Solar Cooling for the Sunbelt Regions – Results from Task 65 activities

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Abstract

The energy demand for air-conditioning is growing faster than any other energy consumption in buildings. The main share of the projected growth for space cooling comes from emerging economies and will more than triple by 2050 to 6,000 TWh/a globally (IEA, 2018). Therefore, the IEA SHC Task 65 "Solar Cooling for the Sunbelt Regions", started in July 2020, is focusing on innovations for affordable, safe and reliable Solar Cooling systems for the Sunbelt regions. The innovation is the adaptation of existing concepts/technologies to the Sunbelt regions using solar energy, either solar thermal or solar PV. The importance of the topic is reflected in the high number of experts participating in IEA SHC Task 65, especially as 50% of the Task experts come from industry and SMEs. This paper presents the Task 65 results of the different activities carried out in last 3 years and highlights the ongoing research projects.

Keywords: Solar thermal cooling, PV cooling, Sunbelt regions, IEA SHC Task 65

1. Introduction

Global energy demand is growing, although its growth rate is less than in the past. Nevertheless, by 2040 an increase of 30% is projected by OECD (2017). Nowadays air-conditioning accounts for nearly 20% of the total electricity demand in buildings worldwide and is growing faster than any other consumption in buildings (IEA, 2018). The undisputed rationales for the increase are global economic and population growth and thus rising standards of living. Growth in the demand of cooling is especially driven by countries with high temperatures. Three emerging countries (India, China, Indonesia) contribute to more than half of the annual growth rates. Additionally, the efficiency of the air-conditioners varies considerably. The most common systems run at half of the available efficiency. If measures are not taken to counteract this increase, the space cooling demand could triple by 2050.

Nowadays e.g. in India, 30% of total energy consumption in buildings is used for space cooling which reaches 60% of the summer peak load. This is already stretching the capacity of the Indian national electricity supply dramatically (Patwardhan et al., 2012). In other countries peak load through air conditioning reaches >70% in hot days (IEA, 2018). Moreover, in the countries of the Association of Southeast Asian Nations (ASEAN) the electricity consumption increased 7.5 times from 1990 to 2017 (IEA, 2019). With the increase in demand comes the increase in the cost of electricity and summer blackouts, which have been attributed to the large number of conventional air conditioning systems running on electricity.

As the number of traditional vapor compression chillers grow so do greenhouse gas emissions, both from direct leakage of high GWP refrigerant, such as HFCs, and from indirect emissions related to fossil fuel derived electricity consumption. Solar air-conditioning is intuitively a good combination, because the demand for air-conditioning correlates quite well with the availability of the sun. The hotter and sunnier the day, the more air-conditioning is required. Interest in solar air-conditioning has grown steadily over the last years. The latest numbers of worldwide installations in 2023 showed nearly 2,000 systems (IEA SHC, 2023). Solar air-conditioning can be achieved by either driving a vapor compression air-conditioner with electricity produced by solar photovoltaic cells or by solar thermal heat to run a thermally driven sorption chiller.

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2. Adaptation of solar cooling technologies

The knowhow capitalised in OECD countries (Europe, US, Australia, etc.) on solar cooling technology (both thermal and PV) is already very great, but very few efforts have been made to adapt and transfer this knowhow to Sunbelt countries such as Africa, MENA, Asian countries, which are all dynamic emerging economies They are also part of the global increase in demand for air conditioning (AC), where solar cooling could play an important role, as these are all highly irradiated regions of the world.

Therefore, the present Task 65 focus on innovations for affordable, safe and reliable cooling systems for the sunbelt regions worldwide (sunny and hot climates, between the 20^{th} and 40^{th} degrees of latitude in the northern and southern hemisphere). It covers the small to large size segment of cooling and air conditioning (between 2 kW and 5,000 kW). The implementation/adaptation of components and systems for the different boundary conditions is forced by cooperation with industry and with support of target countries like India and UAE through Mission Innovation (MI) Innovation Community on "Affordable Heating and Cooling of Buildings" (MI IC7, 2023).

3. Objectives of IEA SHC Task 65

The key objective of IEA SHC Task 65 is to adapt, verify and promote solar cooling as an affordable and reliable solution in the rising cooling demand across Sunbelt countries. The existing technologies need to be adapted to the specific boundaries and analysed and optimized in terms of investment and operating cost and their environmental impact (e.g. solar fraction) as well as compared and benchmarked on a unified level against reference technologies on a life cycle cost bases. Solar cooling should become a reliable part of the future cooling supply in Sunbelt regions. After completion of the IEA SHC Task 65 the following should be achieved:

- Support the development of solar cooling technologies on component and system level adapted for the boundary conditions of Sunbelt (tropical, arid, etc.) that are affordable, safe and reliable in the medium to large scale (2 kW-5,000 kW) capacities
- Adapt existing technology, economic and financial analyses tools to assess and compare economic and financial viability of different cooling options with a life-cycle cost-benefit analyses (LCCBA) model.
- Apply the LCCBA framework to assess case studies and use cases from subtasks A and B to draw conclusions and recommendations for solar cooling technology and market development and policy design.
- Pre-assess 'bankability' of solar cooling investments with financial KPIs.
- Find boundary conditions (technical/economic) under which solar cooling is competitive against fossil driven systems and different renewable solutions.
- Establish a technical and economic data base to provide a standardized assessment of demo (or simulated) use-cases.
- Accelerate the market creation and development through communication and dissemination activities.

4. Latest results of the Subtasks

4.1 Subtask A – Adaptation

The Sunbelt Regions encompass a wide range of climates, from hot and arid deserts to humid subtropical zones. Designing effective solar cooling systems in these regions requires a comprehensive understanding of the prevailing climatic conditions. Designing solar cooling systems for Sunbelt regions requires a holistic approach that considers a wide range of climatic factors. By tailoring systems to these conditions and promoting sustainable practices, the region can harness its abundant solar resources for efficient and eco-friendly cooling solutions. The following sections report the results that have been achieved in Subtask A within the Activities already completed (October 2023).

<u>A1: Climatic Conditions & Applications</u>

Generally, the suitability of (solar) cooling systems and the specific applications thereof are highly contingent on the geographical location. To establish region-specific prerequisites for solar cooling systems, leveraging geographical data is a logical approach. This necessitates the utilization of a Geographic Information System (GIS), which possesses the capability to acquire, store, validate, and visualize data associated with Earth's surface coordinates. Most pertinent geographical data essential for this purpose can readily be sourced from various outlets, including solar radiation statistics, climate records, population demographics, and more.

In the initial phase (Activity A1) of this project, GIS software was employed to amalgamate geographical data in a manner conducive to ascertaining localized reference conditions for solar cooling systems within Sunbelt regions. Moreover, this methodology can be adapted to generate insights into potential deployment sites and the feasibility of specific solar cooling systems. Supplementing this approach with data such as population density and purchasing power lays the groundwork for prospective market studies focusing on particular products or technologies. Consequently, prospective sites can be pinpointed, and economic variables can be factored into the identification of both current and future markets.

The data sources used in this study consist of multiple layers, with each layer containing data on specific topics or numerical values. These data layers are extensive, comprising 145 million grid cells and having a size of approximately 1.5 gigabytes each. The analysis took into account various conditions and sources, including geographic areas requiring cooling (spanning latitudes between 48°N and 44°S), different solar irradiances (DNI, GHI, DIF) and photovoltaic power potential (PVOUT), population density and settlement levels, climate zones based on the Köppen–Geiger climate classification system, water availability, assessment of market risk through Environmental Social Governance (ESG) factors, and considerations of Purchasing Power Parity (PPP) and Gross Domestic Product (GDP). These data sources and conditions played a crucial role in conducting the comprehensive analysis (Figure 1).

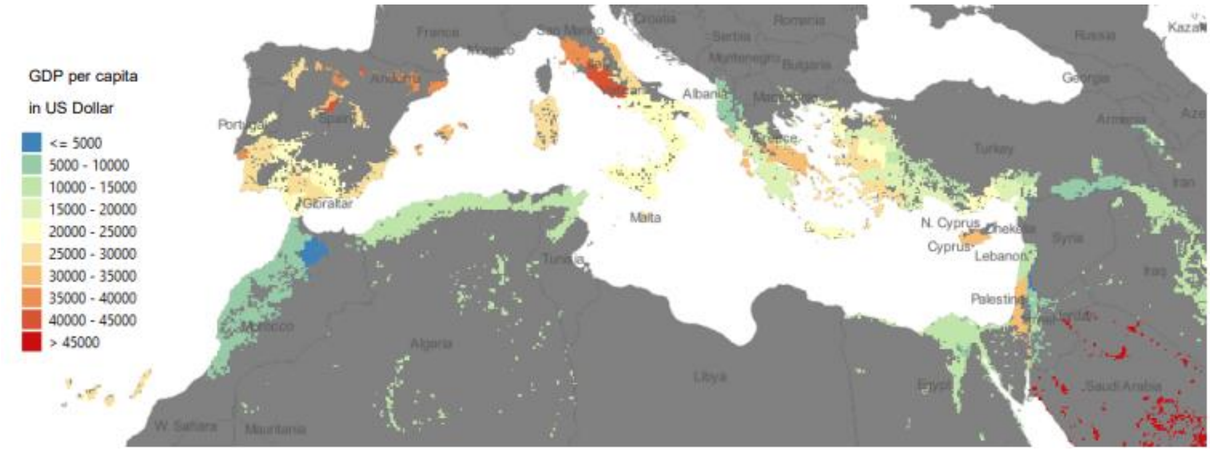

Fig. 1: A world map cut-out focusing on the Mediterranean region was used to identify the potential for a specific Solar Cooling System in building cooling applications. The analysis was conducted on a 10km raster grid, taking into account the Gross Domestic Product (GDP) levels. A detailed high-resolution map is provided in the annex for reference (Source: ZAE Bayern, 2022).

The prospects for further investigation and improvement of the methodology encompass refining the method to provide specific regional or country-level insights for better result quality, conducting a more precise analysis of industrial areas and population distribution to identify clusters of large buildings showcasing cooling network potential, incorporating additional data sources like cooling degree days and energy prices to increase the significance of results by considering economic factors, expanding the study to encompass various building types (residential, commercial, hospital, university, etc.) to enhance its overall value in assessing cooling network potential, applying the methodology's principles to other renewable energy technologies for heating and electricity supply, and exploring the development of interactive web-based maps for improved user exploration, providing flexibility in presenting information according to specific needs and details. These considerations outline potential directions for refining and extending the methodology in future research and applications.

Further details can be found in the published A1 final report (Gurtner et. al, 2023).

A2: Adapted Components

The Sunbelt regions feature diverse climates with critical factors like temperature, humidity, and dust presence. These factors affect the design and performance of solar cooling systems. Reliable data on these conditions is essential for selecting or adapting components to specific markets. Documenting available components is crucial for promoting solar cooling. Activity A2 focuses on documenting components, including collectors (photovoltaic, thermal, etc.), storage units, chillers, and heat rejection systems. This documentation combines climatic conditions and typical applications for effective technical adaptation. It considers the Köppen climate classification to qualitatively assess systems and components in the involved countries.

After a double-stage survey and data collection, a monitoring procedure for Solar Heating and Cooling (SHC) systems was developed in Task 38 Solar Air-Conditioning and Refrigeration. The goal is to adapt it to various SHC system types designed for space heating, cooling, and DHW production. The procedure evaluates performance, estimates primary energy savings compared to conventional systems, and enables comparisons between SHC systems. It helps identify best practices based on climate, building features, and usage conditions. The procedure uses an Excel file for calculations, including primary energy ratio (PER), electrical coefficient of performance, solar heat management efficiency, and fractional savings compared to conventional systems. Key Performance Indicators (KPIs) are defined, and conventional/reference systems are established in collaboration with experts. The Excel file has three levels, each offering different levels of detail and complexity for monitoring systems.

General system data is entered, including location, size, technologies, and major SHC components. The procedure adapts to the monitored system and lists the monitored energy flows based on available sensors. The procedure's three levels provide varying levels of information, depending on sensor availability and system complexity. This scheme was developed considering Task 38 Solar Air-Conditioning and Refrigeration's research.

This study analyzes various components used in solar cooling technologies and their relationships with factors like solar collector type, climatic zone, application, and adapted components (Beccali, 2022). Solar cooling has the potential to effectively decarbonize energy use related to cooling in the Sunbelt regions. With rising cooling demands in these areas, selecting the right components and analyzing existing projects can enhance its impact. The study examines 32 projects from 18 Sunbelt countries, considering their demographic distribution. The Köppen-Geiger climate classification is used to categorize climate zones, crucial for choosing cooling systems and solar collectors. The majority of projects are in hot desert and hot semi-arid climates. About 50% of projects are in the implementation phase, 18% are operational, and 25% are in the concept phase. Evacuated tube collectors are popular in simulations, while flat plate and Fresnel collectors are common in implemented projects. Solar cooling systems are often installed in public buildings (34%) and domestic buildings (25%), with potential applications in food preservation and process industries.

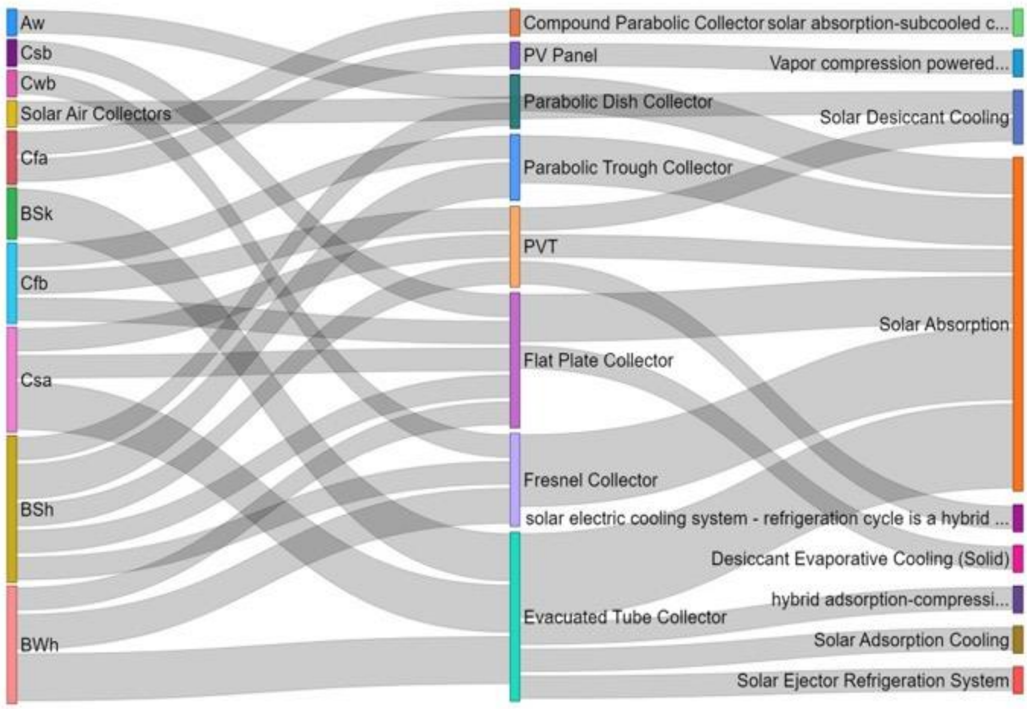

Fig. 2: Representation of weather profile with solar collector and solar cooling technology used

For example, the results showed that heat storage tanks, along with auxiliary heating systems, play a vital role in meeting cooling requirements during periods of minimal or zero solar radiation, particularly at night. The cooling demands in public buildings like offices and educational institutions are primarily concentrated during daytime hours, leading to a reduced need for these components. In contrast, for domestic applications such as villa houses, multi-family buildings, and process industries, cooling needs may extend throughout the entire day. Cold backup components, including vapor compression systems, are employed to extend the cooling capacity even when the solar cooling system is not active.

Furthermore, the Sankey diagram shown in Figure 2 provides valuable insights into the relationship between climate classifications, the types of solar collectors used, and the choice of solar cooling systems. Noteworthy observations from this analysis include:

1. In regions characterized by hot desert climates (BWh), Fresnel and evacuated tube collectors are often preferred for harnessing solar energy.

2. For areas with Hot summer-Mediterranean (Csa) and Tropical and subtropical steppe (BSk) climates, evacuated tube collectors are commonly chosen.

3. Solar absorption cooling emerges as the most prevalent solar cooling technology, followed by PV-assisted cooling and ejector cooling.

This analysis offers valuable guidance for selecting components and systems based on the specific climate zone of a project.

A4: Building and process optimization potential

The primary objective of Activity A4 was to assess the potential of energy-efficient buildings and processes in Sunbelt regions, both for new and existing structures. This involved studying other related projects and examining the integration of solar cooling into retrofitted HVAC systems. Integrating solar cooling into existing HVAC systems can be complex, especially concerning refrigerants and cold distribution methods. The aim was to identify the best technical solutions from both technical and economic perspectives. However, not all the planned analyses yielded useful data, leading to adjustments in the workflow. Some research projects and IEA Energy in Buildings and Communities Programme (EBC) projects were reviewed, but it was found that there are limited recent projects focusing on the application of solar cooling systems in buildings. Nevertheless, the information gathered can serve as a foundation for assessing the potential energy savings achievable through the implementation of solar cooling systems.

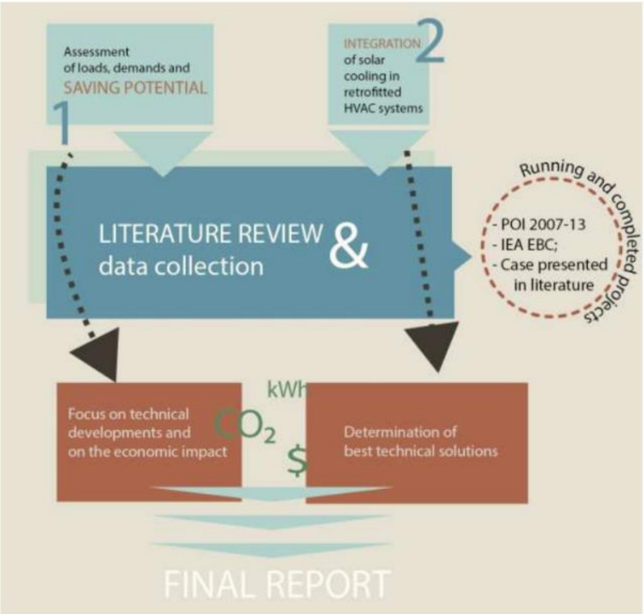

Fig. 3: Flow-chart of the data gathering and processing

The initial phase of Activity A4 involves collecting and analyzing data from various buildings to assess the potential for energy-efficient building processes in Sunbelt regions (Figure 3). This assessment pertains to both new constructions and existing structures. One particular challenge addressed in this study is the integration of solar cooling into pre-existing HVAC systems. This integration presents hurdles related to refrigerants and cold distribution. Additionally, the study explores the application of cold delivery systems to reduce drafts in air-based systems and improve thermal comfort within buildings. The data used in this analysis are sourced from the POI projects and selected completed IEA EBC projects.

In cases where the required data were note available through the primary data collection efforts, a comprehensive analysis of relevant literature was conducted. This approach effectively filled in the missing data gaps. By reviewing existing research papers, reports, and studies relevant to the field, valuable insights and information that enriched the research findings were accessed. This literature-based data acquisition approach is a standard practice in research, ensuring the completeness and credibility of the study.

The literature review revealed that space cooling significantly contributes to the energy consumption of the building sector, accounting for approximately 16% of the final energy consumption in 2021. Furthermore, projections indicate that global electricity usage for space cooling could triple from 2020 to 2050. This trend is particularly prominent in rapidly developing countries like India and Indonesia, which experience cooling-intensive climates. To address these challenges, efforts have focused on providing efficient and environmentally friendly cooling solutions grounded in three fundamental principles: building energy efficiency, system energy efficiency, and renewable primary energy supply. Combining these principles results in cost-effective and sustainable cooling solutions that enhance user comfort and mitigate greenhouse gas emissions, benefiting the environment and climate.

The outcomes of this study underscore the multifaceted nature of achieving energy efficiency in Sunbelt regions, especially concerning solar cooling and building processes (Bonomolo et. al, 2023a). These findings emphasize the importance of robust data analysis, considering a range of factors that impact energy consumption and cooling demands in different building contexts.

Looking ahead, future activities should concentrate on addressing the challenges posed by varying building characteristics, materials, orientations, and occupant behavior. Moreover, there is a need to develop standardized assessment methods to effectively compare the performance of different solar cooling systems. Economic considerations and the economic impact of these systems should also be a priority in future research. Furthermore, the introduction of the Cooling Demand Market Index (CDMI) highlights the growing importance of cooling demand globally (Strobel et. al, 2023), particularly in developing countries experiencing economic growth and climate change. Future work should delve deeper into understanding and mitigating the rising cooling demand in Sunbelt regions to ensure sustainable and energy-efficient solutions.

Further details can be found in the published A4 final report (Bonomolo et. al, 2023b).

4.2 Subtask B – Demonstration

Although solar cooling has a long history, first examples were built in the 1990s, a real market couldn't be established anywhere. Roughly 2,000 solar (thermal) cooling systems exist worldwide. Most of them can be declared as customized, early-stage systems. PV supported cooling developed in the recent years, whereas PV is often only attached to a common electrical driven system and real control and optimized support (or increase of self-consumption) is rather seldom. Several technical and mostly economic reasons are still preventing solar cooling from a wider market uptake. Besides these barriers, the most important approach for introducing these technologies in the Sunbelt is a wide range of demonstrations. It must be assured that solar cooling is seen as a technically reliable, economically viable, and smart solution. The future perspective in Sunbelt countries through the adaptation of components and systems need to be proven by monitored best practice examples for all kind of system configurations and applications. Achievements for Subtask B to date (October 2023).

<u>B1/A2: Show cases on system and component level</u>

A collection of findings examines the constituent elements employed in different solar cooling technologies and their relationships with various variables, including type of solar collector, climate zone, application, and the components integrated into the systems. Solar cooling stands as a promising and efficient means of contributing to decarbonization efforts in nations within the Sunbelt region. Considering the expected increase in cooling needs within these nations, there is a substantial opportunity to identify the best components and conduct comprehensive evaluations of existing/ongoing projects. This approach would expand its scope and amplify its overall influence significantly. The research encompasses 32 studies conducted in 18 countries located in the Sunbelt region. Figure 4 illustrates the demographic distribution of these projects.

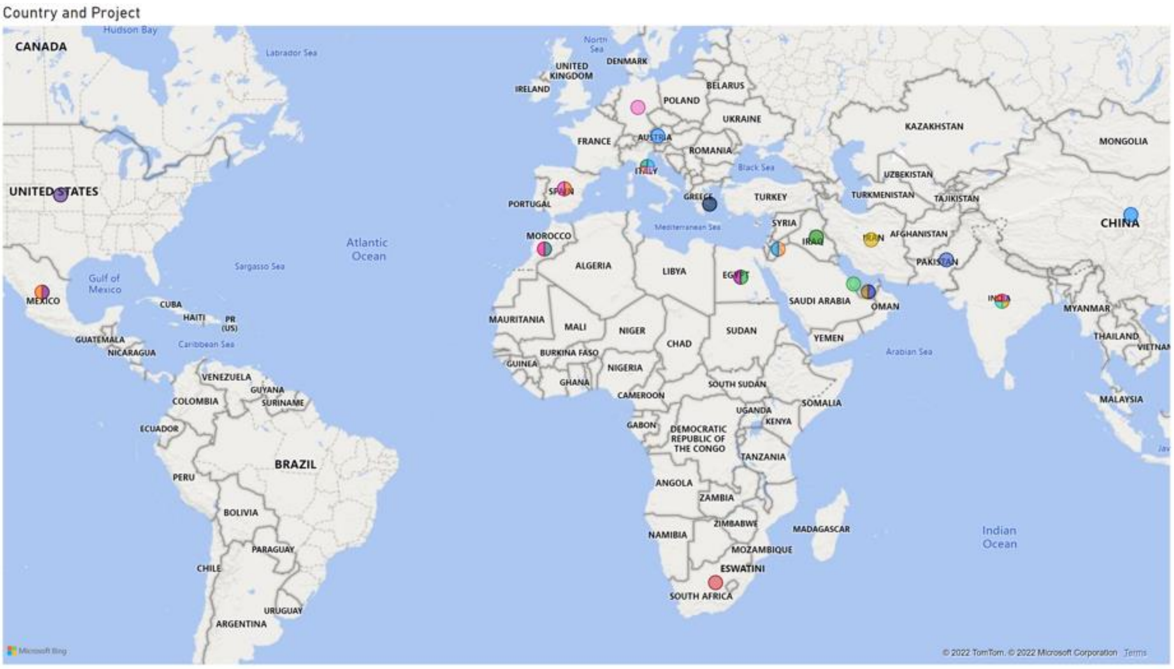

Fig. 4: Case studies located in the Sunbelt region

Project Typology: The studies conducted addressed a diverse range of project types. Among these, 50% of the projects are presently in the implementation phase, while 18% are in operation and have attained established outcomes. 25% of these studies involve conceptual projects examined for implementation through simulation tools like TRNSYS, Python, Matlab, and other mathematical modeling techniques. These tools serve as effective methods to assess system performance before actual implementation. Additionally, the survey includes published works featuring laboratory experiments and simulations validated by real-time building energy usage. This approach ensures a comprehensive and varied analysis.

Solar Collector Types: Solar Cooling uses a range of solar energy harnessing devices. Among these, evacuated tube collectors are utilized in 30% of the analyzed projects, while both flat plate collectors and Fresnel collectors are equally prominent at 17% each. The research also indicates that Fresnel collectors and flat plate collectors are the most commonly chosen options in executed projects, whereas evacuated tubes are predominant in simulation projects. Examining the distribution of different solar collectors across various temperature profiles provides valuable insights into their suitability for different scenarios. Evacuated tube collectors find extensive application across three distinct climate regions: BSk (Cold semi-arid), BWh (Hot desert climates), and Csa (Hot-summer Mediterranean climate). Similarly, flat plate collectors are suitable for a range of five different profiles, spanning from Hot Desert (BWh) to Warm-summer Mediterranean climates (Csb).

Solar Cooling Applications: In the majority of the examined cases, solar cooling systems are installed in public buildings (34%), including offices, schools, and university buildings, enabling direct utilization of solar energy during daytime hours. Domestic buildings (25%) appear to be the next most studied due to prevalent requirements for improved indoor comfort in the Sunbelt region. It is also noted that these systems have promising potential applications in sectors such as food preservation and process industries.

B2: Design guidelines

A detailed questionnaire has been meticulously crafted to cover aspects of solar cooling components, design considerations, sizing, and other sub-systems like heat rejection units and cold distribution systems. This questionnaire was distributed to active participants in the task, and their responses have been collected. Data has been gathered from 10 case studies, detailing component capacities and sizing procedures and covered in activity B1. In activity B2, case studies are presented to illustrate the performance of solar cooling systems under varying boundary conditions. Three distinct case studies, each with its unique scope and attributes, are elaborated upon. The summary is as follows:

Industrial Cooling Potential: Industrial cooling holds significant promise for solar cooling applications. These systems can achieve a high solar fraction, leading to a considerable reduction in CO_2 emissions compared to conventional electricity-driven chillers.

Solar PV and Vapor Compression Chillers: The integration of Solar PV with vapor compression chillers is examined as an emerging solution for decarbonizing cooling systems. A comparative analysis involving different load and weather profiles, suggests that solar PV cooling can result in a lower levelized cost of cooling compared to solar thermal. The study underscores the significance of thermal storage and the effectiveness of lower temperatures in solar thermal collectors for cost competitiveness.

Hybrid Electrical and Thermal Chillers: This study is based on the HyCool project. The focus is on combining electrical and thermal chillers. Both simulation and real-world outcomes demonstrate a significant decrease in electricity consumption when utilizing the topping cycle of the absorption chiller. Progress in policies and economies of scale is expected to boost the cost-effectiveness of these innovative methods.

In conclusion, these case studies underscore the transformative potential of cooling solutions. As technology advances and policies evolve, the adoption of such systems will play a pivotal role in shaping a greener and more energy-efficient cooling future.

B5: Lessons learned (technical and non-technical)

Activity B5 involved identifying and documenting lessons learned, both technical and non-technical, with the purpose of creating a summary for dissemination in Subtask D. The primary objective was to collect trustworthy data and gain valuable insights from various stakeholders. A survey was conducted to gather information on stakeholder's requirements, expectations, and specific circumstances that may prompt the utilization of solar cooling. The primary objective of the survey was to identify crucial factors influencing the adoption of solar cooling technologies across different applications and regions. The gathered information was then analysed to better comprehend the challenges, needs, and desires of the stakeholders involved.

The results obtained from the questionnaire showed that solar cooling technologies are highly valued and important, but their market transformation requires collaboration across various sectors. Engaging with stakeholders, including government agencies, industry players, research institutions, and consumers, is crucial for creating a supportive ecosystem for solar cooling. GIS software aids in effective planning and deployment, while technical training programs build capacity and expertise in the industry. Demonstrating the technical and economic viability of solar cooling and reducing reliance on the electrical grid can promote adoption. A multi-faceted strategy involving awareness-raising, market acceptance, and accelerated penetration can make solar cooling a sustainable solution for cooling needs. This approach contributes to climate change mitigation, economic growth, and energy security.

4.3 Subtask C – Assessment and Tools

The concurrent technical, economic and financial assessment of solar cooling options is of high importance in each stage of the life cycle of a project, starting with comparison of different technology options and pre-design, detailed planning, optimizing of operation but also for policy design with proven concepts. In all life cycle phases, it is crucial to have corresponding tools that deliver the necessary information and key performance indicators for the different stakeholder. The KPIs need to take into consideration economic, financial, social and environmental issues as well as other 'Multiple Benefits'. Tools and their specific outputs permit to provide guidance on optimized system design and implementation and show the level of quality of both the most critical components and systems. The following results have been achieved in Subtask C so far (October 2023).

C1: Design tools and models

The work involved reviewing and adapting tools and models for technical and financial assessment and design for solar cooling and the project phases from pre-feasibility to simulation to monitoring. The focus is the documentation of the tools and their specific application to provide measured data for validating the tools and the adaptation of selected ones for Sunbelt countries.

Three approaches are used to evaluate tools used worldwide and this IEA SHC Task. First, a (i) generic literature research in Web of Science (WoS), (ii) interviews and questionnaires among the IEA SHC Task Expert, and (iii) interactive questionnaires during Task expert meetings.

A total of 1,216 documents were identified as a result of the search in WoS. The query search string used is ALL=("solar cooling" OR "solar refrigeration"), and the index dates covered are 1990/01/01-2021/06/30. A network visualization diagram was generated in VOSviewer. A query search string ("solar cooling") ("design") AND ("software") in the topic field produced 38 documents.

The initial data gathered provide a general idea of which components are being used and which software is being implemented. Based on the information provided by the task participants, the following software are currently being implemented in their applications/research: Matlab, Meteonorm + Excel tool, TRNSYS, EES, and Phyton. This is also reflected in the third evaluation of tools.

Conclusion: Modelling and assessing the technical and economic behavior of solar cooling plants is essential in all design phases up to implementation and optimization. Different tools are used, from sophisticated dynamic simulation models to simple spreadsheet calculations. Companies and their experts often develop their own for their specific components and systems. Generic publicly available models can be found for almost all applications, especially simulation tools. The configuration and data sheets for the entire tool depend on the approach and are often difficult to find.

Further details can be found in the published C1 final report (Daborer-Prado et. al, 2023).

C2: Database for technical and economic assessment

The elaboration of the database and collection of technical (e.g. standard reference systems, etc.) and economic data (energy prices for electricity, natural gas, etc.) for different components (Investment, maintenance, lifetime, etc.) and for the different sunbelt countries (based on subtask B demo cases) is ongoing and is the basis for the following assessments of the various solar cooling concepts. The data base includes future scenarios for technical and economic boundaries (e.g. efficiency of conventional chillers, energy prices) to provide the base and a solid framework for the sensitivity analyses and future scenarios. The database elaboration is also including review of existing useful information of IEA knowledge (e.g. IEA SHC Task 54, and others).

C3: Assessment mechanism

This activity is combined with B3 activity, the review of existing tools (other IEA SHC Task 53, …) and methods for technical (e.g. Solar Performance Factor, etc.) and economic (e.g. Levelized Cost of Heating/Cooling, etc.) provides the bases to select the necessary KPIs for different project phases and stakeholders. A selection of one tool/platform will be forced to be used by this Task, the adaptation of methods and integration of the database (activity C2) are the core activities. The focus is to provide the corresponding methods for the analyses and creation of assessments for certain stakeholders.

4.4 Subtask D – Dissemination

A wide penetration of solar cooling in Sunbelt countries is not only depending on the accomplishment of technical barriers. Non-technical barriers often have a critical role. Financing, policy advise, and dissemination/communication of success stories are among the important activities to overcome also non-technical barriers. The focus is on the implementation of target specific promotion activities based on the collected results, upgrade of material for dissemination for external communication, the implementation of knowledge transfer measures towards the technical stakeholders, the development of instruments and their provision for policy makers. At the time of writing (October 2023), the following results have been achieved in subtask D.

D1: Task65 website and publications

A website included into the IEA SHC portal has been created, see https://task65.iea-shc.org/. It firstly presents the Task purpose and activities and secondly the Task results. It also lists all Task participants and observers. Finally, in the future the website will also host an online best practice collection webpage, presenting the system concepts, state of the art of cooling markets, the main lessons learned and the entire technical and economic KPIs. After the end of the Task the website will become an archive of the Task's collective work results.

Several publications about Task 65 and the experts work related to the different activities have been published: EuroSun 2020, FotoVolt 10/2021, SWC 2021, APSRC 2021, ISEC 2022, EuroSun 2022, APSRC 2022, s@ccess 2023, ICR 2023, SWC 2023). For a comprehensive list please visit https://task65.iea-shc.org/news.

D2: Policy advise and financing models

The work in Activity D2b is ongoing. A list of the most relevant business and financing models that could be used for solar cooling systems has been compiled. A clear distinction has to be made between business models and third-party financing – these terms are often mixed up. Third party financing (TPF) can be part of a business model, but the latter goes well beyond financing. Some examples of ESCO (energy service company) models have existed in the solar thermal sector for a long time. Scottsdale's Desert Mountain High School in Arizona, USA, was one of the first clients to profit from a cooling energy supply contract (Epp, 2014). In 2014 SOLID from Austria financed and installed a 3.4 MW cooling system and signed a 20-year cooling energy supply contract with the school (Figure 5).

Fig. 5: Solar roof for Scottsdale's Desert Mountain High School in Arizona, USA (Source: SOLID, 2014)

Another example is a special purpose vehicle, where a separate legal company is established, which plans, builds, finances and operates the energy production units and signs all the relevant documents such as EPC contracts, O&M agreements or loan contracts. The first solar thermal specialists are already using this model successfully - for example NewHeat in France. The company created an SPV already in 2018 to finance and operate a package of solar industrial and district heat projects (Epp, 2017). Solar fields from the Netherlands also founded an SPV recently for the 37 MW district heating plant under construction in Groningen (Epp, 2022).

Given the special situation in some sunbelt countries with weaker economies, another model can be recommended: the utility-based on-bill repayment model. On-bill repayment is widely used in the United States for energy-saving measures or heating upgrades in the residential sector. Here, the asset including the re-financing agreement can be sold with the house if the owners have to move.

D5: Workshops conducted

The following national and industry workshops as well as SHC Solar Academy trainings have been conducted so far by the Task 65 experts:

- SHC Solar Academy Training for CCREEE, Nov 10th 2020 (online)
- National Workshop for China, Dec 5th 2020 (online)
- National Workshop for Austria, March 24th 2021 (online)
- Industry Workshop Task 65 + HPT Annex 53, Mar 25th 2021 (online)
- SHC Solar Academy Training for SOLTRAIN / SACREEE, Nov. 8th-9th 2021 (Stellenbosch, South Africa)
- Industry Workshop Task 65 & sol.e.h2., Dec. 2nd 2021 (online)
- ISES SHC Solar Academy Webinar Task 65, Oct. 25th + 27th 2022 (online)
- Industry Workshop Task 65 + HPT Annex 53, March 24th 2023 (Innsbruck, Austria / hybrid)
- SHC Solar Academy Training for SOLTRAIN / ECREEE, Oct. 10th-11th 2023 (Praia, Cape Verde)

5. Trends and outlook

One of the main trends in the upcoming years will be that more and more hybrid system solutions of all kinds in the field of solar cooling will come onto the market. They will offer high CO_2 savings also in small to medium cooling capacity ranges with good economic efficiency at the same time. Furthermore, in the area of medium-temperature systems (solar collector temperatures around 160-180 °C) and double-effect absorption chillers, there will be solutions with better efficiency and profitability, since they will have smaller solar fields and lower heat rejection capacities to achieve an investment advantage of up to 40% compared to conventional solar cooling systems.

However, one of the significant challenges of solar cooling lies in the intermittent nature of solar energy availability.

Moreover, quite often in emerging countries the reliability of public grids face challenges and load shedding often appears, such as in South Africa. Especially when focusing on industrial applications including agri-food, manufacturing industry and tourism, the reliability and availability of renewable solutions and its economic impact compared to conventional backups is key.

As the world seeks sustainable alternatives to conventional energy sources, solar cooling has emerged as a promising solution also for industrial applications. Solar thermal energy combined with waste heat recovery and innovative thermal storage concepts (starting from sensible heat, but extending storage solutions to latent heat, using Phase Change Materials (PCM) and thermochemical solutions) is a promising solution to meet cooling demands at a minimum environmental impact. These three key areas are future topics that solar cooling systems leverage the abundant and renewable energy provided by the sun to meet both the heating and cooling needs of industrial processes. This sustainable energy is then utilized to power sorption and hybrid-based systems, which offer efficient cooling capabilities for industrial environments.

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