different metals, protect against atmospheric corrosion and the influence of solar radiation

5.2.2. Cooling system

Depending on cooling system technology, different problems can be observed.

	PROBLEM	POSSIBLE SOLUTION
Planning	Not enough information to estimate cold demand	Cold demand monitoring, previously to the design, taking into account hourly energy demand
Installation	Loss of vacuum (absorption)	It should be avoided or minimized immediately because the introduction of oxygen produces corrosion. If the vacuum must be broken during any special maintenance, the vapour space should be filled with nitrogen or other inert gas to avoid introduction of oxygen
	Heat source temperature sensor installed in a wrong position, so the chiller does not receive the suitable signal to start working	Temperature sensors should be carefully installed to register the right temperatures in the circuits.
	Flow rates of the driving circuit, the heat rejection circuit and the cooling circuit have not been properly regulated	Check flow rates and adjust them to suitable ranges according to chiller manufacturer specifications
	Connections of the driving circuit were inverted	Check connections before the commissioning
	Lack of trained technicians to prepare the chiller commissioning	After-sales management should be guaranteed by chiller manufacturer
Operation	COP less than expected, system does not reach steady state operation and as a result the performance is lower than manufacturer specifications	Several reasons are outlined: 1. The system does not reach steady state operation due to the fluctuation of the heat inlet temperature. - Heat source and/or heat storage are not well-dimensioned to operate with the chiller. The solar

	PROBLEM	POSSIBLE SOLUTION
		collector area should be increased 2. The cold load is smaller than foreseen and it makes the chiller switches on and off many times during operation – an additional cold storage may decrease the switching frequency 3. Control software failures. - Check parameters
	COP less than expected	Check flow rates and adjust them to suitable ranges according to chiller manufacturer specifications
	Anti-freeze protection was not working correctly	Check its function and substitute if there is no other option

5.2.3. Heat rejection system

	PROBLEM	POSSIBLE SOLUTION
Planning	Not enough information to estimate cold demand and the heat rejection unit required	Cold demand monitoring, previously to the design, taking into account hourly energy demand
Installation	Heat rejection unit equipped with non-modulating fans	They should be substituted with continuous or stepwise control fans as an effective measure to reduce parasitic electricity consumption
Operation	Overflow control system failure	Check its function and the water consumption and substitute if it is needed
	Corrosion inside/outside of the cooling tower	Heat rejection unit should be checked and protected against corrosion. Corrosion inside wet cooling towers will affect the hygienic conditions of the water
	Dirty coating inside the heat rejection unit and as a consequence heat transfer reduction	Wet cooling towers should be clean at least once a month but depending on the location (dusty or windy locations) this time period should be reduced to sure the well function of the unit
	Flow rate too low resulting in low performance	Clean the filters located in the heat rejection hydraulic circuit Check the pump, check if there is trapped air or there are closed valves downstream. Substitute if there is no other option
	Chemical treatment failure because dosage pump does not work (wet cooling towers)	Check water parameters and depending on results drain the unit and make a chemical cleaning before filling water in again. Substitute the pump if there is no other option

5.2.4. Monitoring and control

	PROBLEM	POSSIBLE SOLUTION
Planning	Not enough information to estimate cold demand and so standard parameters to control the system are used	During installation and at the system commissioning a careful revision of all control parameters should be made
Installation	Control strategy is not able to regulate the system, so theabsorption chiller stops and the solar loop reaches high temperatures	Check parameters and temperature signals in the control software. Adjust to the specific conditions of the solar cooling system
	Control temperature sensors are not located in the right positions	Check their positions and the registered temperatures
Operation	Data acquisition system failure and there is no access to the control system (system does not work)	Users should have a security copy of the software control. The data acquisition system should be always switched on and the electricity should not be disconnected. A user's guide to connect and re-charge the software inside the system should be provided by the manufacturer
	There is no cooling demand signal (chiller in standby)	Check heat source temperature sensor (position and function) and temperature sensor at the return of cold distribution system
	Loss of control software due to failure of the internal batteries (data acquisition system)	At the end of operation period (seasonal operation) some users switch off the access to electricity as part of the stop process of the solar cooling system. This situation should be avoided at all. Data acquisition system can lose the control software if there is not enough charge inside the internal batteries. At the same time chiller protection mechanisms cannot perform and there is risk of introduction of oxygen

Annex

Introduction

The QAiST project

The long term objective of the QAiST project is to prepare the quality assurance framework so that the European solar thermal heating and cooling industry can provide a sustainable contribution to the targets agreed by the member states (20% of RES by 2020) and become a technological world leader. The participants in the project are leading European institutes working in the field of solar thermal energy.

The project is financed through the Intelligent Energy Europe (IEE) funding scheme. The project leader is the European Solar Thermal Industry Federation (ESTIF)

For more information on the project and the participants, please visit the project web presentation:

http://www.estif.org/projects/ongoing_projects/qaist/project_summary/

Purpose of the enquiry

One of the objectives of the project is to develop basic sets of requirements and test methods for emerging application areas, one of them being the **systems for solar thermal cooling**. With the help of this questionnaire, standardised information on different configurations of such systems will be gathered and statistically evaluated in order to obtain better understanding of different possibilities of integration, usage of components, applications etc. By better understanding the systems, we will be able to propose appropriate testing and rating standards, which will help the technology to improve its position on the market.

Anonymity of the data

All data will be use only for **scientific purposes** and will not be shared with or given to third parties outside the project consortium. All data will be **statistically evaluated** and the results published in the final project report without any references to the manufacturers.

However, if your company/institute has interest in showing the system at one of the project meetings or at national workshops organised within the project, you can send us appropriate material and give us your written approval to do so.

Instructions

Please fill in the provided questionnaire by **ticking the check boxes and option buttons** beside the respective category. Where needed, please fill in the text box (indicated orange).

Apart from the questionnaire, any **further information** on the system (schematic, drawings, performance data, product sheets, publications etc.) would be very helpful.

For any further questions regarding the purpose of the project or the survey, as well as this questionnaire, please contact :

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ehrismann@itw.uni-stuttgart.de

Thank you for your cooperation!

Name		Country	
Function		Tel	
Organisation		Fax	
Address		e-mail	
City		Date	

Projekt location

Country		Latitude		north	☐	south	☐
Town		Longitude		east	☐	west	☐
		Altitude		[m]			

Project name	to be filled out by members of the QAiST project		
Project acronym	to be filled out by members of the QAiST project	Project reference number	

Building

Building category

Residential	☐	University	☐
Public	☐	Laboratory	☐
Commercial	☐	Test plant	☐
Office	☐	School/Kindergarden	☐
Hotel	☐	Sport centre	☐
Sanitary, hospital	☐	Retirement home	☐
other:			

Heat is required for / Typical heating/cooling period

		jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Space cooling	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Space heating	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hot water	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Swimming pool	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
other:		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
other:		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Cooling demand during day and night — Yes ○ No ○ n.a. ○

Building description

Cooled floor area		[m²]
Total cooled volume (optional)		[m³]
Peak cooling load		[kW]
no. of hours with cooling demand		[h]

Building ventilation

Natural	☐		
Mechanical centralized	☐	Heat recovery	☐
Global A.C.	☐		
Supply and return air	☐		

Cold distribution system

Fan coil	☐
Chilled ceiling	☐
floor cooling	☐
Concrete core activation	☐
Air duct	☐
Other:	☐

Cold distribution medium

Water	☐	Nominal supply temp.		[°C]
		Nominal return temp.		[°C]
		Nominal total water flow		[m³/h]
Air	☐	Nominal supply temp.		[°C]
		Nominal return temp.		[°C]
		Nominal supply humid.		[%]
		Nominal return humid.		[%]
		Nominal total air flow		[m³/h]

Cooling strategy

Full air conditionning (strict conditions)	○	Design outdoor temperature		[°C]
Top cooling (no strict conditions with back up)	○	Design outdoor humidity		[%]
Solar alone (no back up)	○			
n.a.	○			

Comments

Heat sources

QAiST Quality Assurance in Solar Heating and Cooling Technology

Solar system

Collector Array	no. 1	no .2 (optional)	no. 3 (optional)
Total area	[m²]	[m²]	[m²]
Tilt angle (0=horiz)	[°]	[°]	[°]
Orientation (0=south, 270=east)	[°]	[°]	[°]
Collector area refers to:			
Aperture area (preferred)			
Absorber area			
Gross area			
Model			
Manufacturer			
Country			
Collector type			
Unglazed absorber			
Flat plate collector			
Double-glazed flat plate collector			
Evacuated Tube collector			
Heat pipe			
Parabolic through collector			
Other:			
Type of installation			
Flat roof			
Tilt roof			
Fully integrated			
Ground			
Other:			
Heat transfer medium			
Water			
Water + glycol			
Air			
Other			
Flow control			
Low flow			
High flow			
Variable			

Heat storage

	type no. 1	type no .2 (optional)	type no. 3 (optional)
Volume	[m³]	[m³]	[m³]
Number of storage tanks	[-]	[-]	[-]
Storage medium			
Water			
Other:			

Auxiliary heating system

			Fuel	
None			Gas	[kW]
Integrated in solar tank			Oil	[kW]
External direct type			Biomass	[kW]
Auxiliary storage type			Electricity	[kW]
Auxiliary storage tank volume	[m³]		other	[kW]
District heating		[kW]		
Combined heat/power CHP		[kW]		
Waste heat		[kW]		
other		[kW]		

Comments

Cooling Equipment

Heat driven chiller			Desiccant evaporative cooling (DEC)		
Model			Model		
Manufacturer			Manufacturer		
Country			Country		
Sorption process:			Sorption process:		
Absorption			Solid		
Adsorption			Liquid		
Steam-jet					
other:					
Working pair			Sorption material:		
Water / Lithium bromide			Silica gel		
Water / Lithium chloride			Lithium chloride		
Water / Zeolithe			Other:		
Water / Silica gel					
Ammonia / Water					
other:					
Chiller is driven by:			DEC is driven by:		
Solar thermal heat (autonomous)			Solar thermal heat (autonomous)		
Solar thermal heat + auxiliary heat			Solar thermal heat + auxiliary heat		
n.a.			n.a.		
Nominal chilling capacity		[kW]	Nominal air volume flow rate:		[m³/h]
		[Tons]	Minimum air volume flow rate:		[m³/h]

Coefficient of Performance COP_thermal (chilling capacity / driving heat ratio)		[-]
Distributed chilled medium temperature		[°C]
Nominal driving heat temperature		[°C]

Cold storage	type no. 1		type no .2 (optional)		type no. 3 (optional)	
Total volume		[m³]		[m³]		[m³]
Number of storage tanks		[-]		[-]		[-]
Storage medium						
Water						
Ice						
other:						
Storage tank capacity		[kWh]		[kWh]		[kWh]
Nominal exchange temp.		[°C]		[°C]		[°C]

Heat rejection (of the heat driven chiller)			Backup chiller (electrically driven vapour compression)		
Model			Model		
Manufacturer			Manufacturer		
Country			Country		
			Chilled fluid type		
			Coefficient of Performance COP_el		[-]
Pool heating			Chilled medium temperature		[°C]
Active ground regeneration			Heat rejection of backup chiller		
Dry cooling			Dry cooling		
Wet cooling			Wet cooling		
Hybrid			Hybrid		
other:			other:		
Thermal heat rejection capacity		[kW]	Chilling capacity		[kW]
Nominal electricity consumption		[kW]	Nominal electricity consumption		[kW]

Comments

Investment costs

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	kit no.*	costs included in total cost yes	no			Comments
Heat sources						
Solar system						
Total cost					€	
Collectors		☐	☐		€	
Supporting structure		☐	☐		€	
Installation		☐	☐		€	
Buffer solar tank		☐	☐		€	
Other mountings		☐	☐		€	
Bringing into service		☐	☐		€	
Controller		☐	☐		€	
Heat storage						
Total cost					€	
Installation		☐	☐		€	
Auxiliary heating						
Total cost					€	
Installation		☐	☐		€	
Cooling Equipment						Comments
Heat driven chiller/DEC						
Total cost					€	
Installation		☐	☐		€	
Other mountings		☐	☐		€	
Bringing into service		☐	☐		€	
Controller		☐	☐		€	
Heat rejection		☐	☐		€	
Cold storage						
Total cost					€	
Installation		☐	☐		€	
Backup chiller (electrically driven vapour compression)						
Total cost					€	
Installation		☐	☐		€	
Distribution system (end device)						
Total cost					€	
Installation		☐	☐		€	
Other mountings		☐	☐		€	
Electrical installations and equipment (not mentioned above)						
Total cost					€	
Installation		☐	☐		€	
Monitoring		☐	☐		€	
Controller		☐	☐		€	
Electric panels		☐	☐		€	
Total investment cost					€	

*if purchased as package/kit please allocate kit components by a kit number
(other mountings e.g. piping, pumps, expansion vessels, filters, valves, heat exchangers, thermal insulation, etc.)

Costs for feasibility study, planning and commissioning

			Comments
Feasibility study		€	
Planning		€	
Commissioning		€	

Running costs (excluding VAT)

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Annual maintenance

Reference year		or by year												
Total cost		€												
Operations														
Refilling of fluid	☐		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Pressure check	☐		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	☐		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	☐		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	☐		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Comments

Annual operation

Reference year		or by year												
Total cost		€												
Gas		kWh												
		€												
Oil		kWh												
		€												
Electricity		kWh												
		€												
Biomass		kWh												
		€												
Water		m³												
		€												
Glycol		l												
		€												
		€												
		€												
		€												
		€												
		€												

Comments

Qualitative assessment

Reasons for choice of this system/Reasons against competitory systems

General user reactions (ease of use, controlability,...)

General assessment	User /owner satisfied or not yes	no	Comments
Overall system properties	☐	☐	
Quality of comfort aspects	☐	☐	
Image and marketing aspects	☐	☐	
Other aspects	☐	☐	
Performance assessment	yes	no	
Sufficient energetic performance?	☐	☐	
Overall reliable operation?	☐	☐	
Solved problems?	☐	☐	
Existing nuisance?	☐	☐	
Potential for optimisation?	☐	☐	

Major lessons learnt

Note: the questionnaire requested also schematics and pictures of the systems.