Solar Cooling for the Sunbelt Regions – Final results from IEA-SHC Task 65

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Abstract

The IEA SHC Task 65 "Solar Cooling for the Sunbelt Regions" started in July 2020 and has been focusing on innovations for affordable, safe and reliable Solar Cooling systems for the Sunbelt regions. The Task 65 finished in June 2024. Its innovative approach was the adaptation of existing concepts/technologies to the Sunbelt regions using solar energy, either solar thermal or solar PV. This paper presents the comprehensive Task 65 results of the different activities carried out in the last four years as well as the research highlights. In Subtask A (Adaptation) climatic conditions, applications, components and systems have been investigated and adapted tools and systems for sun belt countries have been developed. A GIS-based tool is now available for the global identification of possible solar cooling locations, taking into account technical as well as socio-economic factors. Subtask B (Demonstration) put the focus on design guidelines, performance indicators and standardization. An analysis of multiple case studies has been undertaken and lessons learned have been compiled. In Subtask C (Assessment & Tools), design tools have been analysed as well as assessment mechanisms have been developed. A variety of tools for solar cooling design is available. Subtask D (Dissemination) focused mainly on distributing the Task 65 results, but also developed new roadmaps for sunbelt countries with regard to the implementation of solar cooling systems. Financing models have been analyzed and recommendations for policy makers are given as a result.

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

1. Introduction

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. If no measures are taken to counteract this increase, space cooling demand could triple by 2050. In some countries, peak load caused by air conditioning does reach a share of >70% of the total electricity consumption on hot days (IEA, 2018). With an increase in cooling 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 vapor compression chillers for AC purposes increase globally, so do AC-related 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 well-suited alternative, because the demand for air-conditioning correlates quite well with the availability of solar energy. 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 (i) operating a vapor compression air-conditioner with electricity generated by solar photovoltaic cells or by (ii) using solar thermal heat to run a thermally driven sorption chiller. Both these technologies can be used with or without a storage option, such as batteries or thermal storage units.

10.18086/eurosun.2024.08.06 Available at http://proceedings.ises.org

2. Methodology

The know-how on solar cooling technologies (both thermal and PV) in OECD countries (Europe, US, Australia, etc.) is already quite comprehensive thanks to more than twenty years of research and commercial activities on the subject. However, very few efforts have been made to adapt and transfer this knowhow to sunbelt countries e.g. in Africa, in the MENA region or in Asia. The sunbelt countries are located between the 20th and 40th degree of latitude in the northern and southern hemisphere and typically contribute to the global increase in demand for air conditioning (AC) since they are mostly located in hot and/or humid climates. In such climates solar cooling can play an important role in energy savings for AC. Further, all sunbelt countries are in regions of the world with high annual solar irradiation. Therefore, the IEA Task 65 "Solar Cooling for the Sunbelt Regions" focused on innovations for affordable, safe and reliable cooling systems for the sunbelt regions worldwide. 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 selected target countries like India and UAE through Mission Innovation (MI) Innovation Community on "Affordable Heating and Cooling of Buildings" (MI IC7, 2023).

2.1 Task 65 structure

The Task is organized into four main activities, aka subtasks, derived from the described focus areas above. Figure 1 shows the subtask titles and work packages of each subtask.

SUBTASK A: ADAPTATION

A1 Climatic conditions & applications
A2 Adapted components
A3 Adapted systems
A4 Building and process optimization potential
A5 Standardization activities

SUBTASK B: DEMONSTRATION

B1 Show cases on system and component level
B2 Design Guidelines
B3 KPI definitions
B4 Standardized Solar Cooling Kits
B5 Lessons learned (technical and non-technical)

SUBTASK C: ASSESSMENT & TOOLS

C1 Design tools and models
C2 Database for technical and economic assessment
C3 Assessment mechanism
C4 Benchmarking and sensitivity analysis

SUBTASK D: DISSEMINATION

D1 Homepage / publications
D2 Policy advice & financing models
D3 Guideline / Roadmaps for sunbelt countries
D4 Book or booklet
D5 Workshops
D6 Stakeholder Engagement

Figure 1. Structure and work packages of Task 65 (IEA SHC, 2024)

2.2. Key objectives

The key objectives of IEA SHC Task 65 were to adapt, verify and promote solar cooling as an affordable and reliable solution in the rising cooling demand across sunbelt countries. Existing solar AC technologies have been analyzed, adapted to the specific boundaries and optimized in terms of investment and operating cost and their environmental impact (e.g. solar fraction). They have been compared and benchmarked against reference technologies with regard to a life cycle cost base. Task65 wanted to contribute to solar cooling becoming a reliable part of the future cooling supply in sunbelt regions. After the recent completion of IEA SHC Task 65 the following key objectives have been achieved:

- Supporting the development of solar cooling technologies on component and system level adapted for the boundary conditions of Sunbelt (tropical, arid, etc.) with regard to affordability, safety and reliability in medium to large scale (2 kW-5,000 kW) capacities
- Adapting existing tools for assessing technology and economics of solar AC systems
- Comparing the economic and financial viability of different cooling options with a life-cycle cost-benefit

analyses (LCCBA) model.

- Applying the LCCBA model 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-assessing the 'bankability' of solar cooling investments with financial KPIs.
- Finding boundary conditions (technical/economic) under which solar cooling is competitive against fossil-driven systems and different renewable solutions.
- Establishing a technical and economic data base to provide a standardized assessment of demo (or simulated) use cases.
- Accelerating the market creation and development through communication and dissemination activities.

3. Results and analysis

3.1 Final results of Subtask A – Adaptation

Designing effective solar cooling systems in sunbelt regions requires a comprehensive understanding of the prevailing climatic conditions as well as a holistic approach considering a wide range of climatic factors. By tailoring systems to these conditions and promoting sustainable practices, a 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.

A1: Climatic Conditions & Applications

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. 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 2).

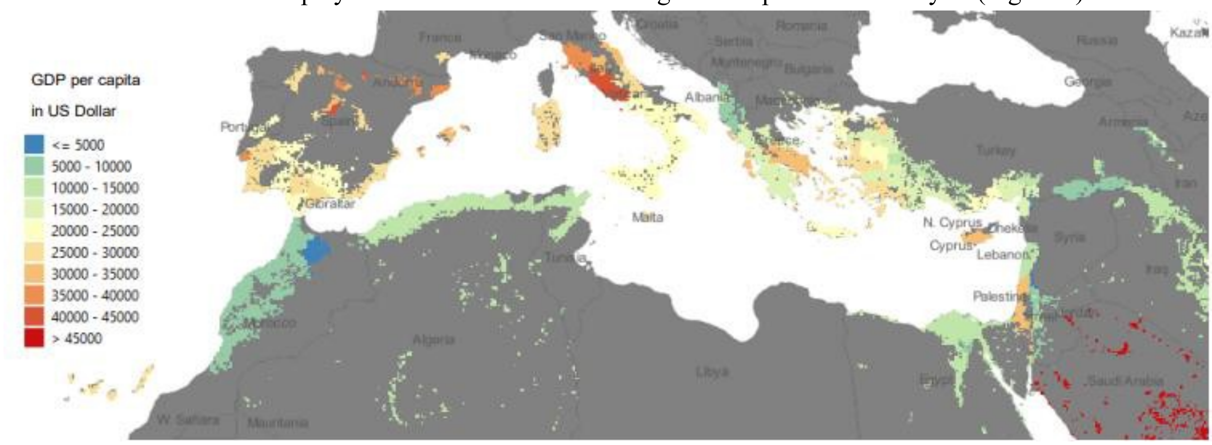

Figure 2. The Mediterranean region was used to identify the potential for a specific Solar Cooling System in building cooling applications. The analysis was conducted on a 10km raster grid, taking into account the Gross Domestic Product (GDP) levels. (Gurtner et.al, 2023).

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 Task 65 A1 final report (Gurtner et. al, 2023).

A2-B1 & A3: Adapted Components and Systems

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-B1 focused 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 (see Figure 3), categorizing climates into five main groups (A, B, C, D, E) to qualitatively assess systems and components in the involved countries.

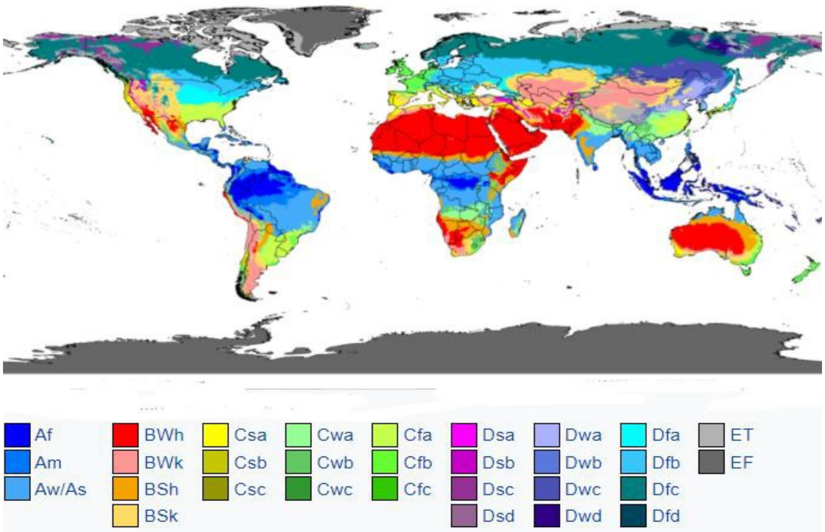

Figure 3. Köppen–Geiger climate map used for data classification (Beccali et.al, 2024)

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 et. al, 2024). Solar cooling has the potential to decarbonize countries in the Sunbelt region effectively. With rising cooling demands in these areas, selecting the right components and analyzing existing projects can enhance its impact. During Task 65, 32 projects from 18 Sunbelt countries have been analysed, considering their demographic distribution, see Figure 4. The Köppen-Geiger climate classification was used to categorize these into climate zones, which is crucial for choosing cooling systems and solar collectors. The majority of projects analysed 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.

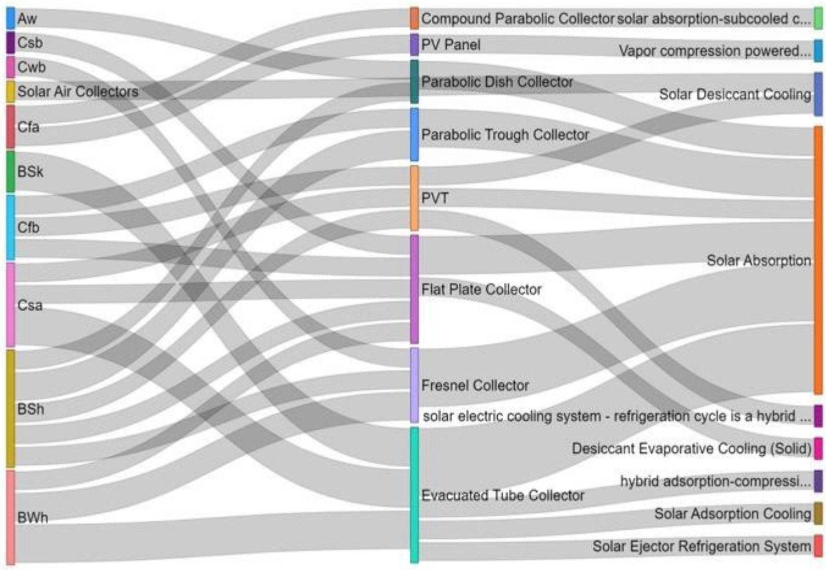

Figure 4. Representation of weather profile with solar collector and solar cooling technology used (Beccali et.al, 2024)

The results show that thermal storage units, 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 demand in public buildings like offices and educational institutions is primarily concentrated during daytime hours, leading to a reduced need for these components. In contrast, cooling demand may extend throughout the entire day and night for domestic applications (such as villa houses and multi-family buildings) and the process industry. Cold backup components, including vapor compression systems, are employed to extend the cooling capacity even when the solar cooling system is not active. Furthermore, Figure 4 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.

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 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. The initial phase of Activity A4 involved collecting and analyzing data from various buildings to assess the potential for energy-efficient building processes in Sunbelt regions. This assessment pertained 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 explored 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 (i) a research programme belonging to EU Horizon 2020 named “POI ENERGIA 2014e2020” (Beccali et. al, 2015) and (ii) selected completed projects from IEA’s Energy in Building and Communities Programme (https://iea-ebc.org/). In cases where no necessary data were obtained 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. The literature review revealed that global 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, 2023). 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. Further details can be found in the published A4 final report (Bonomolo and Strobel, 2023).

A5: Standardisation Activities

The Activity A5 covered two main aspects, which can be found in the published A5 final report (Vasta and Sapienza 2024):

1. Standardization and Definition of Key Performance Indicators (KPIs): The aim was to establish standardized definitions to create a unified language for solar cooling. KPIs are pivotal in assessing and comparing different solutions and technologies within the field. Given the diverse nature of solar cooling systems and components and their current limited adoption in energy systems, it is crucial to develop a precise and comprehensive set of KPIs. A selection process has been devised to choose appropriate KPIs, with seven base KPIs identified initially, which will be expanded to encompass materials, components, and systems.
2. Examination of Existing Standards and Regulations: Activity A5 investigated the present state of standardization and regulation concerning solar heating and cooling across Sunbelt countries. Various countries and international bodies have already formulated standards covering performance testing, system design, equipment specifications, safety requirements, and installation practices for solar heating and cooling systems. Prominent organizations in this realm include ISO, CEN, ASHRAE, among others. The Australian Standard AS5389 was deemed most suitable for solar cooling in the Sunbelt region, offering a comprehensive framework for the design, installation, operation, and maintenance of solar heating and cooling systems. However, AS5389 does not specifically address solar cooling systems in the Sunbelt region. To adapt it, several modifications were proposed, including additional design considerations, guidelines for cooling load calculation, recommendations for solar collector selection, guidance on thermal energy storage, and measures for evaluating system performance tailored to the Sunbelt region's needs. These adaptations aim to align the existing standard with the specific requirements and challenges of solar cooling systems in the Sunbelt region.

3.2 Final results of Subtask B – Demonstration

Solar thermal cooling has a long history (with first commercial examples having been built in the 1990’s), however a real commercial market did not establish itself anywhere in the world. 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, mainly driven by the cost decrease for PV modules in the recent decade. PV cooling has become the dominant type of solar cooling system globally due to its simplicity in installation and low cost. No robust numbers exist for installed PV cooling systems globally, but, as an example, several millions of these systems are in operation in Australia alone. The technology for both solar thermal and solar PV cooling is commercially available worldwide. However, mostly economic reasons are still preventing solar cooling from gaining a wider global market uptake, especially in Sunbelt regions with lower purchasing power. One important approach for introducing these technologies into Sunbelt countries is a wide range of demonstrations locally. It must be assured that solar cooling is seen as technically reliable, economically viable (reasonable), and smart.

B1: Show Cases on System and Component Level

A number of installed projects was examined in order to find 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 in identifying the best components and conduct comprehensive evaluations of existing/ongoing projects. This approach is expected to help expanding the scope of solar cooling and amplify its overall influence significantly. The research undertaken in this work package encompasses 31 studies conducted in 18 countries located in the Sunbelt region. Figure 5 illustrates the demographic distribution of these projects.

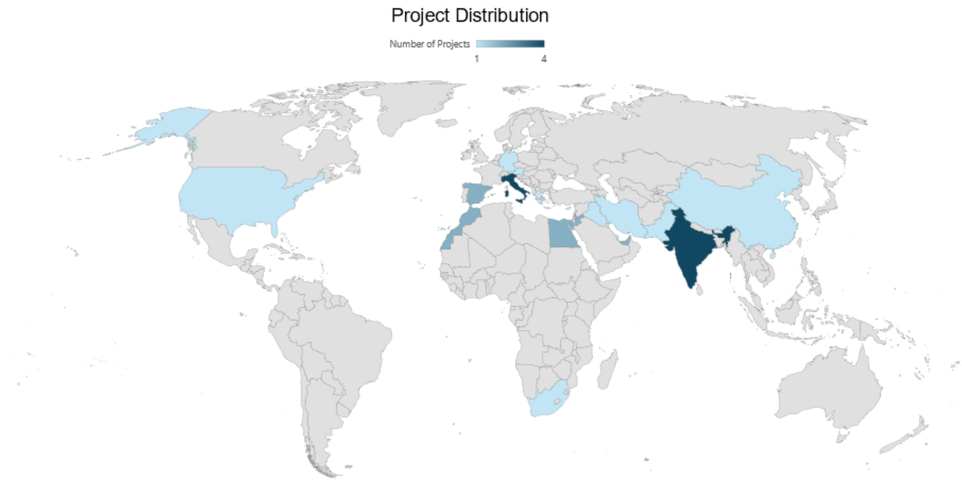

Figure 5. Case studies located in the Sunbelt region (Beccali et al., 2024)

The studies conducted included a diverse range of project types. Among these, 50% of the projects are currently in the implementation phase, 25% of the projects are in conceptual phase, 19% are in operation and have attained established outcomes, 3% are validated concepts and the remaining 3% are projects that have been modelled using simulation tools like TRNSYS, Python, Matlab, or other mathematical modeling techniques. Additionally, the study also includes published works featuring laboratory experiments and simulations validated by real-time building energy usage. This mixed approach ensures a comprehensive and varied analysis. The analysis shows that 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). With regard to buildings the analysis shows that 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. The third most studied application (19%) includes indoor test facilities and process industry. The remaining applications include district cooling, food processing and preservation and highrise buildings.

B2: Design Guidelines

This work package included the collection of design and system integration guidelines for solar cooling projects. For this purpose, a comprehensive questionnaire was created that goes into detail about various solar cooling components, design, sizing and other sub-systems such as heat rejection unit and cold distribution system. Data from 10 case studies are collected and presented showing the performance of solar cooling systems with varying boundary conditions. Additionally, three different case studies, each with their own scope and unique characteristics, are discussed. The summary is as follows:

- Industrial cooling offers significant opportunities for solar thermal cooling applications. Such systems can achieve a high solar fraction and thus significantly reduce CO2 emissions compared to conventional electricity-powered chillers.
- The integration of solar PV with vapor compression chillers as an emerging solution for decarbonization of cooling systems. A comparative analysis considering different load and weather profiles suggests that solar PV cooling can result in lower levelized cost of cooling compared to solar thermal.
- Hybrid chillers emphasizes the potential of combining electrical and thermal chillers. Both simulation and practical results indicate a significant reduction in electricity consumption when using the topping cycle of an adsorption chiller.

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

B3-C3: This work packages had not been finished at the time of writing of this publication, please refer to Task65 webpage (https://task65.iea-shc.org/) for a future publication of report B3-C3.

B4: Standardized Solar Cooling Kits

The activity B4 focused on the standardization of solar cooling kits 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 published B4 report (Weiss et. al 2024) 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

B5: Lessons Learned (Technical and Non-Technical)

Activity B5 involved identifying and documenting lessons learned, both technical and non-technical, to create 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 survey's primary objective was to identify crucial factors influencing the adoption of solar cooling technologies across different applications and regions. The gathered information was then analyzed 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.

3.3 Final results of 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.

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 main 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 were used to evaluate tools used worldwide and within this IEA SHC Task. Firstly, a generic literature research in Web of Science (WoS), secondly interviews and questionnaires among the IEA SHC Task Expert, and thirdly interactive questionnaires during Task expert meetings. A total of 1,216 documents were identified as a result of the search in WoS. The initial data gathered provided 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. All software tools are commercially available and are ready to be used. Further details can be found in the published C1 final report (Daborer-Prado et. al, 2023).

C2: Database for Technical and Economic Assessment

Activity C2 was aimed at creating a comprehensive database of technical and economic data for solar cooling components and Sunbelt countries, supporting extensive assessments and providing insights into future scenarios. This database should establish a solid framework for sensitivity analyses and future scenario planning for solar cooling concepts. The IEA SHC Task 53 databases (IEA SHC, 2018) form the basis for the economic analysis of solar cooling systems (entire system, ST or PV based, including all main components already installed). An internal Task 65 expert survey has been conducted to further refine cost and technical figures for the database. The data base is comprehensive and listing every item here is not possible. As an example, technical components listed include:

- Solar sources: Flat plate collector, Evacuated tube collector, Photovoltaic
- Heat sources: Natural gas, Combined heat and power, Heat pump and reversible heat pump, Absorption heat pump and reversible absorption heat pump, District heating, Natural gas boiler, Condensing natural gas boiler, Electrical heater, Oil boiler, pellet boiler
- Cold sources: Air- or water-cooled vapor compression chiller, Single effect absorption chiller, Double effect absorption chiller, Adsorption chiller, District cooling
- Heat rejection: Wet cooling tower, Dry cooling tower, Hybrid cooling tower
- Storage: Hot water storage, Cold water storage, Battery storage

These components can be used as reference system or as part of the solar heating and cooling system. Please refer to Task65 webpage (https://task65.iea-shc.org/) for a future publication of report C2.

C3-B3: Assessment mechanism / C4: Benchmarking/Sensitivity analysis

These work packages had not been finished at the time of writing of this publication, please refer to Task65 webpage (https://task65.iea-shc.org/) for a future publication of both reports C3-B3 and C4.

3.4 Final results of 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.

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 near 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. The website will further act as 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, EusroSun 2024). For a comprehensive list please visit https://task65.iea-shc.org/news.

D2: Policy Advice and Financing Models

Solar cooling solutions typically require high upfront capital expenditures. They may also be perceived as risky by potential clients due to their complexity or unfamiliarity with solar cooling technologies. These and other non-technical barriers underscore the importance of developing client- and service-oriented solar cooling solutions for greater market penetration – in particular in the sunbelt regions. However, a common language in this interdisciplinary developmental area is missing, which limits effective communication and collaboration among stakeholders. The aim of this work package was to establish a common understanding of technical terms and core concepts in economics and financing that are necessary for the development of successful business and financing models for solar cooling. The following topics are covered:

1. Business Models vs. (Third Party) Financing.
2. Basic Financing Options for Solar Cooling Investments.
3. Business Models including Third Party Financing for solar cooling investments and services.
4. Life-Cycle Cost-Benefit Analyses to support Business Model development and financing solutions.

This work shall serve as a basis for better informed discussions among technical and non-technical stakeholders from various disciplines, which are crucial for advancing client-oriented financing and business models to achieve greater market penetration of solar cooling solutions. Further details can be found in the published D2 final report (Bleyl 2024).

D3: Roadmaps for Solar Cooling in Sunbelt Countries

Activity D3 was dedicated to provide guidelines and recommendations on the development of roadmaps and policy recommendations to accelerate and spread the development of solar cooling technologies. A literature review provided information and compared exemplary roadmaps and documents on cooling demand and solar technologies, respectively. The review results identify promising methods and possibilities in roadmap and implementation plan formulation. Furthermore, existing roadmap manuals and analyses and Task 65 results are introduced to provide background information and to collect input for new roadmap and policy recommendations.

The screening and review outcomes indicate that a linkage between the solar cooling technologies and their potential field of application on a national scale, directly targeting the most fruitful operation, is promising. As a final result of Activity D, an adapted and updated process recommendation on the roadmap development following a step-by-step approach has been developed. Additionally, a list of policy recommendations is delivered as potential guidance for policy makers to promote solar cooling technologies on a national level. Further details can be found in the published D3 final report (Strobel & Jakob, 2024).

D4: Booklet

A comprehensive summary in the form of a booklet will be published later in 2024.

D5: Workshops

The goal of work package D5 was to organise four half-day workshops dedicated to the industrial players (manufacturers and installers, consultants, policy makers) in sunbelt countries. This goal has been exceeded by far since 11 workshops have been organised and conducted altogether during the four-year period of Task 65. 567 participants have been recorded. Detailed information on the individual workshops as well as workshop agendas can be found in the published final report on D5 (Kohlenbach and Jakob, 2024).

D6: Stakeholder Engagement

A multitude of intermediate and final results has been generated during Task 65 and part of its activity was to ensure efficient communication of these results to all interest groups. Stakeholders from sunbelt countries have been selected as a specific interest group. These include end-users, industry, researchers, operators, policy makers etc. Work package D6 was tailored to this specific audience with a focus on knowledge transfer towards the different stakeholder groups in sunbelt countries. The following three steps have been implemented in order to achieve this:

1. **Identifying key stakeholders** around the sunbelt countries
2. **Involving stakeholders** through one-to-one meetings, workshops and conferences in their countries.
3. **Inviting stakeholders** to participate in demonstration projects

The process of identification firstly included collecting 90 individuals and organisations from the total observer list of Task 65. Secondly, a first email has been sent to 44 individuals and organisations in sunbelt countries identified from this collection. Thirdly, a second email and a questionnaire were sent to 19 individuals and organisations which expressed interest to proceed further. The analysis of questionnaire feedback provided a comprehensive list of topics of interest for stakeholders in sunbelt countries, Finally, 5 individuals and organisations expressed interest to get further involved in Task 65 goals. Invitations to workshops, conferences and personal one-to-one meetings were sent to all stakeholders interested during the following involvement/invitation phase of the process. The uptake on workshops was excellent with 63% of stakeholders participating in one or more workshops. Conference participation could not be quantified due to lack of participant statistics from each conference. Meetings were not requested by stakeholders despite opportunities for such being offered by Task 65 leaders whenever possible. Invitations to participate in demonstration projects have been continuously offered to Task 65 participants from the stakeholder group and three project proposals have been submitted together with Task65 experts and stakeholders from sunbelt countries. Detailed information on the process and the results can be found in the published final report on D6 (Kohlenbach and Jakob, 2024a).

4. Conclusions and outlook

In Subtask A (Adaptation) climatic conditions, applications, components and systems have been investigated and adapted tools and systems for sun belt countries have been developed. A GIS-based tool is now available for the global identification of possible solar cooling locations, taking into account technical as well as socio-economic factors. Subtask B (Demonstration) put the focus on design guidelines, performance indicators and standardization. An analysis of multiple case studies has been undertaken and lessons learned have been compiled. In Subtask C (Assessment & Tools), design tools have been analysed as well as assessment mechanisms have been developed. A variety of tools for solar cooling design is available. Subtask D (Dissemination) focused mainly on distributing the Task 65 results, but also developed new roadmaps for sunbelt countries with regard to the implementation of solar cooling systems. Financing models have been analyzed and recommendations for policy makers are given as a result.

5. Acknowledgements

This work has partially received funding from the German Federal Ministry for Economic Affairs and Energy (BMWi / PtJ) under grant agreement No. FKZ 03ETW024B (SorptionTakeOff).

The funding of Austrian's participation of IEA SHC Task 65 (FFG no. 883011) through the Austrian Research Promotion Agency (FFG), the program "research cooperation international energy agency" and the Federal Ministry on Climate Action, Environment, Energy, Mobility Innovation and technology is gratefully acknowledged.

This project has also received partly funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement no. 101138697 (RE-WITCH).

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