Final Deliverable
Best Practice Brochure

Date: 30.06.2015

By Dr. Uli Jakob[1]

[1]Institution Green Chiller Association for Sorption Cooling e.V.

Address Stendaler Strasse 4, D-10559 Berlin , Germany

Phone +49 (0) 172 9651476

e-mail uli.jakob@greenchiller.de

IEA Solar Heating and Cooling Program

The Solar Heating and Cooling Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency. Its mission is *"to enhance collective knowledge and application of solar heating and cooling through international collaboration to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050.*

The member countries of the Programme collaborate on projects (referred to as "Tasks") in the field of research, development, demonstration (RD&D), and test methods for solar thermal energy and solar buildings.

A total of 53 such projects have been initiated to-date, 39 of which have been completed. Research topics include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44)
- Solar Cooling (Tasks 25, 38, 48, 53)
- Solar Heat for Industrial or Agricultural Processes (Tasks 29, 33, 49)
- Solar District Heating (Tasks 7, 45)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52)
- Solar Thermal & PV (Tasks 16, 35)
- Daylighting/Lighting (Tasks 21, 31, 50)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42)

In addition to the project work, there are special activities:

- SHC International Conference on Solar Heating and Cooling for Buildings and Industry
- Solar Heat Worldwide – annual statistics publication
- Memorandum of Understanding with solar thermal trade organizations
- Workshops and conferences

Country Members

Australia	Germany	Singapore
Austria	Finland	South Africa
Belgium	France	Spain
China	Italy	Sweden
Canada	Mexico	Switzerland
Denmark	Netherlands	Turkey
European Commission	Norway	United Kingdom
	Portugal	United States

Sponsor Members

European Copper Institute	Gulf Organization for Research and Development
ECREEE	RCREEE

Contents

Executive Summary

Subtask D is about Dissemination and policy advice. The work in this subtask covers horizontal activities related to subtasks A, B, and C. The objectives of this subtask are the implementation of targeted promotion activities based on the collective work results; production of dissemination material for external communication; the implementation of knowledge transfer measures towards the technical stakeholders; the development of instruments and their provision for policy makers and the creation and promotion of certification and standardization schemes.

This Subtask D2 activity was aimed to produce a high quality brochure presenting selected reduced number of Best practice examples. Therefore, input from other activities like C3 and the Task 48 participants have been explored to use it for this activity. In activity C3 first draft of “IEA Quality Engineered Solar Air-conditioning Design Examples: A companion to the IEA Solar Cooling Handbook” has been prepared including three solar cooling technologies: a small-scale single-effect absorption chiller system in Austria, a medium-size single-effect absorption chiller system including DHW production in France and a large-scale double-effect absorption chiller system in Australia. Additional 9 further best practice examples were collected from the Task 48 participants, thus a total of 12 projects are summarized in the best practice brochure.

The selected solar cooling projects presented in the brochure represent different applications like office buildings (6), school/institute buildings (4), commercial buildings (1) and residential buildings (1). The projects are located in North America (1), Europe (4) and mostly in South-East Asia (7). The cooled floor spaces of these buildings range between 240 m² up to 11,000 m². The best annual electrical COP_{el} are between 6 and 25, which is an average value of about 12.9. The specific installed system costs are 7,300 EUR/kW for small-scale systems and in average 1,900 EUR/kW for large-scale systems.

1. Introduction

This Subtask D2 activity is aimed to produce a high quality brochure presenting selected reduced number of Best practice examples. Within the IEA-SHC Task 48 work several best practice examples were identified by the task participants, which were collected and clustered in this brochure. The aim of this best practice brochure is to present the todays main applications for solar cooling including different countries/continents, climates, sorption chiller and solar thermal collector technologies.

A template for best practice installations has been set up (see Appendix) to collect data from worldwide best practice examples for the different solar cooling technologies (closed systems: absorption and adsorption chillers; open systems: DEC und liquid sorption systems). The template is based on the experiences and use from the previous EU funded SOLAIR project. New cases have been gathered for the final best practice brochure.

The selected solar cooling projects presented in the brochure represent different applications:

- 6 office buildings,
- 4 school/institute buildings,
- one commercial buildings and
- one residential building block.

The projects are located in different regions of the world. One of the projects is installed in North America, four in Europe and seven in South-East Asia as shown in Figure 1.

Figure 1: Locations of best practice examples (Source: Green Chiller / FreeWebElements)

Table 1 lists the collected projects for the Best Practice Brochure with information about the project name and place, the country, the installed solar cooling technologies and which Task 48 participant has contributed the original filled in template with the requested data, schemes and photos. Based on those inputs detailed descriptions about each best practice project have been prepared, which can be found in the following Chapter 2.

Table 1 – Selected best practice examples

Project	Country	Technology	Contributor
Desert Mountain High School, Scottsdale, Arizona	USA	Single-effect water/LiBr absorption chiller	SOLID
Building block in ZAC Jacques Coeur in Port Marianne area, Montpellier	France	Single-effect water/LiBr absorption chiller	TECSOL
Lindner office building, Arnstorf	Germany	Single-/double-effect water/LiBr absorption chiller	ZAE Bayern
Feisfritzwerke office building, Gleisdorf	Austria	Ammonia/water absorption chiller	University of Innsbruck
Jožef Stefan Institute, Ljubljana	Slovenia	Water/silica gel adsorption chiller	SorTech
United World College, Singapore	Singapore	Single-effect water/LiBr absorption chiller	SOLID
Linuo office building, Jinan	China	Single-effect water/LiBr absorption chiller	Shanghai Jiao Tong University
Vanke Real Estate office building, Dongguan	China	Single-effect water/LiBr absorption chiller	Shanghai Jiao Tong University
Shanghai electric office building, Shanghai	China	Single-/double-effect water/LiBr absorption chiller	Shanghai Jiao Tong University
GEL building, Shanghai	China	Water/LiBr absorption / silica gel adsorption chiller + DEC system	Shanghai Jiao Tong University
Restaurant, Honjyo city	Japan	Water/zeolite adsorption chiller	InvenSor
Office building	Australia	Double-effect water/LiBr absorption chiller	CSIRO

2. Best practice examples

2.1. Desert Mountain High School, USA

Installation year	2014
Technology	Single-effect water/LiBr absorption chiller
Collector area	4,935 m²
Chiller	1,750 kW

The selected best practice example in North America is the Desert Mountain High School in Schottsdale, Arizona (Figure 2). The three-storied building has a yearlong cooling demand. To distribute the cold in the building there are fan coils and air ducts. The design temperatures of the distribution fluid (water) are 7°C for supply and 13°C for return. The volume flow is about 500 m³/h. The only heat source is a flat plate solar collector field with a gross area of 4,935 m². The used heat transfer fluid is water. To buffer the solar energy there is a water storage tank with 34.5 m³ installed. The cooling demand is covered by an absorption chiller with 1,750 kW cooling capacity (Figure 3). The manufacturer of the chiller is Broad (model type BDH151X83.3/95-34.4/29.4-7.6/12.7-B3-200). The design temperatures of the single-effect absorption chiller are 13°C for the chilled outlet and 7°C for chilled inlet temperature, respectively. The inlet heating temperature is about 72°C and the outlet is 60°C. The heat rejection system by the manufacturer Marley (model type NC 8400) is a wet cooling tower with a capacity of 3,500 kW. Its design temperatures are 35°C for inlet and 29.4°C for outlet.

Figure 2: Roof mounted solar collectors at Desert Mountain High School (Source: SOLID)

The existing monitoring data (period of 3 months in 2014) shows a supplied solar thermal energy of 1,415,543 kWh, the resulting useful energy for cooling is 1,373,226 kWh. The specific collector yield is in average about 10,000 kWh/m²/day. The cooling yield that is provided by the chiller is 908,516 kWh. The **annual thermal COP_{th} of the absorption chiller is 0.65** and **COP_{el} reaches 25**. The estimated life time of the system is defined with 30 years. In this period the costs for maintenance will be about 45,000 EUR.

Figure 3: Absorption chiller with 1,750 kW cooling capacity (Source: SOLID)

2.2. Building block in ZAC Jacques Coeur in Port Marianne area, France

Installation year	2012
Technology	Single-effect water/LiBr absorption chiller
Collector area	240 m²
Chiller	35 kW

The project in Montpellier handles with an existing building block, which was built in 2010 (Figure 4). The building can be separated in two parts, building A and B. Building A includes offices and shops on an area of 11,000 m². Building B is only for residential purposes. They are 167 dwellings on a floor space of 10,600 m². The strategy of sizing the collector was to use the available roof space of the buildings and cover them in a simple way with the maximum numbers of solar collectors. On the roof of building A nearly 500 m² were available. Finally a gross area of 240 m² double glazed flat plate solar collectors could be installed (Figure 5). The generated heat of the collectors is used in winter for DHW only. But in summer the collectors primarily provide the demand of cooling and support the DHW if there is the possibility (Figure 6). The working fluid in the solar circuit is water/glycol. For solar cooling there is a 35 kW absorption chiller from Yazaki installed. The system is supplemented by a 1.5 m³ hot water storage tank, which is also used for preheating of the DHW. Additionally there is a 10 m³ storage capacity in Building B for the dwellings.

Figure 4: Building situation (Source: TECSOL)

Figure 5: Solar collector fields with drain back system (Source: TECSOL)

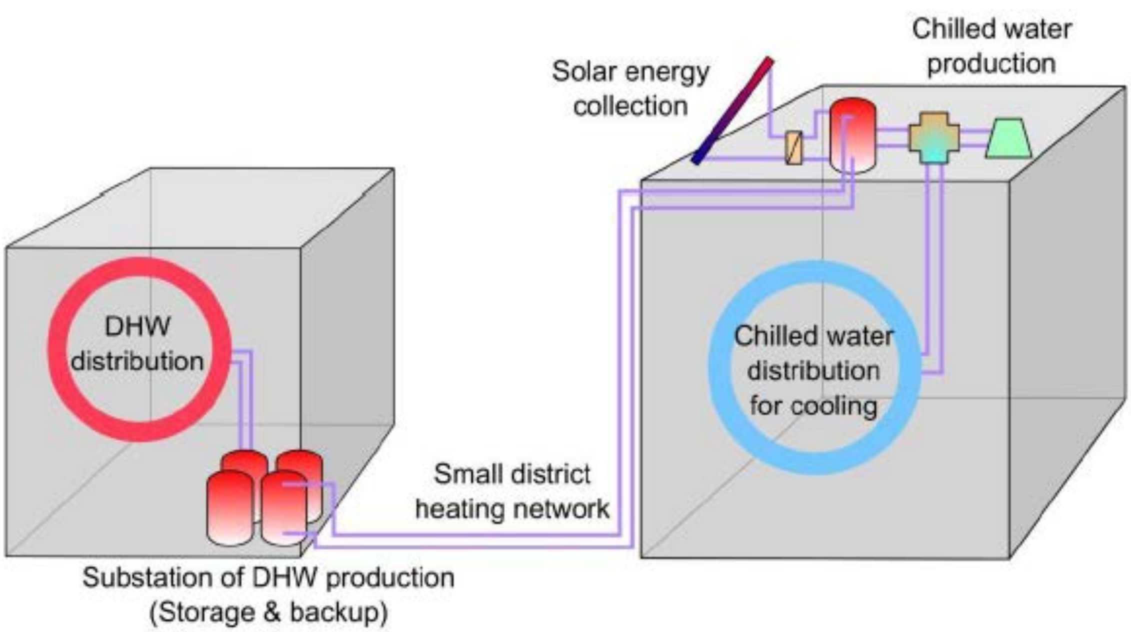

Figure 6: Hydraulic principle of the solar system in reference to the two building (Source: TECSOL)

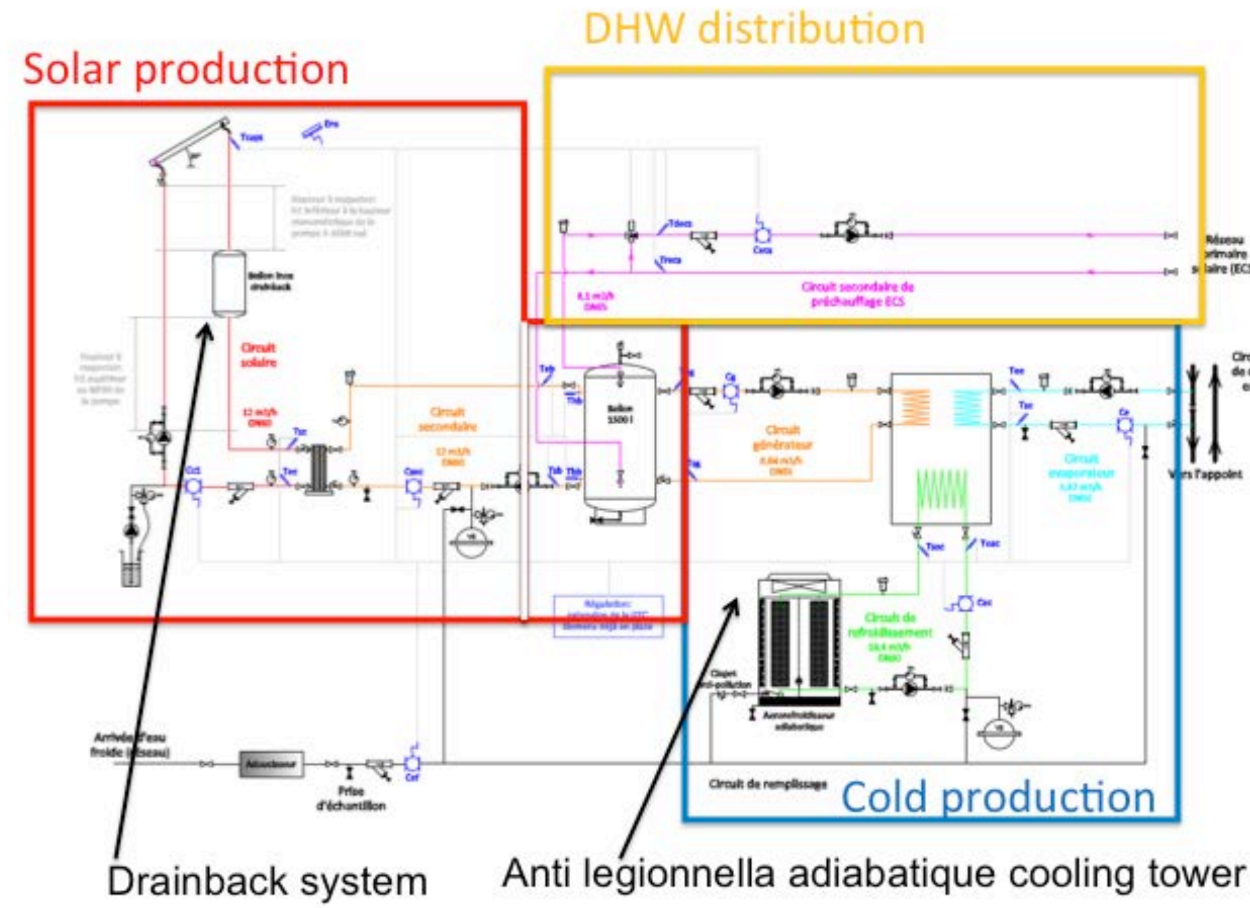

Figure 7: Detailed hydraulic scheme of the SHC system of the two buildings (Source: TECSOL)

The comparison of the monitoring data of the years 2013 and 2014 shows that the collected solar energy in 2014 with 24,500 kWh was 15% lower than 2013 with 30,000 kWh. Thereof, 9,800 kWh of solar energy were used for the solar cooling system in 2013 and was therefore 800 kWh higher than in the year 2014. The cooling energy supplied by the absorption chiller was in both years nearly the same (2013: 6,000 kWh and 2014: 5,700 kWh). A difference is between the solar energy supplied to the DHW system with 18,000 kWh for the year 2013 and 11,300 kWh for the year 2014. Those differences are showing the impact of poor summer weather in 2013. Nearly constant are the values of the **COP_{th} with values of 0.60** in both years and an **average electrical COP_{el} of 12.2 (2013) and 12.0 (2014)**. The results show that the concept for a combined solar cooling and DHW system is a possibility to maximise the solar resource and system simplicity to gain an economical optimum.

2.3. Lindner office building, Germany

Installation year	2010
Technology	Single-/double-effect water/LiBr absorption chiller
Collector area	286 m²
Chiller	90 kW

The office building of the company Lindner in Arnstorf (Figure 8) has a total heat demand of the building for space heating of 400,000 kWh and the cooling demand is 35,000 kWh. Cooling is required in this area from April till September during daytime. Distributed on three floors there is a cooled floor area of 1,300 m². From that arises a cooled volume of 4,000 m³. The peak cooling load of the building amounts 90 kW at 380 hours of cooling hours per year. The maximum heat load is 160 kW at 3,000 hours a year. A chilled ceiling is used as a cold distribution system. It runs at temperatures of 15°C inlet and 18°C outlet. The volume flow of the water flow is between 10 and 27 m³/h. In addition to the solar collectors to ensure the heat demand of the building, there is a gas boiler back-up system installed. The total flat roof area is occupied with solar collectors (aperture area 286 m²), which are tilted to 35°. Manufacturer of the flat plate solar collectors is STI (model type FKA 270). As heat transfer fluid water-glycol is used with high-flow control. The hot water storage has 17 m³.

Figure 8: Lindner office building with flat plat collectors on the roof (Source: ZAE Bayern)

The heat of the solar collectors is supplied to a single-/double-effect absorption chiller with the working pair water/LiBr (Figure 9). The chiller is manufactured by Thermax (model type LTGD3). Its cooling capacity is 90 kW. The thermal COP switches between 0.7 (single-effect mode) and 1.2 (double-effect mode). The outlet temperature of the chiller is 15°C and the inlet temperature is 3°C higher. The heating temperatures are 95°C for inlet, while the outlet temperatures are at 81.2°C. The dry heat rejection system from Günther (model type GFHe 090.1B/2x4-S(S)-F4/2P) has a recooling capacity of 201 kW by inlet temperatures of 36°C with a temperature spread of 7°C. For back-up there is an integrated gas burner in the absorption chiller, which has a capacity of 75 kW.

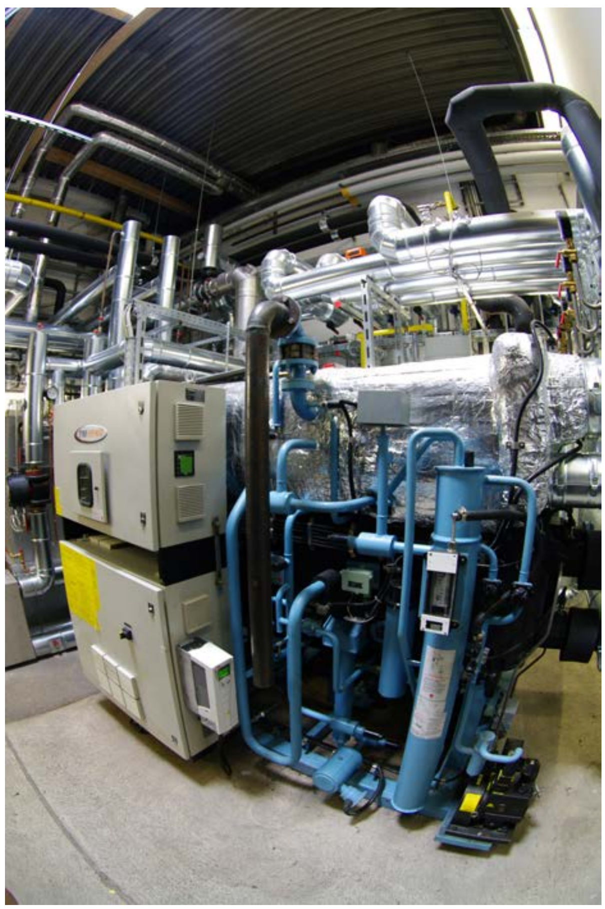

Figure 9: Solar/gas driven single-/double-effect absorption chiller at Lindner (Source: ZAE Bayern)

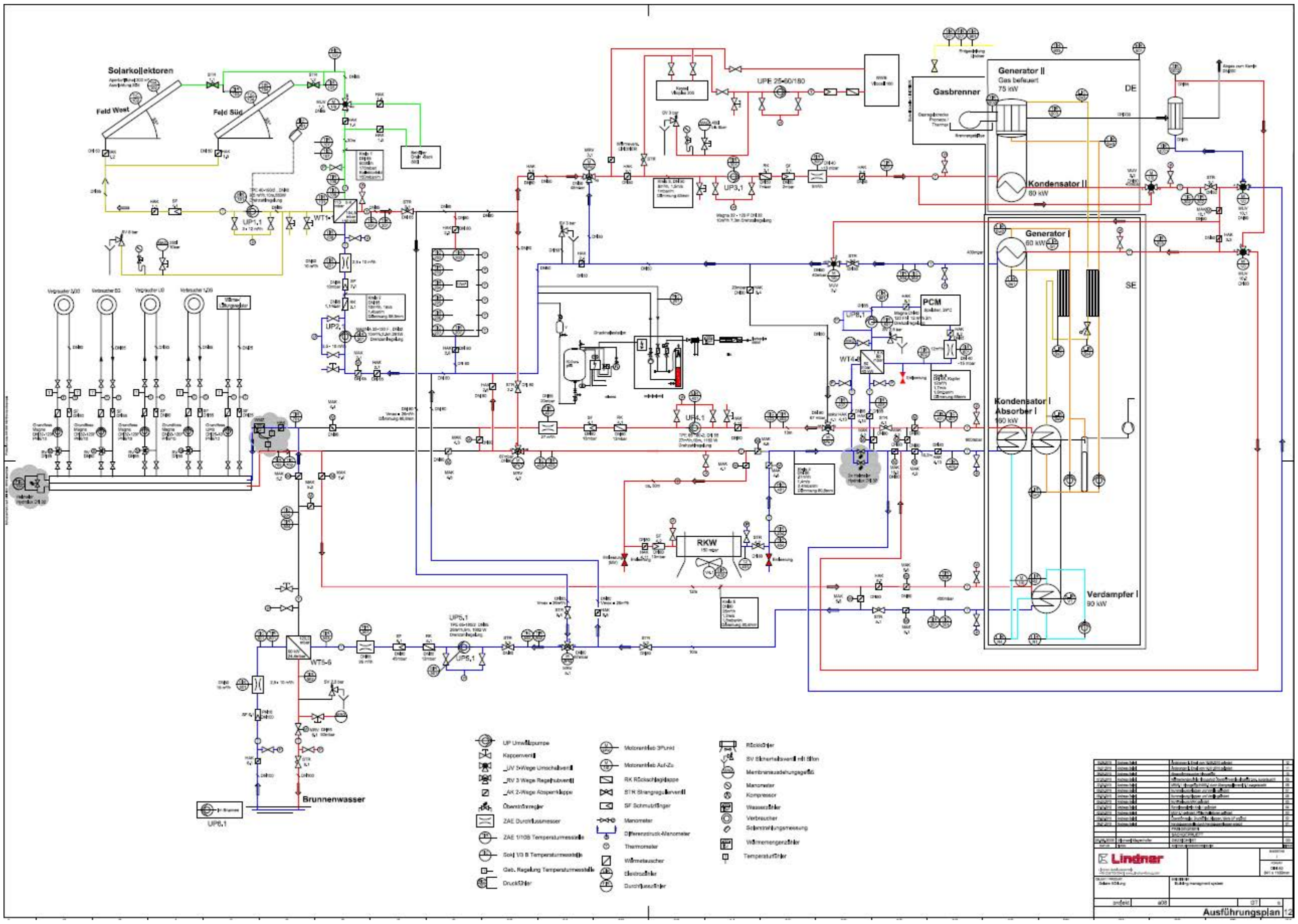

Figure 10: Hydraulic scheme of the solar cooling system (Source: ZAE Bayern)

For the year 2011 monitoring data exist to evaluate the performance of the system. 270,000 kWh/a were supplied from solar. For cooling were 50,000 kWh/a of useful energy generated. The amount of useful energy for space heating from the collectors is 30,000 kWh/a. The specific collector yield is 285.71 kWh/(m²a). 35,000 kWh/a of cooling energy were provided to the absorption chiller. The amount of rejected heat from the chiller is about 58,333 kWh/a. The **thermal COP_{th} is 0.6** and the solar fraction of cooling is 65%. 12,000 kWh/a of gas were required by the back-up system. **The annual electrical COP_{el} is 7.1**. The measured auxiliary power consumption (e.g. pumps, fan, chiller control, etc.) is 4,800 kWh/a.

The total cost can be splitted into investment costs of 190,000 EUR and installation costs of 45,000 EUR. The resulting total specific costs are 2,611 EUR/kW. The life time of the system is assumed up to 15 years.

2.4. Feisfritzwerke office building, Austria

Installation year	2010
Technology	Ammonia/water absorption chiller
Collector area	64 m²
Chiller	19 kW

The project Feisfritzwerke, Gleisdorf uses an ammonia/water absorption chiller to cover the cooling demand of the office building (Figure 11). The typical cooling period in Gleisdorf in Austria is from May till August. The cooling demand is just during the day, which is summed up to 700 h per year. In this project, which deals with an office building, the solar heat is used for the space cooling with 23,700 kWh and space heating with 105,000 kWh. The cooled floor area is about 1,000 m² with a total cooled volume of 3,250 m³. The peak cooling load is about 21 kW and the peak heating load about 60 kW, respectively. As a cold distribution system chilled ceiling are used. The difference between the chilled water supply temperature (16°C) and the return temperature (19°C) is 3 K. The maximum volume flow of the distribution fluid is 4.6 m³/h.

Figure 11: Office building of the Feisfritzwerke (Source: UIBK)

The heat sources for the building are two CHP units, district heating (since 2013) and solar collectors with an gross area of 64 m² and a tilt angle of 20° (Figure 12). The utilized collector type is a flat plate from the manufacturer SOLID. It is installed on a flat roof. The heat transfer fluid is water-glycol with a low flow control. The hot water storage has a volume of 10 m³. Overall there are 5 hot water storage tanks. The solar cooling system uses an absorption chiller with the working pair of NH_3/H_2O from the company Pink (model type PC19). The cooling capacity is 19 kW with a thermal COP_{th} of 0.6. The chilled outlet temperature is 16°C, the inlet temperature is 19°C. The heat inlet temperature is 75°C. Due the difference of 7 K, the heat outlet temperature is 68°C. For heat rejection there is wet cooling tower from the manufacturer Annen installed. The recooling capacity is 57 kW at a recooling inlet temperature of 26°C and an outlet temperature of 30°C, respectively.

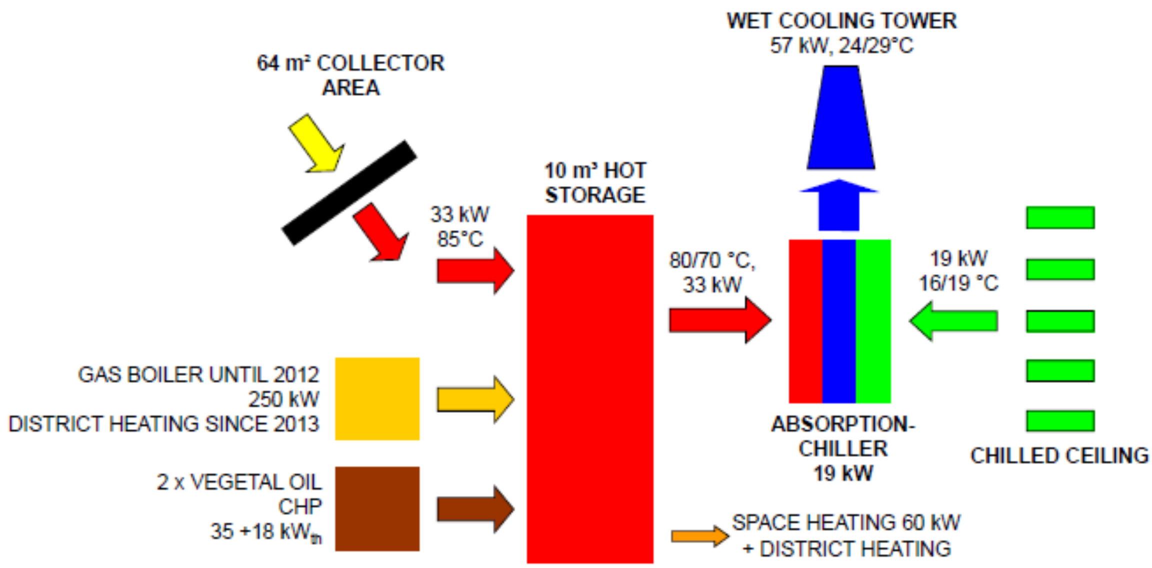

Figure 12: Scheme of the solar cooling system at Feisfritzwerke (Source: UIBK)

The performance of this reference system was monitored for a period of one year (2012 – 2013). The annual supplied solar thermal energy is 67,378 kWh/a. From this value arise a useful solar energy from the collector for cooling of 24,379 kWh/a. For space heating about 5,491 kWh/a solar energy could be used. The specific collector yield is 467 kWh/m²a. During the monitoring period the backup system provided 75,995 kWh/a of heat. The annual cooling energy provided by the chiller is 14,675 kWh/a. The amount of rejected heat from the chiller is 39,053 kWh/a. The auxiliary power consumption (pumps, fan, chiller, etc.) is 2,440 kWh/a. The **annual thermal COP_{th} of the chiller is 0.602** and the **annual electrical COP_{el} is 6.014.**

2.5. Jožef Stefan Institute, Slovenia

Installation year	2014
Technology	Water/silica gel adsorption chiller
Collector area	93 m²
Chiller	20 kW

A water/silica gel adsorption chiller is used in the office building of the Jožef Stefan Institute in Ljubljana in 2014. Therefore, a gross area of 93 m² is installed on the roof, which is a total collector aperture area of 60 m² of 648 high-efficiency vacuum heat pipe collectors (Figure 13). Manufacturer of the innovative solar collectors is Viessmann (Model type VITOSOL 200-T SPL). The cooling demand in Ljubljana is from April till October during daytime. The solar heat from the collectors is used for space cooling with 9,500 kWh and space heating with 76,000 kWh. The cooled floor area is about 380 m² with a total cooled volume of 910 m³. The peak cooling load is about 24 kW and the peak heating load about 89 kW, respectively.

Figure 13: Vacuum solar collectors on the roof of the Jožef Stefan Institute (Source: JSI)

The vacuum tube collectors provide a capacity of 41 kW at a tilt angle of 35°. The heat is supplied to an adsorption chiller with 20 kW cooling capacity at 85°C and outlet temperature of 72°C (Figure 14). The adsorption chiller is from the company SorTech (model type eCoo 20/IPS), which has a thermal COP_{th} of 0.65. As a cold distribution system an air duct system with fan coils is used. The chilled water temperatures are for the supply 13°C and the return 18°C, respectively. The maximum volume flow of the distribution fluid to the air/water heat exchanger is 3.5 m³/h. If the solar irradition is not adequate, a gas boiler is used as back-up system. Furthermore, a hot water storage volume of 3.9 m^3 is installed. To reject the heat of the chiller there is a hybrid recooler of the company Aermec (Model Type WTR 8024CTB) with 57 kW present, which works at temperatures of 25/30°C.

Figure 14: Installation with 20 kW adsorption chillers and heat storage (JSI)

The performance of this solar cooling system was monitored for a period of one year (August 2014 – July 2015). The annual supplied solar thermal energy is 27,500 kWh/a. For solar cooling purposes 12,300 kWh/a of solar energy could be used, which is more then for space heating with 8,960 kWh/a. The specific collector yield is 458 kWh/m²a. The annual cooling energy provided by the chiller is 5,700 kWh/a. The amount of rejected heat from the chiller is 18,00 kWh/a. The **annual thermal COP_{th} of the chiller is 0.48.**

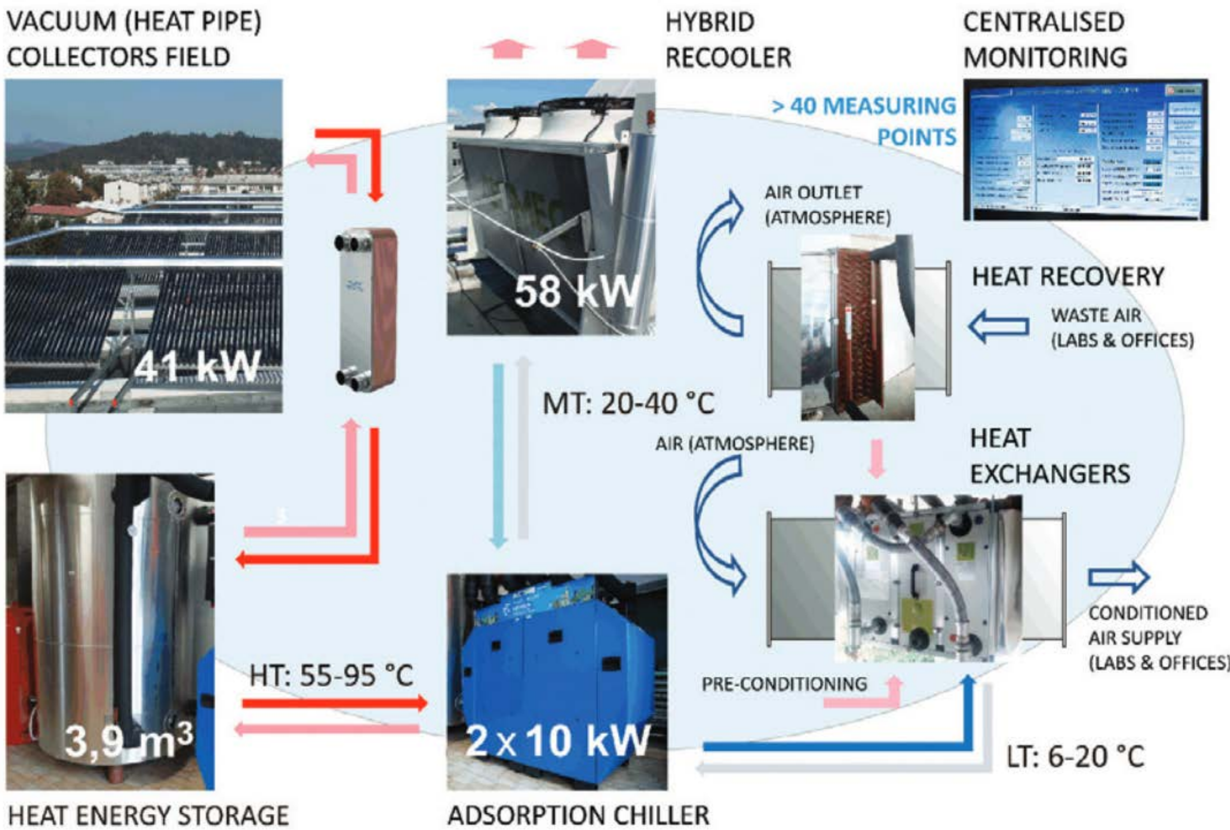

Figure 15: Scheme of the solar cooling system at the Jožef Stefan Institute (Source: JSI)

The investment costs for the solar cooling system are 90,000 EUR and for the installation additional 35,000 EUR. The resulting total specific costs are 6,250 EUR/kW. The life time of the system is assumed up to 20 years with maintenance cost of 800 EUR/a.

2.6. United World College, Singapore

Installation year	2011
Technology	Single-effect water/LiBr absorption chiller
Collector area	3,872 m²
Chiller	1,470 kW

Another best practice project is the United World College (UWC) in Singapore (Figure 16). Due the climate in this region, the cooling demand is all the year around during day and night. The different buildings have 5 to 6 floors with a peak cooling load of 5,600 kW. For the cold distribution fan coils are used. The chilled water supply temperature is 11°C and the return temperature 16°C. To generate heat for the building only solar collectors are available. The total flat plate collector gross area is 3,872 m² (aperture area of 3,523 m²) with a tilt angle between 15° and 20° (Figure 17). The solar collectors are manufactured by the company OekoTech (model type Gluatmugl HT). The heat transfer fluid is water with low flow control. In addition two hot water storage tanks with a total size of 60 m³ (2x30 m^3) are installed. There is no back up system built-in.

Figure 16: UWC building blocks with roof mounted flat plate collectors (Source: SOLID)

For the solar cooling system there is single-effect water/LiBr absorption chiller with a performance of 1,470 kW installed. The chiller is from the manufacturer Broad. The COP_{th} is 0.7 by a chilled outlet temperature of 8°C and an inlet temperature of 16°C. The heating temperatures are between 65°C and 105°C. The heat rejection is running with wet cooling towers. As back-up system there are compression chillers from the company Trane with a total capacity of 5,630 kW and COP_{el} of 6 installed. A wet cooling tower with a capacity of 4,700 kW rejects the heat of these chillers.

The one year monitoring data of the solar cooling system (Figure 17) from 2013 shows that out of the collected solar heat of 1,566 MWh/a about 1,406 MWh could be used to run the chiller, which then provides 949 MWh of cold. With that the **annual thermal COP_{th} of the chiller is 0.675** and the **annual electrical COP_{el} is 6.3.** The system was operating in total 2,046 h/a. The costs of the whole systems are about 3.9 Mio. EUR, which then leads to a total specific costs of 2,653 EUR/kW.

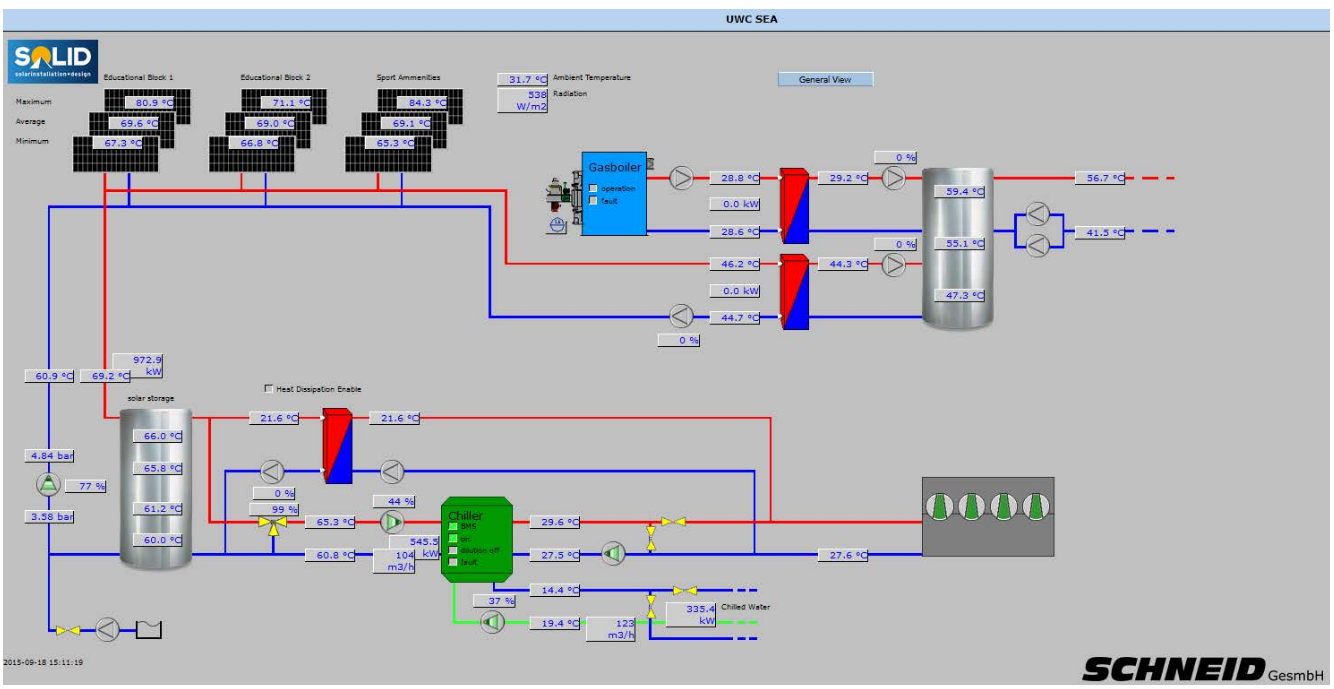

Figure 17: Monitoring scheme of the solar cooling system at the UWC (Source: SOLID)

2.7. Linuo office building, China

Installation year	n.a.
Technology	Single-effect water/LiBr absorption chiller
Collector area	168 m²
Chiller	35.2 kW

The office building of the company Linuo in Jinan has a cooling demand of 43,200 kWh. Secondly there is the space heating demand of 27,000 kWh and for DHW about 17,000 kWh. The cooling period in this area is from June till September during daytime. In this one-storied building with a cooled area of 240 m² the total cooled volume is about 840 m². The daily hours of cooling and heating demand and DHW load are given with 10 hours. The peak load of cooling is 36 kW, the peak value of heating is 30 kW and the peak DHW load is 5 kW, respectively. Fan coils realize the cold distribution. Those are running at temperatures of 12.5°C/7°C with a volume flow of 5.47 m³/h. The solar collectors with an aperture area of 168 m² and a tilt angle of 15° are satisfying the heat demand for the three purposes (Figure 18). The evacuated tube collectors from the manufacturer Linuo Paradigma (model type LN 58-1800-16) have an aperture area of 1.6 m² each and a gross area of 2.5 m² each, respectively. As heat transfer fluid water-glycol is used. A hot water storage tank with 2 m³ is also installed. An electric heater with a capacity of 18 kW is complementing the solar system.

Figure 18: Installation of evacuated tube collectors on the roof (Source: SJTU)

The single-effect water/LiBr absorption chiller from the manufacturer Yazaki (model type WFC-SH 10) has a capacity of 35.2 kW and a COP_{th} of 0.7. This chiller provides chilled water temperatures of 12,5°C/7°C (cooling mode) or heating temperatures of 47.4°C/55°C (heating mode). A wet cooling tower with a capacity of 85.4 kW is used for heat rejection at temperatures of 35°C inlet and 31°C outlet. As a heating back-up system with 10 kW capacity and a COP_{el} of 3.1 there is also an air source heat pump installed (Figure 19).

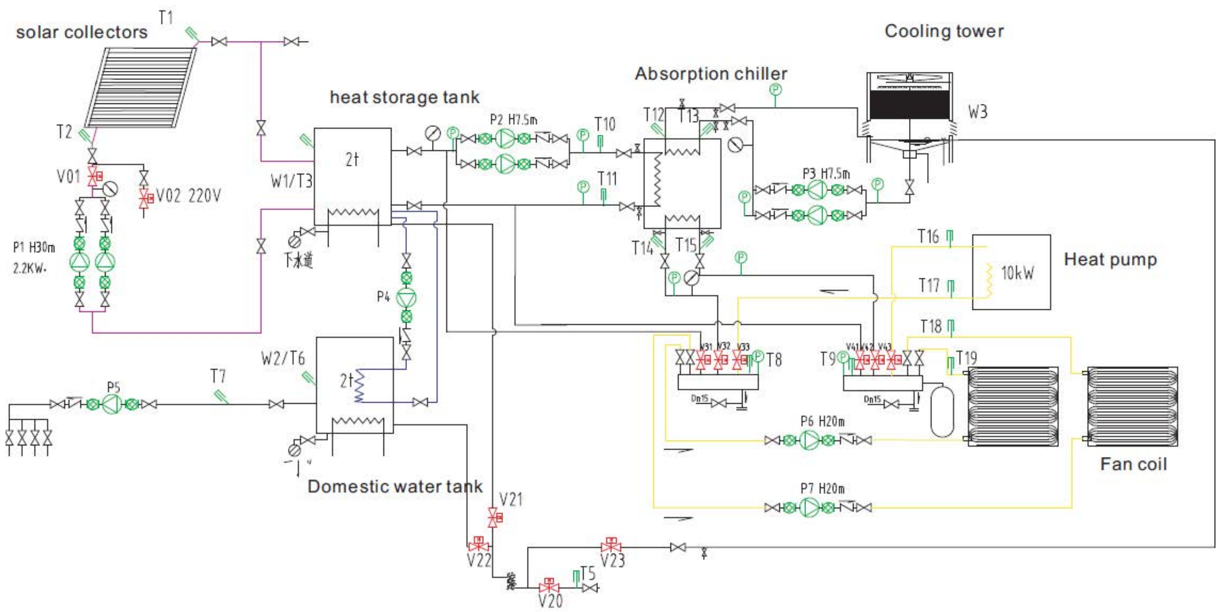

Figure 19: Scheme of the solar cooling system at the Linuo office building (Source: SJTU)

Over a period of four months (June till September) monitoring data was collected to check the performance of the system. From these data it arises that the amount of supplied annual solar thermal energy is 70,560 kWh/a. The value of the useful energy from the collector for cooling is 29,400 kWh/a. The amount of useful energy from the collector for space heating and domestic hot water is 41,160 kWh/a. The specific collector yield for this system is 420 kWh/(m²a). 14,700 kWh/a is the value of the annual cooling energy, which is provided by the chiller. The average **measured thermal COP_{th} of the chiller is 0.5**.

The costs for the complete system are at 131,164 EUR plus installation costs of 26,233 EUR. Specific installed costs can be valued with 4,472 EUR/kW. During a life time of 15 years the scheduled maintenance costs are at 700 EUR/a, which leads to a ROI for the whole system of 6-7 years.

2.8. Vanke Real Estate office building, China

Installation year	n.a.
Technology	Single-effect water/LiBr absorption chiller
Collector area	144 m²
Chiller	45 kW

The Vanke Real Estate office building in Dongguan in the Guangdong province has a total cooled area of 440 m² and a total cooled volume of 1,320 m³, respectively. The building has a cooling demand of 24,000 kWh during the months May till October on daytime. It is supplied by an absorption cooling system. During the cooling period the peak cooling load is about 45 kW at 8 hours a day. Fan coils are used for the cold distribution with design temperatures of 12°C/7°C at a volume flow of 11 m³/h. An area of 144 m² ground installed parabolic trough collectors from the manufacturer Hengshui Zhongye (model type ZY-CS-2.4-3), which covers the heat demand for the solar cooling system (Figure 20). The collector area refers to an aperture area of 8 m² for one collector. A hot water storage tank with a volume of 1 m³ is used. The absorption chiller from Broad (model type BCTDH70) has a capacity of 45 kW and a COP_{th} of 0.65. The heating temperatures are 98°C/88°C. Furthermore, there is a wet cooling tower as heat rejection system with a capacity of 110 kW. Its design temperatures are at the inlet 35°C and at the outlet 31°C. The back-up vortex chiller is from the manufacturer McQuay (model type WGZ020BM) with a cooling capacity of 66.3 kW and a COP_{el} of 4.98.

Figure 20: Installation of parabolic collectors on the ground besides the building (Source: SJTU)

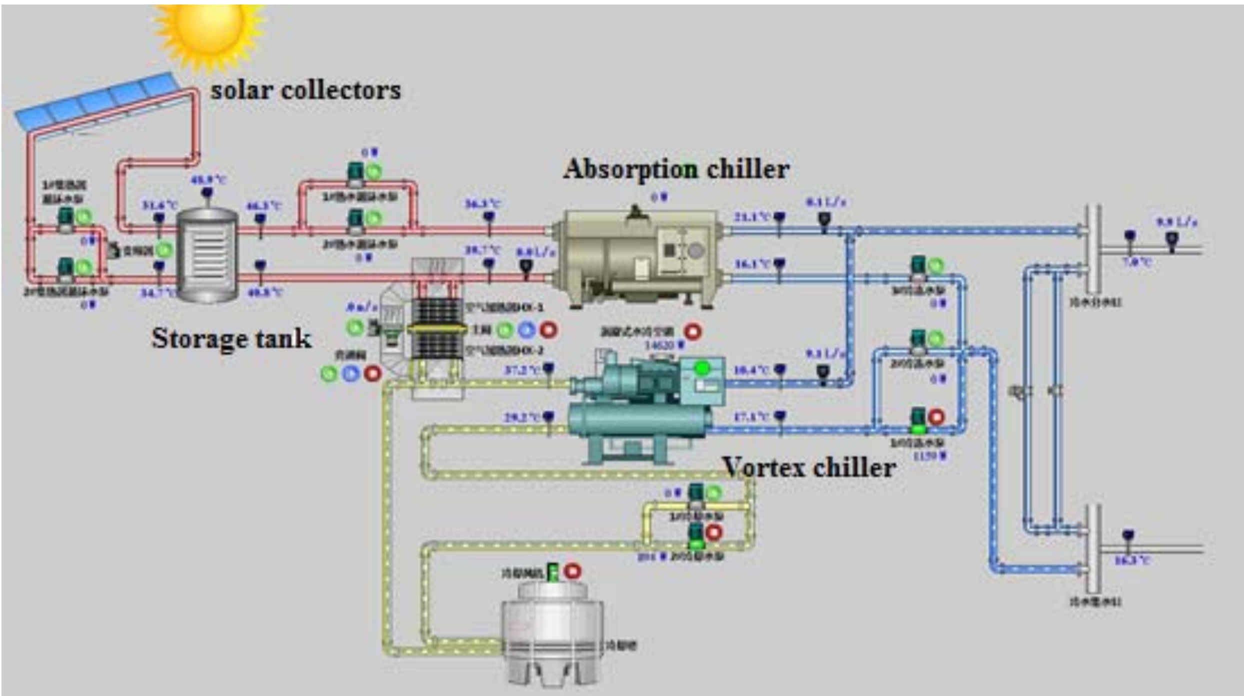

Figure 21: Scheme of the absorption chiller system with the vortex chiller (Source: SJTU)

Monitoring data from a period of May till October gives an overview about the performance (Figure 21). The measured annual thermal solar energy is 25,920 kWh/a from it arises a useful energy for cooling of 11,664 kWh/a. From that the absorption chiller provides 5,250 kWh/a of cooling. The **thermal performance COP_{th} of the chiller is 0.45**.

The costs of the solar cooling system are about 77,368 EUR. In addition there installation costs of 13,158 EUR. The specific installed costs amounts then to 2,012 EUR/kW. Over a life time of 15 years the ROI will be about 8 years. Here are the maintained costs per year 800 EUR.

2.9. Shanghai Electric office building, China

Installation year	2012
Technology	Single-/double-effect water/LiBr absorption chiller
Collector area	550 m²
Chiller	91 kW / 134 kW

The Shanghai Electric company has installed a solar cooling system for experimental purposes in its own office building with 280 m² cooled floor space and 1,120 m³ cooled volume, respectively. Fresnel collectors drive the absorption cooling system including a thermal storage (Figure 22). The solar heat is used for space cooling (114,000 kWh) and space heating (76,800 kWh). Over a period of five months (May-September) in the region of Shanghai is the typical cooling period. During this time the peak cooling load amounts 125 kW at 8 hours per day as well as the same hours for heating at a peak load of about 105 kW. Fan coils are used to distribute the cold in the building. The absorption chiller runs in two operating mode: single-effect mode with chilled water supply temperatures of 8.4°C and return 12°C. In double-effect mode the cold water supply temperature is 1.4K lower than in single-effect mode. In both operating modes the volume flow is 23 m³/h. Fresnel collectors are used as heat source with an area of 550 m², but each collector module has an aperture area of 23 m². The Fresnel collectors are from the company Parasol Energy (model type LFR&Cavity) using thermal oil as heat transfer fluid. The system is completed by an heat storage with molten salt with a volume of 4.8 m³. In addition an electrical back-up heating system with a capacity of 30 kW is installed.

Figure 22: Single-/double-effect absorption chiller and Fresnel collectors on the roof of the Shanghai Electric office building (Source: SJTU)

The cooling capacity of the absorption chiller is 91 kW in single-effect mode and 134 kW in double-effect mode, respectively (Figure 22). The COP_{th} is either 0.7 (single-effect) or 1.2 (double-effect) depending on the operating mode. From this it can conclude that the cold water outlet temperatures of the chiller are between 8.4°C and 7°C to provide the supply temperatures for the fan coils. A wet cooling tower is used as heat rejection system. The recooling temperatures are 31°C for inlet and 36°C for outlet, respectively. With those temperatures the heat rejection can provide a recooling capacity of 200 kW.

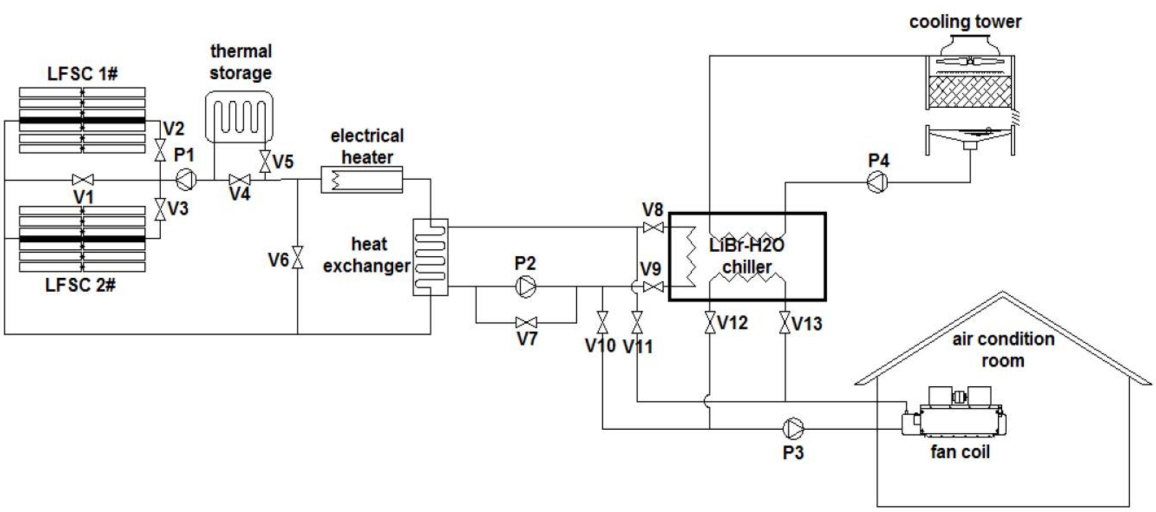

Figure 23: Schematic of the solar energy and heat storage system (Source: SJTU)

Monitoring data from a period of one year (2013-2014) gives a clear indication about the performance of the system. The supplied solar thermal energy has an amount of 160,600 kWh/a while the useful energy from the Fresnel collectors for cooling is about 67,000 kWh/a. For space heating and DHW the amount of the useful energy from the collector is 40,150 kWh/a. The specific collector yield is 292 kWh/(m²a). During the measured year the chiller provided in total 58,100 kWh/a for cooling purposes. The **annual COP_{th} of the chiller is 0.83**.

Total system costs have a declared value of 200,000 EUR while the installation costs are at 50,000 EUR. The specific installed costs varies between 1,866 EUR/kW (double-effect mode) and 2,747 EUR/kW (single-effect mode). The average value is then about 2,200 EUR/kW. The absorption chiller system has a life time of 15 years with predicted annual maintenance costs of 5,000 EUR/a.

2.10. GEL building, China

Installation year	2012
Technology	Water/LiBr absorption + silica gel adsorption chiller + DEC system
Collector area	140 m²
Chiller	6 kW (absorption) / 15 kW (adsorption) / 1,000 m³/h (DEC silica gel)

At the Shanghai Jiao Tong University a combination of three different solar cooling systems are installed at the Sino-Italian Green Energy Laboratory (GEL). The LEED gold certificated university building has a cooling demand of 112,500 kWh/a and for space heating 67,500 kWh/a, respectively. The cooling load is during May till September. Furthermore the cooled floor area of the 3 storied building is 1,500 m² with a total cooled volume of 4,500 m³ (Figure 24).

Figure 24: Entrance view of the GEL building (Source: SJTU)

The peak cooling load amounts 150 kW at 8 hours per day of cooling demand, while the peak heating load is 120 kW at 8 hours per day. Fan coils and chilled ceilings are used for cold distribution with a chilled water supply temperature of 15°C and an inlet temperature of 20°C by a volume flow of 25 m³/h. Furthermore, air ducts are installed for the DEC System, which have a supply temperature of 22°C with a humidity of 40% and a return air of 26,7°C with a humidity of 50%. The heat source for the absorption and adsorption chiller are two vacuum tube collector fields (heat pipe and CPC, respectively) from the manufacturer Linuo-Paradigma (Figure 25). Moreover, solar air collectors with vacuum tubes are installed to cover the heat demand for the regeneration of the DEC system. All three collector fields have together a total aperture area of 140 m² with a tilt angle of 28°. The low flow controlled systems uses water as heat transfer fluid (absorption and adsorption system) as well as air for the DEC system. Additionally there are two water heat storage tanks of 2.5 m³ installed. The water/Libr absorption chiller with 6 kW cooling capacity is from the company Daikin and the water/silica gel adsorption chiller from Shuangliang. The thermal COP_{th} is 0.6 and 0.45, respectively. Both chillers provide chilled water temperatures of 15/10°C at heating temperatures of 90/80°C and 80/65°C, respectively. A wet cooling tower from the company Lianfeng (model type BL 15T/H) with a recooling capacity of 70 kW is used for the heat rejection at inlet temperatures of 37°C and outlet temperatures of 32°C. Supplementary there is a solid DEC system with silica gel to generate the cold air for the air duct system. The DEC system is built by SJTU (model type TDSC-10) with an design air volume flow of 1,000 m³/h and a minimum air volume flow of 500 m³/h. As back-up there is a water source reversible heat pump installed with a heating/cooling capacity of 170/158 kW and a COP_{el} of 3.4.

Figure 25: Installation of vacuum tube collectors (heat pipe + CPC), PV panels and solar air collectors at the GEL building from the left to right (Source: SJTU)

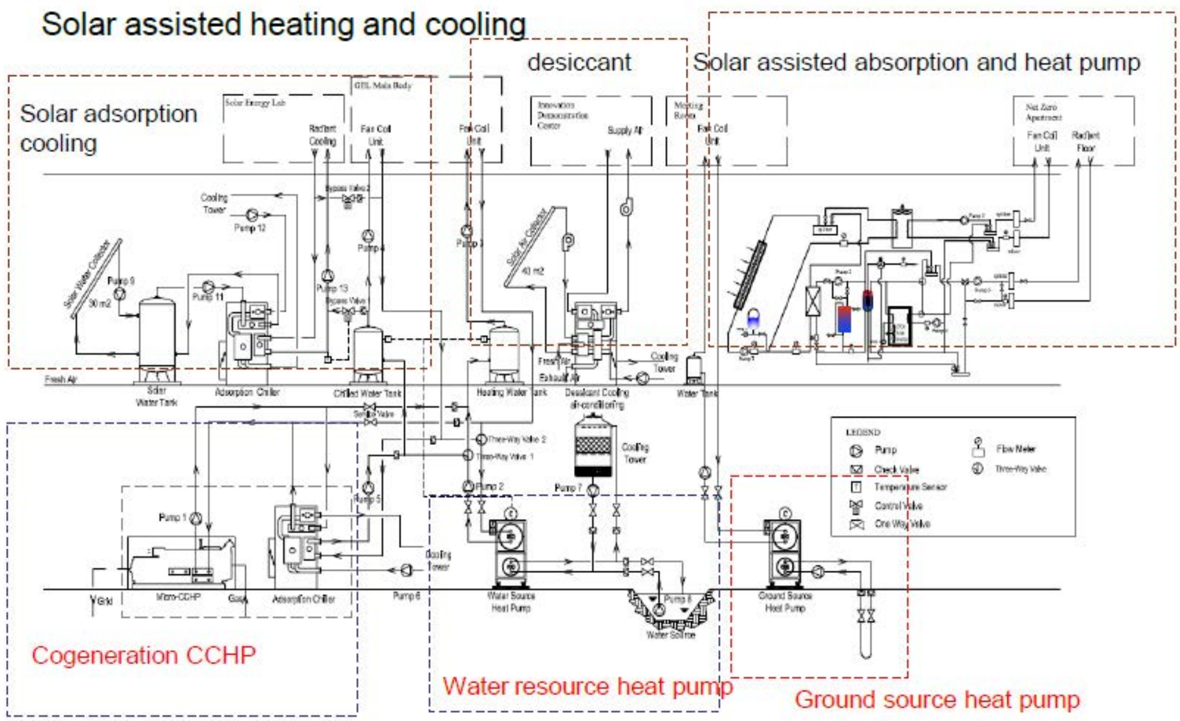

Figure 26: Scheme of GEL solar cooling and heating system (Source: SJTU)

Monitoring data from 2012 to 2013 is available for the GEL building to monitor the system performance. The total annual solar thermal energy supplied to the system is 34,913 kWh/a. Useful energy for cooling is about 15,313 kWh/a and the useful value of energy for space heating is 19,600 kWh/a, respectively. The specific collector yield is 525 kWh/(m²a). The annual cooling energy provided by the chillers is 23,275 kWh/a, while the rejected heat energy in the same period is about 69,826 kWh/a. Furthermore, the **annual COP_{th} of the sorption chillers are about 0.5**. For the regeneration of the two desiccant wheels in the DEC system a heat input of 7,000 kWh/a is needed. The total air-conditioning of the DEC system is about 5,600 kWh/a with a fraction of 4,300 kWh/a by the desiccant wheel operation only. The **annual thermal COP_{th} of the DEC system is 0.8**. The sum of the required cooling energy back-up is 85,000 kWh/a, which has an annual COP_{el} of about 3.5.

The cost of the total system is 187,500 EUR with additional installation cost of 62,500 EUR. The specific installed costs for the adsorption chiller system is about 5,556 EUR/kW. For a period of 15 years the amount of yearly maintenance costs are 1,000 EUR/a. Summed up there is an expected ROI after 7- 8 years.

2.11. Restaurant, Japan

Installation year	2014
Technology	Water/zeolite adsorption chiller
Collector area	192 m²
Chiller	10 kW

For the commercial building (restaurant) in Honijo city, Japan (Figure 27) a combination of an electrically driven heat pump/chiller and a solar assisted water/zeolite adsorption chiller as back-up is realized. The restaurant has a cooling demand of 127,103 kWh and for space heating of 80,483 kWh. In addition there is a heat demand for hot water of 58,418 kWh. On an area of 450 m² and a volume of 1,170 m³ the two-storied building has a cooling load from May till October. The average hours of cooling and heating demand are 4 hours a day, while the hours of DHW demand is 3 hours per day. The peak cooling load is 105 kW and the peak heating load is 45 kW, respectively. The restaurant uses fan coils for the cold distribution. The heat transfer fluid is water with 12/7°C temperature level by a volume flow of 16.8 m³/h. A gross area of 192 m² of flat plate collectors supplies in combination with a 252 kW capacity gas boiler as back-up the required heat for the adsorption chiller as well as for the heating and DHW. The 15° tilted and ground installed collectors are from the manufacturer Osaka-Technocrat (model type STC-12). As heat transfer fluid water-glycol is used. The heat from the different heat sources is stored in three hot water storage tanks with a total volume of 4.5 m³.

Figure 27: Front view of the restaurant in Honijo (Source: InvenSor)

The main electrically driven chiller/heat pump is from the manufacturer SUNPOT (model type GSHP-3003UR), which has a cooling capacity of 120 kW and an electrical COP of 4.5. The chilled water temperatures are 12/7°C, while the heating temperatures in heat pump mode are 32/37°C. The heat rejection of this system is realized by geothermal boreholes with a capacity of 91 kW. For the peak cooling and as a back-up system there is an adsorption chiller from InvenSor installed (model type LTC-10), which supports the main electrical chiller. The adsorption chiller has a cooling capacity of 10 kW and a COP_{th} of 0.6 (Figure 28). The heat rejection of the adsorption chiller is done with a dry recooler with additional water spraying system (adiabatic pre -ooling of the inlet ambient air to the dry recooler). Furthermore, a small cold water storage tank with 0.5 m^3 is used in the system.

Figure 28: Adsorption chiller of the solar cooling system (Source: InvenSor)

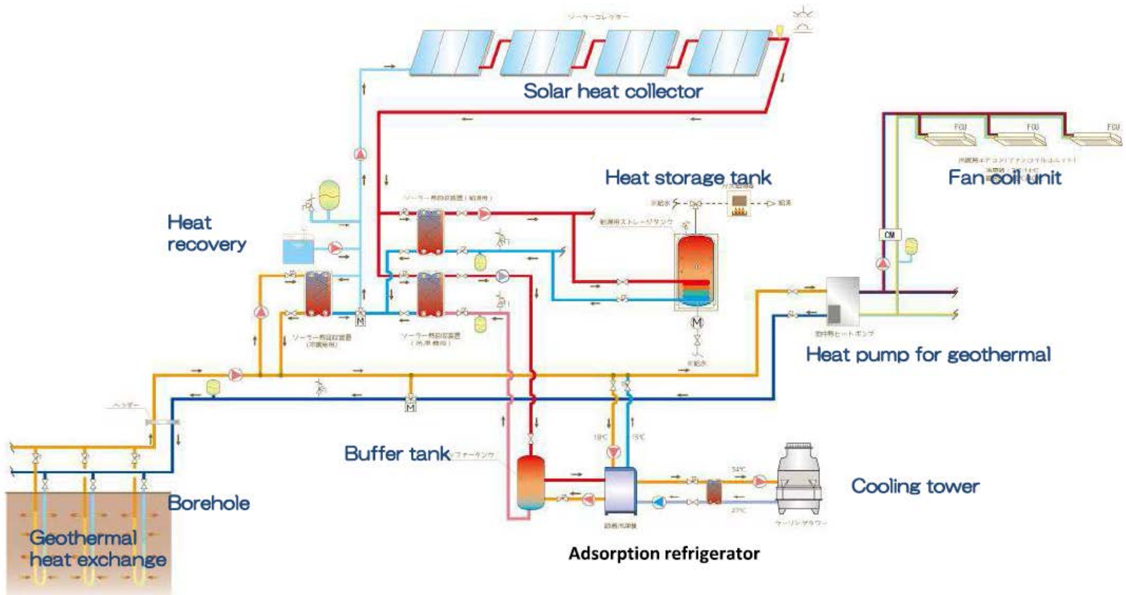

Figure 29: System flow of the cooling system (Source: Osaka Technocrat Ltd.)

The monitoring predicts a supplied annual solar thermal energy of 139,053 kWh/a. The amount of the useful energy from the collector for cooling is 38,297 kWh/a while the value of the fraction for space heating and DHW is 100,774 kWh/a. The determined specific collector yield is 776 kWh/(m²a).

The investment costs of the complete system including heat pump/chiller, geothermal boreholes, solar collectors, storage tanks, adsorption chiller and dry recooler is 668,500 EUR plus installation costs of 280,800 EUR. For the adsorption chiller system the specific installed costs are about 7.302 EUR /kW. The maintenance costs are at 1,400 EUR per year and the life time of the overall system is predicted about 15 years.

2.12. Office building, Australia

Installation year	n.a.
Technology	Double-effect water/LiBr absorption chiller
Collector area	1,000 m²
Chiller	1,000 kW

The Commonwealth Scientific and Industrial Research Organization (CSIRO) has invented a design guide for solar cooling with double-effect or triple-effect absorption chillers (Figure 30). The difference between normal single-effect absorption chillers and double-/ or triple-effect absorption chillers is the higher thermal COP_{th}. While single-effect absorption chillers have a COP_{th} of about 0.7, the COP_{th} of double-effect chillers doubles up to 1.4 or triple-effect chillers can reach a COP_{th} of 1.8, respectively. The advantage of the higher COP_{th} is that a given cooling capacity can be achieved with less heat input from the solar field and with that a reduced heat rejection. But these absorption chillers requires higher heating temperatures around 180°C and 210°C, respectively, which can be only provided by concentrating solar collectors such as parabolic trough or Fresnel collectors (locations with high direct solar radiation necessary, heat transfer mediums: pressurized water, thermal oil or steam). On the other hand the benefit of these high efficient absorption chillers is the lower area of solar fields as well as the reduced need of the fuel of the back-up system, for example natural gas. When the chiller is running in solar mode, the greenhouse gas emissions are very small. If the chiller runs on gas, the greenhouse gas emissions are similar or often better than conventional vapour compression systems.

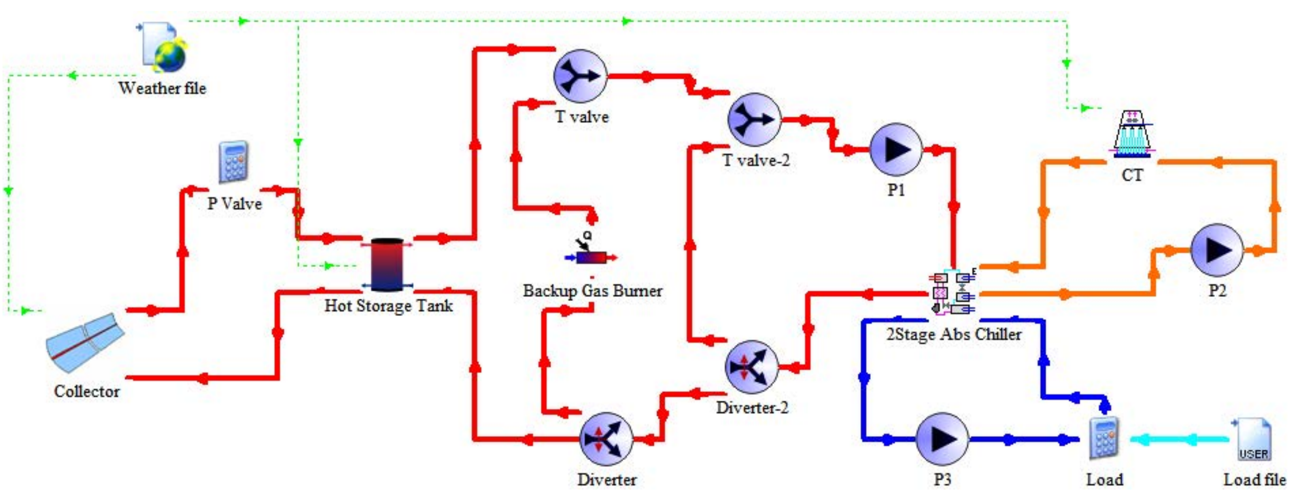

Figure 30: TRNSYS schematic of simulated solar cooling system with double-effect absorption chiller (Source: CSIRO)

The design guide focuses on the scenario application described in Table 2. This scenario application is considered to be a generally robust, high performance cost-effective approach.

Table 2: Application description and scenario limits covered by the design guide (Source: CSIRO)

Criteria	**Application Description/ Limits**
Chiller technology	Double- or triple-effect absorption chiller
Solar collector technology	Concentrating solar thermal collectors (Fresnel, parabolic trough or other high efficiency non-imaging concentrating collector)
Heat transfer fluid	Pressurised hot water, with hot water buffer storage
Heat rejection technology	Wet cooling tower
Back-up cooling technology	Gas burner (either separate or integrated in with the chiller). This design guide should not be used if some other back-up or autonomous solar approach is intended.
Size	At least 500 kW
Climate	At least 1.3 MWh/year of DNI solar radiation

A TRNSYS simulation gave detailed information about the performance of the investigated solar cooling systems. Two different buildings types (type A: 10 storey square building, which represent a block of flats typical of a large Australian city like Sydney, Melbourne or Brisbane and type B: one storey rectangular buslding, which represents a typical office building located in medium-small Australian cities like Newcastle, Canberra, Townsville, Cairns or in the suburbs of a big Australian city) and heat loads were investigated for four simulated climate zones. Based on Meteonorm weather data for Adelaine, Brisbane, Darwin and Melbourne the building peak load and the chiller capacities are different.

The simulated hot water fired double-effect absorption chiller is from Broad (model type BH20) with a thermal COP_{th} at design conditions of 1.41 and chilled water temperature of 7°C and a cooling water temperature of 30°C. The electrical consumption is assumed to be less than 0.01 W per W of thermal cooling capacity. In the study a parabolic trough collector from Solitem (model type PTC1000) is simulated. In general, solar concentrators (Fresnel or parabolic trough) should be able to DNI at an efficiency of at least 65% by a DNI of 900 W/m² to provide temperatures of 180°C. For triple-effect absorption chillers with system temperatures of 210°C the collectors should be able to capture DNI with an efficiency of 60% by a DNI of 900 W/m². As a back-up system the efficiency of the gas burner should be greater than 80%. An important result of the simulation is the influence on the solar fraction of reducing absorption chiller capacity at constant collector area.

A **case study example for an office building in Adelaide, Australia** is illustrating the key design outcomes from the design guide. The selected air-conditioning of the building requires 2.0 MW of cooling. The double-effect chiller has a cooling capacity of 1.0 MW to provide 50% of the design capacity. The flow rates for hot, cooling and chilled water are 44 m³/h, 210 m³/h and 122 m³/h, respectively. A 1.0 MW vapour compression chiller provides the other 50% of the cooling demand. The required heat for the absorption chiller is supplied by 1,000 m² of parabolic trough collectors operating at 180°C. As a back-up system there is a gas burner with an efficiency of 80%. A 12 m³ storage tank for pressurized hot water is also included.

Table 3 shows the results of the double-effect absorption chiller solar cooling system compared to that of an air-cooled vapour compression chiller and a water-cooled vapour compression system. The case study gives as well information about the estimated costs and ROI of the system (Table 4).

Table 3: Comparison of system annual operating energy usage, cost and CO_2 emission (Source: CSIRO)

System	**50% Solar Cooling / 50% Water cooled vapour compression**	**Air-cooled vapour compression (COP 4)**	**Water-cooled vapour compression (COP 6)**
Building cooling load (MWh/a)	1494	1494	1494
Solar fraction	40%	-	-
Electricity usage (MWh/a)	196	374	300
Gas usage (GJ/a)	480	-	-
Water usage (ML/a)	3.3	-	2.7
Total running cost[1] (USD/a)	41,040	67,230	58,820
Total CO_2 emission[2] (t/a)	242	400	322

[1]Running costs based on 18 cent USD/kWh electricity price, 0.6 cent USD/MJ gas price and USD 1.7/KL recycled water price.

[2]CO2 emissions based on 1.07 kg/kWh electricity and 0.24 kg/kWh gas.

Table 4: Estimated plant costs for payback period calculation (Source: CSIRO)

Item	50% Solar Cooling / 50% Water cooled vapour compression	Water-cooled vapour compression (COP 6)
Solar collectors (USD) (300 USD/m^2)	300,000	-
Chillers (USD) (300 USD/kW absorption chiller) + (150 USD/kW vapour compr. chiller)	450,000	300,000
Additional plant (USD)	50,000 (cooling tower) 30,000 (pressure vessel)	40,000 (cooling tower)
Design & installation (by Lang factor) (USD)	830,000	340,000
Total (USD)	1,660,000 (340 USD/kW for V/C chiller) (1,320 USD/kW for solar)	680,000 (340 USD/kW)

Finally, a sensitivity analyses on energy prices and solar cooling installed cost is done. The results show that for the determined total specific cost for the solar cooling system of 1,320 USD/kW the ROI would be above 27 years (also at a doubled electricity price of 36 cent USD/kWh) for the case study in Australia. The ROI could come done for the given situation below 10 years if the solar cooling installed cost decrease to 500-700 USD/kW (depending on electricity price).

3. Conclusions

This high quality brochure presents twelve Best practice examples selected from the activity C3 “IEA Quality Engineered Solar Air-conditioning Design Examples: A companion to the IEA Solar Cooling Handbook” and from further projects of the Task 48 participants.

The aim of this brochure is to present the todays main applications for solar cooling including different countries/continents, climates, sorption chiller technologies (closed systems: absorption and adsorption chillers; open systems: DEC systems) and solar thermal collector technologies (air, flat plate, vacuum tube, parabolic trough and Fresnel collectors). Moreover, the main focus of this Best practice brochure is to constitute a media support to disseminate on the success stories available on solar cooling through several fundamental criteria: reliability, efficiency/performance, cost competitiveness.

The selected solar cooling projects presented in this brochure represent finally different applications like office buildings (6), school/institute buildings (4), commercial buildings (1) and residential buildings (1). The projects are located in different regions of the world. One of the projects is installed in North America, four in Europe and seven in South-East Asia. The cooling capacity of the installed solar cooling systems divides in an area from 10 kW to 1,750 kW. Here, the cooled floor spaces of these buildings range between 240 m² up to 11,000 m². The best annual electrical COP_{el} are between 6 and 25, which is an average value of about 12.9. The determined specific installed system costs are 7,300 EUR/kW for small-scale systems and in average 1,900 EUR/kW for large-scale systems (Figure 31).

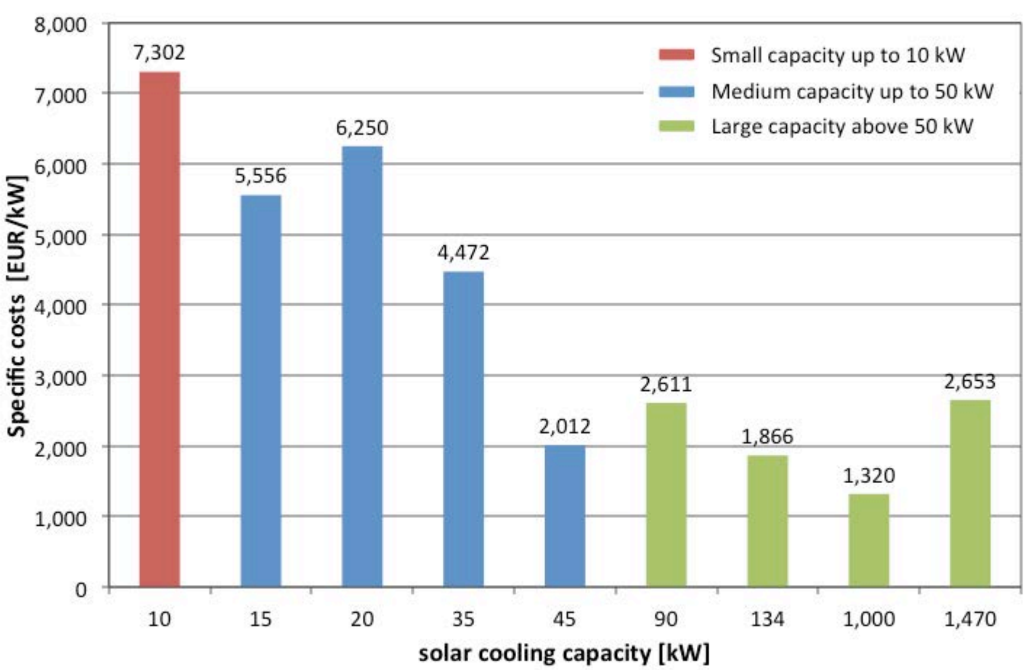

Figure 31: Specific costs of installed best practice solar cooling systems (Source: Green Chiller)

4. Bibliography

CHP	Combined heat and power
COP	Coefficient of performance
CSIRO	Commonwealth Scientific and industrial organisation
DEC	Desiccant and evaporative cooling
DHW	Domestic hot water
DNI	Direct normal irradiation
el	electrical
H_2O	Water
JSI	Jozef Stefan Institute
LiBr	Lithium bromide
NH_3	Ammonia
ROI	Return of investment
SJTU	Shanghai Jiao Tong University
SOLID	Gesellschaft für Solarinstallation und Design
th	thermal
UIBK	University of Innsbruck
UWC	United World College
ZAE	Bayerisches Zentrum für Angewandte Energieforschung

5. Acknowledgements

This work had been partly funded by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety of Germany under grant number 0325982A.

6. Appendix

Template prepared for the collection of technical data for the Best practice examples.

Version 1.0

M-D2.1: Template for best practice installations

1. Project location

Country		Latitude		
Town		Longitude		
Region		Altitude		m

2. Building

Category:		**Heat demand for:**		
Residential		1. Space cooling		kWh
Public		2. Space heating		kWh
Commercial		3. Hot water		kWh
Office		4. Swimming pool		kWh
Hotel		5. Other:		kWh
Sanitary, hospital				
Other:				

Typical cooling period

jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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

Cooled floor area		m2
Total cooled volume		m3
Average number of floors		-
Peak cooling load		kW
no. of hours with cooling demand		h
Peak heating load		kW
no. of hours with heating demand		h
Peak DHW load		kW
no. of hours with DHW demand		h

Subtask D – Activity D2 Page 1/4

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Task 48

Version 1.0

M-D2.1: Template for best practice installations

1. Project location

Country		Latitude		
Town		Longitude		
Region		Altitude		m

2. Building

Category:		**Heat demand for:**		
Residential		1. Space cooling		kWh
Public		2. Space heating		kWh
Commercial		3. Hot water		kWh
Office		4. Swimming pool		kWh
Hotel		5. Other:		kWh
Sanitary, hospital				
Other:				

Typical cooling period

jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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

Cooled floor area		m2
Total cooled volume		m3
Average number of floors		-
Peak cooling load		kW
no. of hours with cooling demand		h
Peak heating load		kW
no. of hours with heating demand		h
Peak DHW load		kW
no. of hours with DHW demand		h

Subtask D – Activity D2   Page 1/4

Version 1.0

M-D2.1: Template for best practice installations

1. Project location

Country		Latitude		
Town		Longitude		
Region		Altitude		m

2. Building

Category:		**Heat demand for:**		
Residential		1. Space cooling		kWh
Public		2. Space heating		kWh
Commercial		3. Hot water		kWh
Office		4. Swimming pool		kWh
Hotel		5. Other:		kWh
Sanitary, hospital				
Other:				

Typical cooling period

jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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

Cooled floor area		m2
Total cooled volume		m3
Average number of floors		-
Peak cooling load		kW
no. of hours with cooling demand		h
Peak heating load		kW
no. of hours with heating demand		h
Peak DHW load		kW
no. of hours with DHW demand		h

Subtask D – Activity D2 Page 1/4

Version 1.0

M-D2.1: Template for best practice installations

1. Project location

Country		Latitude		
Town		Longitude		
Region		Altitude		m

2. Building

Category:		**Heat demand for:**		
Residential		1. Space cooling		kWh
Public		2. Space heating		kWh
Commercial		3. Hot water		kWh
Office		4. Swimming pool		kWh
Hotel		5. Other:		kWh
Sanitary, hospital				
Other:				

Typical cooling period

jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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

Cooled floor area		m2
Total cooled volume		m3
Average number of floors		-
Peak cooling load		kW
no. of hours with cooling demand		h
Peak heating load		kW
no. of hours with heating demand		h
Peak DHW load		kW
no. of hours with DHW demand		h

Subtask D – Activity D2 Page 1/4