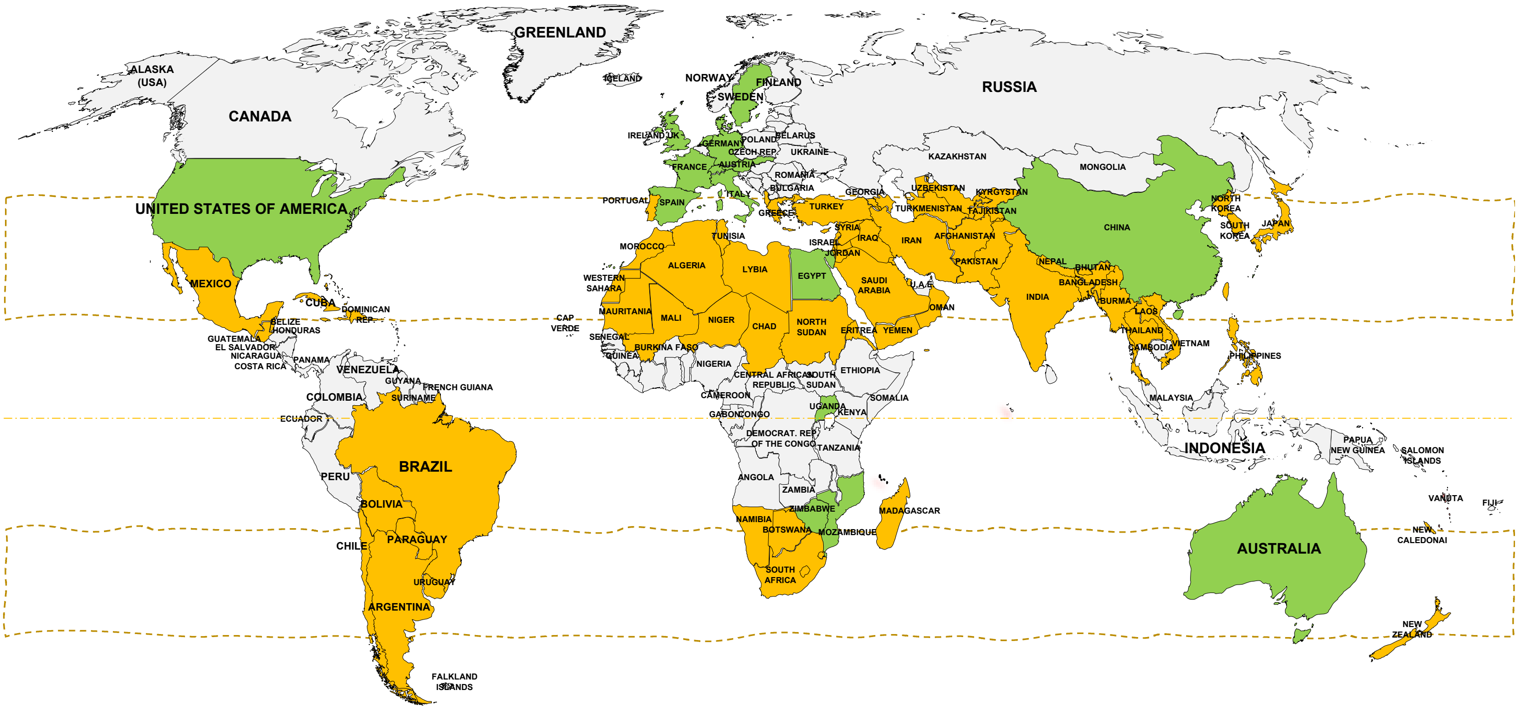
Standardized Solar Cooling Kits



IEA SHC TASK 65 | SOLAR COOLING FOR THE SUNBELT REGIONS

Technology Collaboration Programme

by iea

Standardized Solar Cooling Kits

This is a report from SHC Task 65: Solar Cooling for the Sunbelt Regions and work performed in Subtask B: Demonstration

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Cover photo credit: World map with Sunbelt regions (marked yellow) and the 18 countries of the participating Task 65 experts (marked green), source: Neyer Brainworks & JER

Solar Heating & Cooling Technology Collaboration Programme (IEA SHC)

The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives (*"*Implementing Agreements*"*) of the International Energy Agency.

Our mission is *"Through multi-disciplinary international collaborative research and knowledge exchange, as well as market and policy recommendations, the IEA SHC will work to increase the deployment rate of solar heating and cooling systems by breaking down the technical and non-technical barriers."*

IEA SHC members carry out cooperative research, development, demonstrations, and exchanges of information through Tasks (projects) on solar heating and cooling components and systems and their application to advance the deployment and research and development activities in the field of solar heating and cooling.

Our focus areas, with the associated Tasks in parenthesis, include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54, 69)
- Solar Cooling (Tasks 25, 38, 48, 53, 65)
- Solar Heat for Industrial and Agricultural Processes (Tasks 29, 33, 49, 62, 64, 72)
- Solar District Heating (Tasks 7, 45, 55, 68)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56, 59, 63, 66)
- Solar Thermal & PV (Tasks 16, 35, 60)
- Daylighting/Lighting (Tasks 21, 31, 50, 61, 70)
- 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, 57)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46, 71)
- Storage of Solar Heat (Tasks 7, 32, 42, 58, 67)

In addition to our Task work, other activities of the IEA SHC include our:

- SHC Solar Academy
- *Solar Heat Worldwide*, annual statistics report
- SHC International Conference

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Australia	European Commission	SACREEE
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Contents

1 Executive Summary

This document is the final report of activities B4, “Standardized solar cooling kits” of the IEA SHC Task 65, “Solar Cooling for the Sunbelt Regions. The report presents experiences from 11 component and/or system suppliers of solar cooling kits, which adapted/investigated their products/concepts for Sunbelt region conditions. Moreover, several findings on system adaptations for Sunbelt regions are collected and analyzed from manufacturers, equipment providers, solar system providers and researchers. The essential findings/results of the report are:

- Eight different products/concepts adapted to the constraints of the Sunbelt regions are presented, including information on Sunbelt specific adaptations or experiences.
- Use of medium-temperature solar systems to operate two-stage absorption chillers to increase competitiveness.
- Cleaning collector systems when dust contamination happens can reduce typical performance by 20% per month. Therefore, it is recommended to clean the system every 14 days, which will then result in an average performance loss of only 5%.
- Lack of knowledge of design guidelines including the effects of part load conditions and techno-economic boundary conditions.
- Heat rejection systems in dry climates present significant challenges.

2 Scope of Activity B4

The scope of activity B4 encompasses several key elements aimed at advancing the adoption and efficacy of solar cooling systems for the Sunbelt regions. Guided by previously defined standards of minimum quality of technical and economic performance, best practice solar cooling systems have been searched and documented, enriched with pertinent insights to facilitate adaptation to specific needs across diverse climatic conditions.

Efforts to standardize processes and solar cooling kits across diverse capacity ranges and technological variations are essential for optimizing operations, promoting interoperability, and fostering widespread adoption. The data gathered through these efforts can be utilized to propel standardization initiatives, streamlining processes, harmonizing solar cooling kits, and facilitating widespread adoption of solar cooling as a viable and accessible solution across various contexts and applications. Leveraging pre-assembled, pre-designed component groups and standardized configurations further enhances this endeavour by reducing investment and installation costs associated with solar cooling systems, optimizing resource allocations, and increasing scalability.

3 Introduction

The preceding IEA SHC Task 48 (task48.iea-shc.org) introduced a comprehensive brochure showcasing twelve exemplary applications, highlighting the versatility and efficacy of solar cooling technologies. This brochure, a testament to the progress made in the field, not only delineated the diverse applications of solar cooling across different regions and climates but also underscored the pivotal role of chiller and solar thermal collector technologies in driving this advancement.

The brochure (Jakob, 2015) highlighted different sorption chiller technologies, including closed systems, absorption and adsorption chillers, open systems, and desiccant and evaporative cooling (DEC) systems. It also covered various solar thermal collector technologies, such as air, flat plate, vacuum tube, parabolic trough, and Fresnel collectors. Additionally, it emphasized the importance of reliability, efficiency, and cost competitiveness as fundamental criteria for success in solar cooling implementations.

IEA SHC Task 48 / task48.iea-shc.org

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:

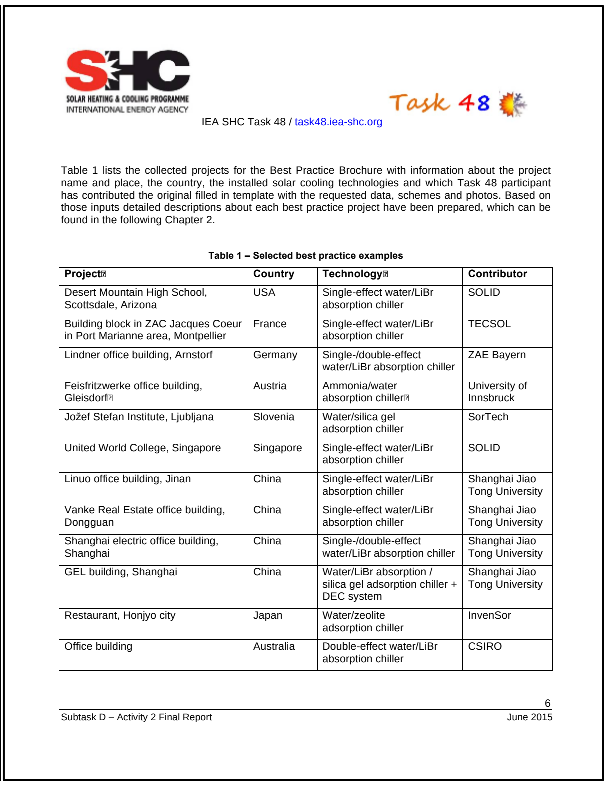
- 6 office buildings,
- 4 school/institute buildings,
- one commercial buildings and
- one residential building block.

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)

5

Subtask D – Activity 2 Final Report June 2015



IEA SHC Task 48 / task48.iea-shc.org

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

6

Subtask D – Activity 2 Final Report June 2015

Furthermore, the Solar Cooling Handbook referenced in chapter 10.3 Experiences (Jähnig et.al, 2013, p. 281 ff) an end-user survey aimed at evaluating the quality of existing installations of small-scale solar cooling plants and acquiring valuable insights into system configurations, planning, installation, commissioning, operation, and maintenance practices. Installation durations varied due to coordination difficulties and component delivery delays, but pre-assembled systems helped mitigate these challenges. Commissioning, crucial for optimal system performance, was often of low quality or neglected entirely, leading to operational inefficiencies. Maintenance strategies emphasized simplicity to ensure long-term functionality and minimize end-user workload, with automatic cleaning recommended for cooling towers. Centralized system controllers were deemed essential for efficient operation and communication between components, with remote monitoring capabilities offering benefits for both end-users and system suppliers.

The survey provides recommendations for system suppliers based on ten monitored small-scale solar heating and cooling systems. The study emphasized the importance of careful system design and component selection to optimize energy performance and ensure significant energy savings. Critical issues such as electricity consumption of auxiliary components, heat rejection components, part-load operation, system pressure drop, nominal flow rates, use of cold storage, and heat rejection temperature were discussed to guide system design and ensure significant energy savings. The report underscored the importance of adapting the heat rejection system to local climatic conditions and constraints to optimize the performance of solar cooling systems.

4 Utilizing Solar Technologies for Cooling

The sun serves as the primary energy source for solar cooling in Sunbelt regions. The data collection reveals the deployment of various solar technologies to harness this energy for use in cooling systems. Among the technologies involved are solar thermal collectors, including flat plate (FP), evacuated tube (ETC), parabolic trough (PTC), and Fresnel collectors, all of which capture the sun's energy (Figure 1). Additionally, photovoltaic (PV) technology is employed to directly convert sunlight into electricity as well as Photovoltaic Thermal (PVT) collectors, which are hybrid solar energy systems combining photovoltaic and solar thermal technologies into a single device. These technologies play a crucial role in harnessing solar energy for cooling purposes in Sunbelt regions.

A wide range of solar collectors is available for use in solar cooling and air-conditioning systems. The choice of the appropriate collector type depends on several factors, including the selected cooling technology, radiation availability, and other site-specific conditions. It is crucial to select a collector type that matches the specific requirements of the cooling system and the environmental characteristics of the site.

Figure 1: Flat plate, evacuated tube, parabolic trough and Fresnel collectors (from left to right below), Sources: JER.

5 Solar Cooling Systems for Sunbelt Regions: Types, Technologies, and Standardization

Solar cooling systems can be categorized into two main types: electricity-driven and heat-driven. Electricity-driven systems use photovoltaic panels to directly convert sunlight into electricity, powering conventional vapour-compression-based cooling systems. On the other hand, heat-driven systems utilize solar thermal collectors to capture sunlight and convert it into heat energy. This heat energy is then used to drive absorption chillers, adsorption chillers, or desiccant-evaporative systems.

Designing off-the-shelf solar cooling kits for Sunbelt regions presents a multifaceted challenge due to the diverse technologies, climatic conditions, applications, and specific site requirements involved. To address this challenge effectively, it is necessary to combine various technologies to meet the specific demands of system design and installation in these regions. Extensive research has been conducted to identify best practices and gathered data on solar cooling systems have been documented and summarized to facilitate the development of standardized solutions for the Sunbelt regions.

5.1 Absorption Cooling

Absorption chillers utilize a continuous cycle process based on two liquids: a refrigerant and a carrier fluid. The refrigerant is periodically absorbed and desorbed in/from the carrier fluid, providing cold through the simultaneous evaporation and absorption of the refrigerant. Heat is required to desorb the refrigerant from the carrier fluid. Cold is provided in the form of chilled water (Kohlenbach and Jakob, 2014).

5.1.1 chillii® Cooling Kits

SolarNext AG specializes in developing and commercializing standardized "solar cooling kits" and custom-made solar and thermal cooling systems for private, commercial, and industrial applications. Their product portfolio includes absorption machines with cooling capacities ranging from 10 kW to 10 MW, along with a system controller designed for simple or complex thermodynamic systems. SolarNext has implemented numerous solar cooling systems worldwide. Their absorption cooling kits feature optimally harmonized system components, offering ready-to-install solutions for various applications. These kits eliminate the need for customers to undertake layout and dimensioning, and they are available for steam-fired, hot water-fired, and direct-fired applications.

The solar thermal cooling project referenced here was installed at a German Army Camp in Mali in 2022 to provide air-conditioning for a new cafeteria and kitchen spanning 3,500 square meters. The project utilized a chillii® Cooling Kit HLC350adb, featuring a chillii® HLC350 lithium bromide absorption chiller with a cooling capacity of 348 kW (Figure 2). The system included an adiabatic re-cooling unit with performance control. Thermal energy was provided by 700 square meters of evacuated tube collectors with a capacity of 450 kW. Additionally, the system incorporated two hot water buffers, each with a volume of 10,000 liters, to ensure efficient operation.

The design was based on the following specifications (Table 1):

Table 1: Summary table of received information for chillii® Cooling Kit (Source: SolarNext)

CHILLII® COOLING KIT HLC350ADB	TECHNICAL	DATA
DESIGN SPECIFICATIONS	Cooling load	348 kW
	COP th	0.78
	Working pair	Water/lithium bromide
HOT WATER LOOP	Supply temperature	95 °C
	Return temperature	80 °C
HEAT REJECTION LOOP	Supply temperature	32 °C
	Return temperature	38 °C
COLD WATER LOOP	Supply temperature	16 °C
	Return temperature	10 °C
RE-COOLER	Ambient temperature	45 °C
	Wet bulb temperature	28 °C

Figure 2: Lithium bromide absorption chiller with closed circuit cooler and vacuum tube solar collector field (from left to right), Sources: SolarNext.

Sunbelt specific adaptations:

The adaptation of the cooling kit for the location of Mali primarily focused on the condenser. A condenser was specifically designed to operate at temperatures between 32°C and 38°C to avoid issues related to the high wet bulb temperature in Mali. The absorption chiller was consequently designed for the condenser circuit.

Additionally, an adiabatic coil circuit cooling tower (closed system) was employed to address the special environmental conditions caused by the fine sand and sandstorms prevalent in Mali. The use of adiabatic coolers with pads was not feasible due to the sharp-edged sand, which would quickly damage the pads or cause premature clogging. Furthermore, an open system was ruled out due to the fine sand, as even with system separation, the condenser circuit would face constant clogging, significantly reducing its performance and consequently, the cooling capacity of the absorption chiller.

5.1.2 SunBeltChiller

ZAE Bayern is a non-university research institute that conducts energy research between fundamental principles and practical application. Their activities are focused on the reduction of CO_2 emissions through renewable energies and efficiency measures. The SunBeltChiller (SBC) was developed with the research project “Solar thermal energy system for cooling and process heating in the Sunbelt region”, funded by the German Federal Ministry for Economic Affairs and Climate Action (BWMi).

One of the most widely used solar thermal cooling systems are two-stage absorption chillers (Double-Effect) powered by concentrating solar collectors. However, in regions like the Sunbelt, with high ambient temperatures regularly above 30°C, these systems require a wet cooling tower. Often, in these regions, the availability of water is limited; therefore, wet re-cooling systems cannot be used for regulatory or economic reasons. The SBC is a modified Double-Effect (DE) absorption chiller.

The SBC is powered by concentrating solar collectors at temperatures higher than 160° C (Figure 3). In the first step, the solar collectors drive a special absorption chiller called Double Lift (DL) machine which can be re-cooled at very high temperatures (approx. 90° C). In the second step, the waste heat from the DL machine drives a "classic" single effect (SE) absorption chiller (Figure 4), which is re-cooled against the ambience. The overall efficiency of these two steps is equivalent to a Double Effect (DE) absorption chiller with a COP of 1.35.

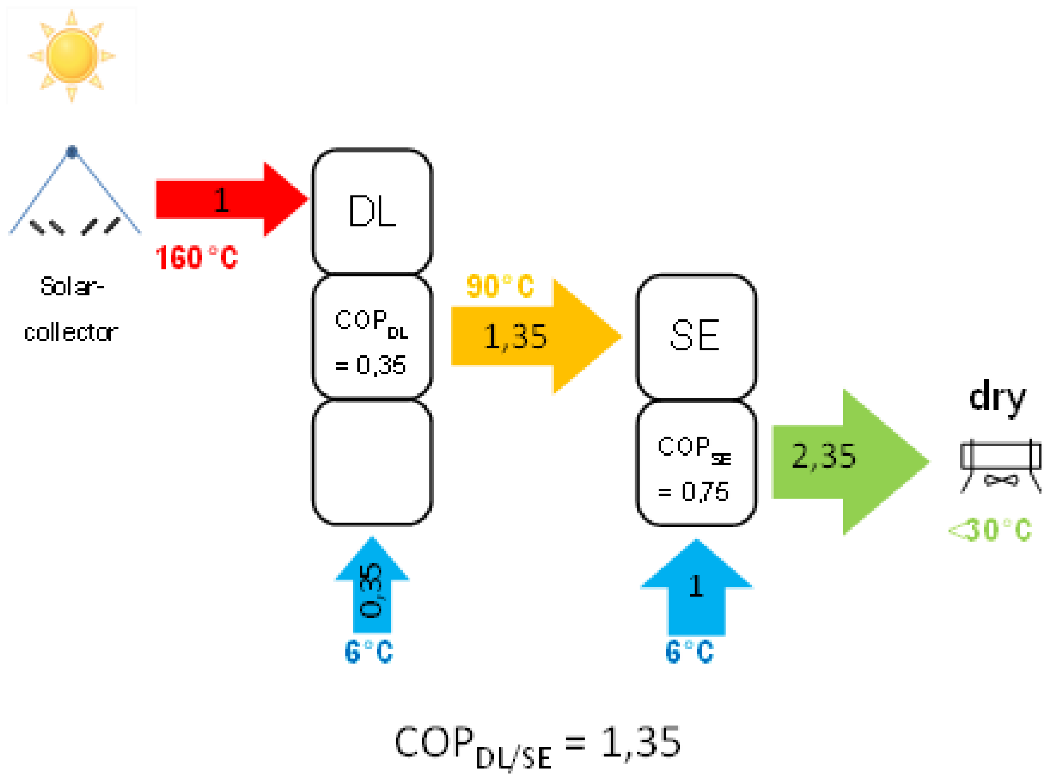


Figure 3: SunBeltChiller combination of double-lift and single-effect chiller, Source: ZAE Bayern.

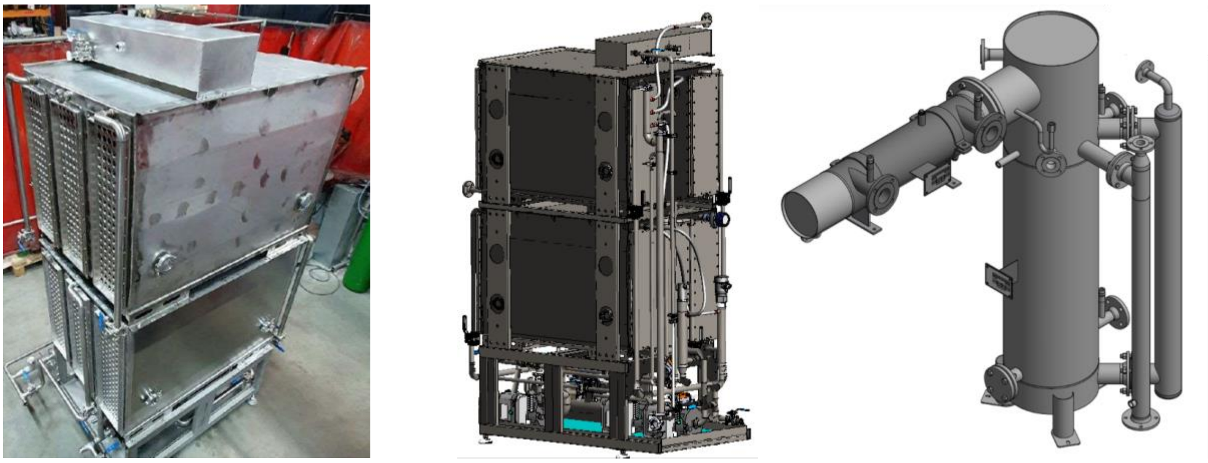


Figure 4: SunBeltChiller demonstrator in lab-scale (SE and HT stage DL, from left to the right), Sources: ZAE Bayern.

Sunbelt specific adaptation:

Thanks to the two-stage generation of cold and by using heat and cold storages, the operation of the Single Effect can be shifted to the night hours and thus to periods with lower outside temperatures (Figure 5). This eliminates the need for a wet cooling tower. In addition, the SunBeltChiller system can provide additional heat at around 90° C.

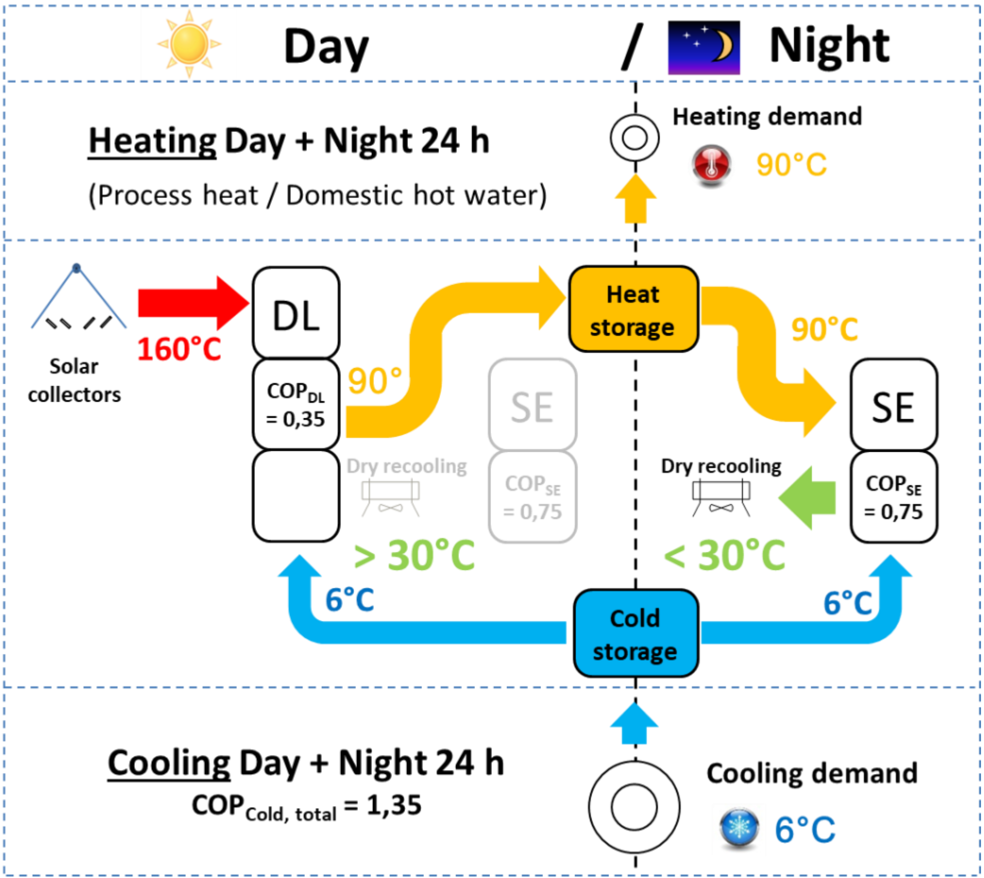


Figure 5: The SunBeltChiller system, Source: ZAE Bayern.

The SunBeltChiller is therefore a solar thermal cooling (and heating) system that, despite high ambient temperatures, does not require a wet cooling tower and promises high efficiency. More information can be found at https://task65.iea-shc.org/Data/Sites/1/publications/IEA-SHC-Task65-DA1--Climatic-Conditions-and-Applications.pdf and https://task65.iea-shc.org/Data/Sites/1/publications/2023-12-Task65-Sunbelt-Chiller.pdf

5.1.3 PURIX Chiller

PURIX ApS is a manufacturer of air-cooled absorption cooling systems, specializing in modular and Plug & Play solar cooling solutions (Figure 6). Their product range is tailored to meet the needs of the high-volume market segment for cooling and air conditioning appliances, ranging from 2.5 kW to 25 kW (Table 2). Most of the cooling systems sold by the company are powered by solar thermal systems, either utilizing existing installations or dedicated setups. While some systems are configured to work with a backup heat supply, such as district heating or boilers, others incorporate a thermal energy storage system, PURIX TES-X.

Table 2: Summary table of received information for PURIX chiller A25s (Source: PURIX)

A25S	TECHNICAL	DATA
DESIGN SPECIFICATIONS	Cooling load	2.5 kW
	Cascade up to 10 units	25 kW
	COP th	0.8
	COP el	16
	Working pair	Water/lithium bromide
HOT WATER LOOP	Supply temperature	70-90 °C
HEAT REJECTION LOOP	Supply temperature	20-40 °C
COLD WATER LOOP	Supply temperature	18 °C
	Return temperature	13 °C

Figure 6: PURIX 5 kW solar cooling system for a cold storage room installed in Kigali, Rwanda, Source: PURIX.

Applying conventional single-stage absorption cooling technology with R718 as a non-flammable and natural refrigerant, the company's sustainable and modular cooling systems address two essential challenges related to cooling: decoupling electricity consumption from cooling generation and phasing out F-gas-based refrigerants. The PURIX TES-X is typically charged during daylight hours, and cooling is discharged during the night. By employing bulk phase change materials (PCM) in combination with patented direct contact technology, the system achieves a high energy density of thermal energy storage while maintaining competitive costs through the elimination of PCM encapsulation.

Sunbelt specific approach:

With a global market reach for low-capacity cooling and air conditioning systems and a sourcing strategy focused on local sourcing, the technology is widely applicable for sunny regions worldwide.

5.2 Adsorption Cooling

Adsorption chillers use a quasi-continuous process based on a solid and a liquid. The liquid serves as the refrigerant, while the solid acts as the carrier medium. The refrigerant is adsorbed in the solid, providing cold through evaporation. Once the solid is saturated with refrigerant, the process is reversed, and the refrigerant is desorbed from the solid. Heat is required for desorption. The adsorption process is not continuous but alternates between adsorption and desorption. Cold is provided in the form of chilled water (Kohlenbach and Jakob, 2014).

5.2.1 SolabChiller

ARES B.V. specializes in the development and commercialization of solar cooling systems. The company offers two cooling kits under the SolabCool brand, which are commercially available. In addition to these kits, SolabCool supplies dry-coolers, thermostats, glycol units, humidity sensors, and other relevant equipment for solar cooling systems.

The SolabChiller is an air/water solid material heat pump (Table 3). This device can be placed outside. The dry-cooler is integrated into the design (Figure 7). The heat pump has 4 hydraulic interfaces (2 hot water supply and return pipes, and 2 cold water supply and return pipes). It operates with a thermostat suitable for cooling.

Table 3: Summary table of received information for SolabChiller (Source: ARES)

SOLABCHILLER	TECHNICAL	DATA
DESIGN SPECIFICATIONS	Cooling load	5 kW
	COP th	0.6
	COP el	12
	Working pair	Water/silica-gel
HOT WATER LOOP	Supply temperature	65-90 °C
HEAT REJECTION LOOP	-	Directly air cooled
COLD WATER LOOP	Supply temperature	15-30 °C

Figure 7: SolabChiller, Source: ARES.

SolabPump is a water/water solid material heat pump (Table 4). This device can be placed inside (Figure 8). The heat pump has 6 hydraulic connections. (2 hot water supply and return pipes, and 2 cold water supply and return pipes and 2 pipes for the heat rejection supply and return). The SolabPump is also available as a cascade system. Up to 4 pumps can be connected.

Table 4: Summary table of received information for SolabPump (Source: ARES)

SOLABPUMP	TECHNICAL	DATA
DESIGN SPECIFICATIONS	Cooling load	5 kW
	Cascade up to 4 units	20 kW
	COP th	0.6
	COP el	12
	Working pair	Water/silica-gel
HOT WATER LOOP	Supply temperature	65-90 °C
HEAT REJECTION LOOP	Supply temperature	25-40 °C
COLD WATER LOOP	Supply temperature	15-30 °C

Figure 8: SolabPump, Source: ARES.

Sunbelt specific collaboration:

ARES is collaborating with a university in the Sunbelt region to evaluate the performance of it's cooling kits, as the commercially available ones are not suitable for these regions.

5.2.2 eCoo and Zeo Chiller

Fahrenheit GmbH cooling product solutions are developed to meet a wide range of requirements. The company's adsorption chiller, a component of solar cooling systems, operates on the principle of adsorption. It utilizes materials such as silicates (Table 5) or zeolites as the adsorbent and water as the refrigerant. This eliminates the need for traditional refrigerants and electricity to power moving parts like compressors. Their product portfolio includes adsorption machines with cooling capacities ranging from 5 kW to 100 kW, which can also be cascaded.

During the adsorption phase, the adsorbent material absorbs water vapor under vacuum conditions, causing more water to evaporate and generating cooling from 8°C to 20°C. In the desorption phase, the material, coated on heat exchangers, is regenerated by available waste or solar heat, preparing it for a new cycle. By combining a minimum of two modules, a constant cooling load can be provided.

Solar thermal energy can serve as the primary driving force for the system by supplying the necessary heat, making it an eco-friendly and efficient cooling solution (Figure 9). Especially suitable for sunny regions or applications where independence from the grid is desired, solar cooling with adsorption technology helps reduce CO_2 emissions and provides a sustainable alternative to conventional methods. Additional components of the solar cooling system include storage units to regulate the heat flow in and the cooling flow out of the device, as well as a re-cooling system to remove the resulting low-grade heat.

Table 5: Summary table of received information for eCoo 20 (Source: Fahrenheit)

ECOO 20	TECHNICAL	DATA
DESIGN SPECIFICATIONS	Cooling load	20 kW
	COP th	0.65
	COP el	38
	Working pair	Water/silica-gel
HOT WATER LOOP	Supply temperature	50-95 °C
HEAT REJECTION LOOP	Supply temperature	22-40 °C
COLD WATER LOOP	Supply temperature	8-21 °C

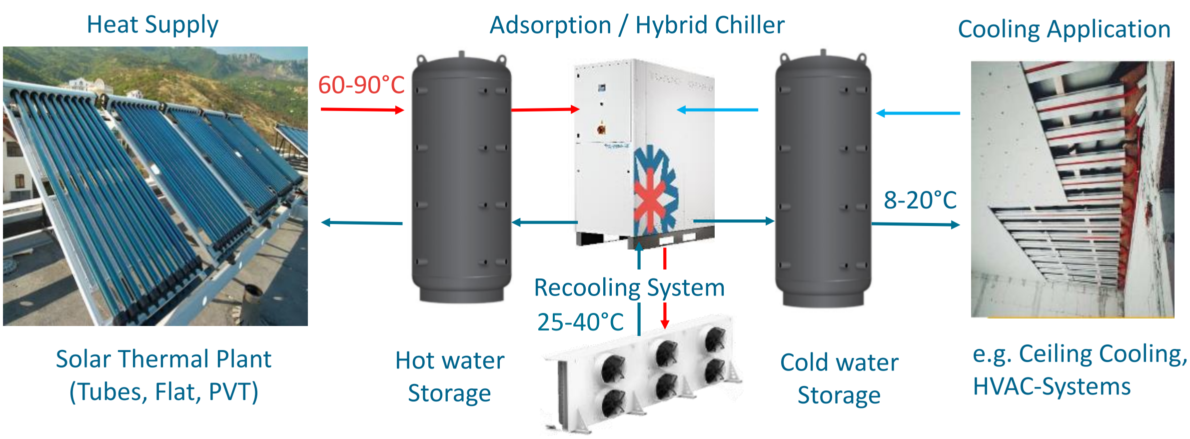


Figure 9: Typical solar cooling set-up. The system can be run by solar heat up from 60 °C to 90°C and produce cold water with temperatures from 8 °C to 20°C depending on the conditions, Source: Fahrenheit.

Sunbelt specific experiences and insights:

Over the last 10 years, several adsorption cooling manufacturers have installed various Solar Cooling Systems in Sunbelt regions worldwide. In Southern Europe, machines have been delivered for different projects such as cooling public buildings, small production sites, and machine cooling. These systems utilize flat solar thermal collectors, vacuum tube collectors, and PVT. To accommodate the special conditions of hot ambient temperatures, Fahrenheit tailored some of its adsorption modules, coated with Zeolite, as they can operate effectively with higher re-cooling temperatures (Figure 10).

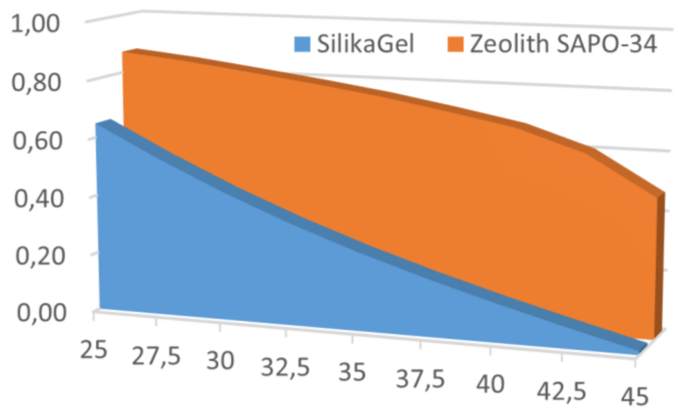


Figure 10: Comparison of Adsorption-potential (kg/kg) of silicate and zeolite in dependency of heat rejection temperatures (x-ordinate), Source: Fahrenheit.

The Sunbelt region offers abundant solar energy, providing a stable and robust heat source for cooling systems. However, the high ambient temperatures in these regions affect the re-cooling potential and reduce the cooling load. A comparison of dry and adiabatic re-cooling systems on the same system illustrates that the adiabatic system is capable of meeting the required cooling load despite the high ambient temperatures (Figure 11).

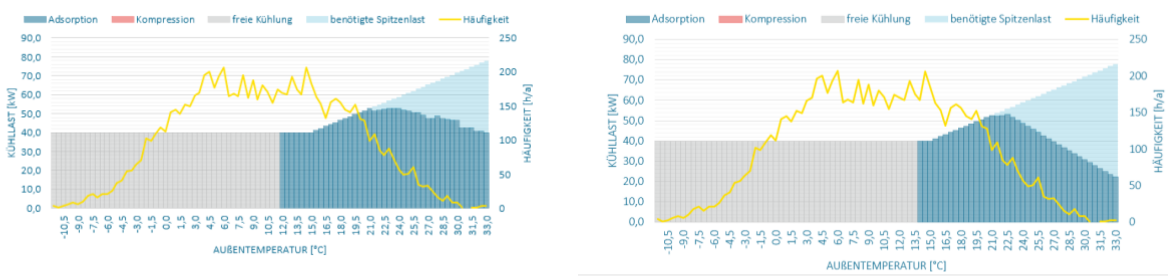


Figure 11: Comparison of dry and adiabatic re-cooling systems, Source: Fahrenheit.

High air humidity also impacts heat rejection, often requiring alternative solutions to balance the necessary cooling load. When cooling tasks cannot be solely managed by adsorption, the use of an additional compression chiller is recommended. The company has integrated this into their hybrid chiller, combining both technologies and controlling them as a single device.

Another challenge posed by high air humidity is the need to consider the dew point when controlling cooling applications. This is especially crucial for surface cooling, such as ceiling elements, where condensation must be carefully managed.

5.3 Desiccant-Evaporative Cooling

Desiccant-evaporative systems (DEC) provide cold as conditioned air by dehumidifying and chilling the air. These systems use either a solid or a liquid to remove humidity from the air, which is then chilled through the evaporation of water. Heat is required to continuously remove the humidity taken out of the air from the liquid or solid (Kohlenbach and Jakob, 2014).

5.3.1 Freescoo

SolarInvent SrL is an SME dedicated to developing the freesoo business idea, which focuses on efficient and affordable air conditioning solutions powered by renewable heat sources. While the “freescoo” technology is currently not commercially available, it is in the final stages of development, with several case studies and prototypes already operational.

Freescoo is an air conditioning concept based on a particular DEC (Desiccant and Evaporative Cooling) technology which permits dehumidification towards adsorption and cooling in one component (Table 6). Its main features include cooled adsorption beds, high-efficiency indirect evaporative cooling, and versatility for ventilation, cooling, IEC, dehumidification, heating, and heat recovery. Operating on heat (T>=60°C) and water, it offers high global electrical efficiency (with a typical EER >10 at nominal load and >20 at partial load) and supports various system configurations. The company provides preassembled and ready-to-install DEC HVAC units for both residential and commercial applications, offering services such as air change, dehumidification, cooling, heating, heat recovery, and indirect evaporative cooling (Figure 12).

Table 6: Summary table of received information for freescoo VMC 3.0 (Source: SolarInvent)

FREESCOO	TECHNICAL	DATA
DESIGN SPECIFICATIONS	Cooling load	3.2 kW
	COP th	0.8
	COP el	>10
	Air flow rate	320 m^3/h
HOT WATER LOOP	Supply temperature	65 °C

Figure 12: freescoo VMC 3.0, Source: SolarInvent.

The freescoo concept achieves energy savings and reduces CO_2 emissions by 70-80% when powered by renewable heat sources, has coupling with multifunctional heat pumps, allowing for better utilization of solar thermal energy and waste heat, operates as an indirect evaporative cooler, enabling free cooling, and also allows for heat recovery. No special precautions are needed during production and maintenance due to environmentally friendly substances/fluids. In combination with solar thermal systems, freescoo can provide heat dissipation.

Sunbelt specific experiences:

The company has installed and monitored several units in hot, humid, or dry climates, experiencing climatic conditions similar to those of the Sunbelt Regions. The technology utilized in the freescoo system allows for easy adaptation to various temperature and humidity conditions. System adaptation involves properly sizing the adsorbent and evaporative components. Through experiments, it has been discovered that in environments with very high temperatures and dry conditions, the evaporative cooling process can achieve exceptional efficiency. However, this may lead to increased water consumption, which could be a significant concern in certain contexts. In applications with hot climates and high humidity, increasing the capacity of the freescoo adsorbent beds and providing higher regeneration temperatures allows the system to handle the increased workload on the latent load, overcoming potential limitations posed by highly humid climates.

5.3.2 CEEE Solar Cooling Concept

CEEE is a leading research institution at the University of Maryland specializing in air-conditioning, refrigeration, and heat pumping. They focus on modelling and optimization tools for energy conversion systems, alongside detailed studies on innovative energy conversion components and systems. With expertise in traditional heat pumping technologies like vapor compression, absorption, and adsorption, combined with their industry-wide software, they bridge the gap between academic research and industry application.

The concept evaluated involved a PVT collector – combining PV electricity and solar heat from the same collector (Figure 13). The electricity generated by the PV system is utilized for sensible cooling through a vapor compression system with high evaporator temperatures, avoiding the need for dehumidification entirely. As a result, the system achieves a COP that is 50% to 100% higher than traditional vapor compression systems that also dehumidifies and cools. The thermal energy captured by the PVT collector is used to regenerate a desiccant system, either liquid or solid, providing the necessary dehumidification for the combined system.

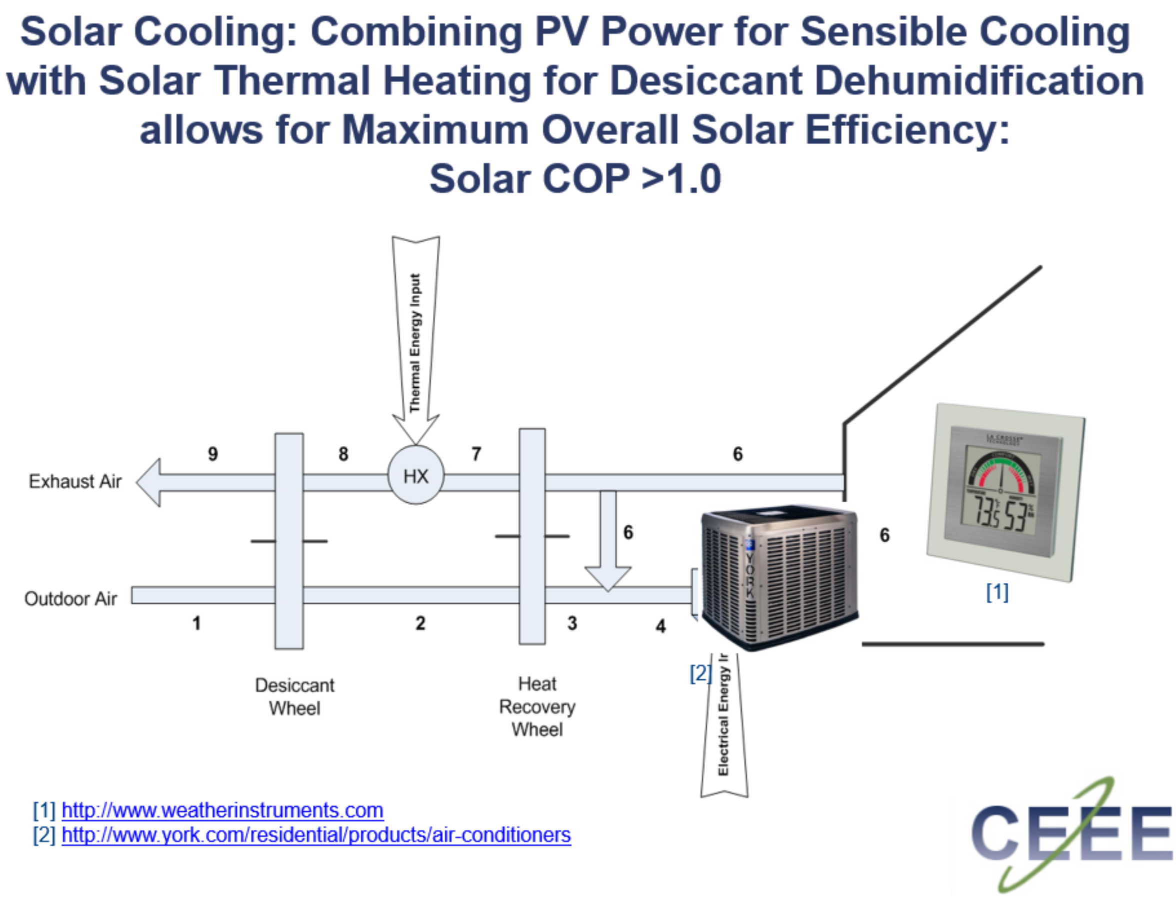


Figure 13: Desiccant and evaporative cooling with PVT collector to regenerate the desiccant system as well as to supply electricity to the vapour compression chiller for sensible cooling, Source: CEEE.

Sunbelt specific expectations:

Modelling results, validated by experimental data from CEEE, indicate that COP values above 1.0 can be expected by such a system under Abu Dhabi conditions.

5.4 Vapour-Compression Cooling

Vapour-compression cooling systems use a compression-based technology cycle to provide cooling. They utilize electricity to power compressors. The basic working principle involves the circulation of a refrigerant through a closed loop, undergoing phase changes to absorb heat from one area and release it in another (Kohlenbach and Jakob, 2014).

5.4.1 PV Cooling with Ice Slurry

The Institut für Luft- und Kältetechnik gGmbH (ILK Dresden) is an independent free research institution with the legal status of a non-profit limited liability company. ILK Dresden conducts industry-related research, development, and technology transfer in the fields of air handling and refrigeration technology and their applications including related scientific and technical fields.

A research study introduces a novel cooling concept that utilizes a PV-powered system with slurry storage to increase PV self-consumption for cooling supply (Figure 14). The system was implemented to cool a logistics hall of a wild fruit processing company. Here, the concept, implementation, and initial experiences of this innovative approach to cooling is presented.

Figure 14: Photos from installation site, Source: ILK Dresden.

The cooling design was developed for a cold storage facility measuring 24 x 36 x 8 m, divided into three temperature zones (-18°C, 4°C, and 11°C) to accommodate various chilled goods (Figure 15). To maximize self-sufficiency and reduce grid consumption, a PV system (approximately 100 kW) was installed on the roof, along with an ice slurry storage system and an additional battery to power pumps and fans at night.

The system comprises three propane chillers, four scrape type ice slurry generators, and a low-temperature cooling system using carbon dioxide. A dry cooler equipped with humidification mats is utilized to reduce water temperature during summer and to provide heat in winter for the 11°C area (if the waste heat generated by refrigeration for the -18°C and 4°C areas is insufficient for heating).

The refrigeration system operates with a forecast-based control system, and all components used are readily available on the market. The complexity lies mainly in the regulation and control system, particularly managing the different operating modes in summer and winter, including heating and cooling, as well as sensitive cooling loads for the 11°C area.

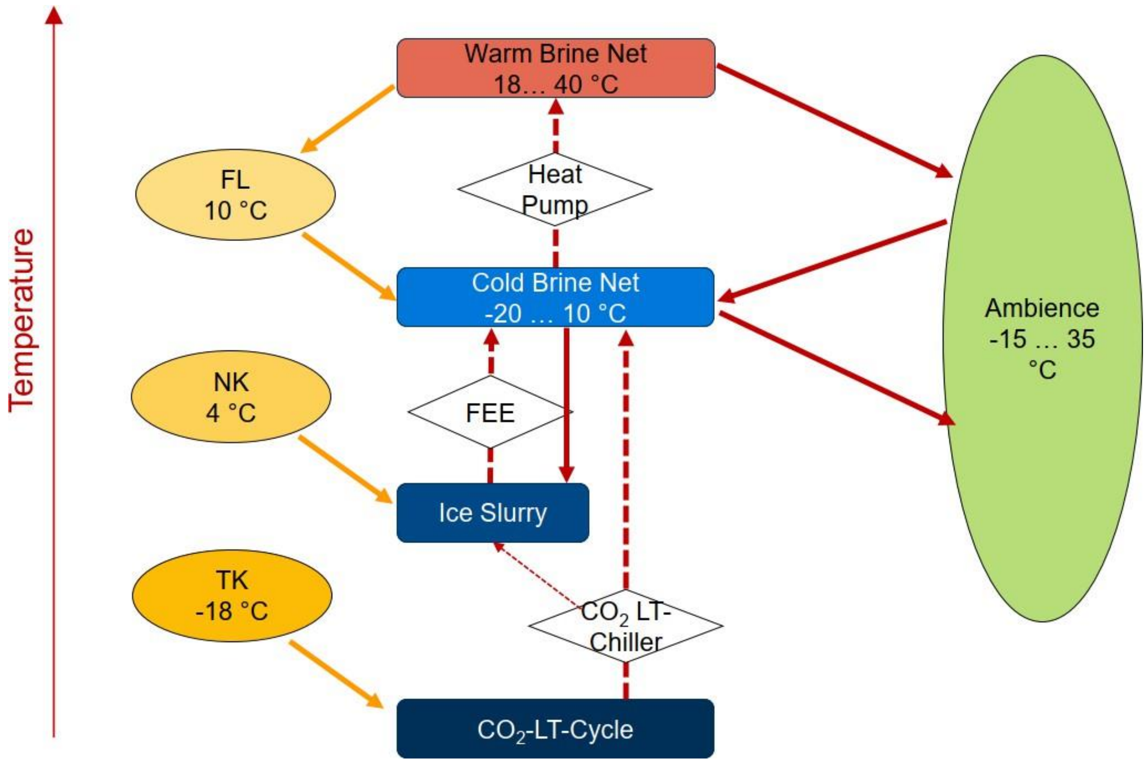


Figure 15: Schematic representation of heat flows, Source: ILK Dresden.

Sunbelt specific potentials:

Installing this system in the Sunbelt regions would simplify the complex control system due to more constant temperatures, consistent solar irradiation throughout the year, and roughly equal day lengths. Additionally, heating requirements for the 11°C area would be eliminated. However, challenges may arise regarding the availability and maintainability of the slurry ice maker components. Nonetheless, the opportunities and potential are significant:

The system provides additional backup for cooling supply, even in the event of insufficient grid stability. There are greater synergies between energy supply and demand compared to sites in Germany.

Favourable electricity tariffs could allow a large portion of refrigeration to be generated during periods of low ambient temperatures (such as at night) and stored in the ice storage system. This reduces grid load and increases cooling generation efficiency.

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6 Findings on System Adaptations for Sunbelt Regions

Many contributors, including manufacturers, equipment providers, solar system providers, and researchers, shared their valuable experiences and insights regarding the adaptation of cooling kits to Sunbelt regions. By analysing various combinations of available technologies on the market, further insights into solar cooling systems were gained.

- For countries in the Sunbelt regions, where **high Direct Normal Irradiation (DNI) values are prevalent, medium-temperature solar systems** (concentrating solar installation using Fresnel approach) with temperatures ranging from 160-180ºC are **more competitive when combined with higher COP two-stage absorption chillers** compared to standard low-temperature solar systems using flat plate or ETC technology with single-stage chillers.

- Pertaining to **PTC systems, dust contamination** can reduce performance by approximately 1% per day in summer (worst case), leading to a typical performance loss of 20% per month. The objective is to **clean the system every 14 days, resulting in an average performance loss of 5%** within that timeframe. Cleaning methods include high-pressure cleaners or manual cleaning the mirror surface with a window squeegee to dry it (which makes about a 3% difference in performance, but also takes twice as long). However, it is more efficient to clean the system more frequently with a high-pressure cleaner in order to achieve a higher average performance. Each cleaning with a high-pressure cleaner takes about 2 hours and requires approximately 500 litres of water for a system with 288 m² gross collector area.

- The **cleaning frequency of CPC systems is relatively low**, yet data suggests that this has a minor impact on performance. Roof installations are partially cleaned by rain during the winter season. However, in instances of heavy soiling, manual cleaning with a water hose is recommended, resulting in up to a 30% difference in performance between clean and heavy soiled systems.

- Unclear techno-economic boundary conditions for solar cooling systems and **lack of knowledge** on competition with other solar cooling options.

- **Lack of clear design guidelines** for system sizing due to a variety of system configurations.

- **Challenges in solar system design**, especially with pressurization systems and integration with absorption chillers.

- Due to **low temperature differences (ΔT) in the absorption chiller**, high flow rates are required in the solar fields, **leading to larger pipe sizes to avoid pressure drops**.

- **Limited knowledge on the effect of part load conditions on absorption chillers** and the optimal operational points.

- **Heat rejection systems in dry climates** pose significant challenges.

- **More research** is needed **on control strategies** for the operation of solar cooling systems.

7 Bibliography

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