Task 65

What Role Will Solar Cooling Play For Sustainable Cooling In The Global South?

IEA SHC Task 65 on Solar Cooling for the Sunbelt Regions concluded after four years of investigating how to adapt, verify, and promote solar cooling (solar thermal and PV) as an affordable and reliable solution to the growing cooling demand in the world's Sunbelt regions - the Global South. Eighty-three experts from 17 countries, including four UNIDO GN-SEC (Global Network – Sustainable Energy Centres) countries (Egypt, Mozambique, Uganda, and Zimbabwe) analyzed the adaptation of existing technologies to the specific boundary conditions and optimization in terms of investment and operating cost and their environmental impact. Generally, they focused on the combination of cost reduction, simplifications of the systems, and stimulation of market conditions through policies. This article highlights the key results for implementation/ adaptation of components and systems for the different boundary conditions to develop a market uptake of solar cooling in the Sunbelt regions.

"The future of solar cooling lies in the Global South, where the demand for cooling will increase dramatically due to increasing heat waves and the climate crisis."

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Why This Task?

Air-conditioning (AC) accounts for nearly 20% of the total electricity demand in buildings worldwide and is growing faster than any other consumption in buildings, according to the IEA's The Future of Solar Cooling. The undisputed rationales for the increase are global economic and population growth and, thus, rising standards of living. Growth in cooling demand 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 to 6,000 TWh/a 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.

With an increase in cooling demand comes an 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 increases globally, so do AC-related greenhouse gas emissions, both from direct leakage of high Global Warming Potential (GWP) refrigerants, such as Hydrofluorocarbons (HFCs) and from indirect emissions related to fossil fuel derived electricity consumption. Solar cooling is intuitively a well-suited alternative because the demand for air-conditioning correlates quite well with the availability of solar energy. Interest in solar cooling has grown steadily over the last years. As of 2023, nearly 2,000 systems have been installed worldwide, as reported by IEA SHC's Solar Heat Worldwide. Solar cooling can be achieved by 1) operating a vapor compression air-conditioner with electricity generated by solar photovoltaic cells or by 2) 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.

Task Highlights – Main Results & Importance

From July 2020 to June 2024, a multi-disciplinary, international team of solar cooling researchers and industry representatives joined SHC Task 65:Solar Cooling for the Sunbelt Regions to investigate ways to make solar cooling applications

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more competitive and affordable in the Sunbelt regions. Based on the results, technical and economic suggestions for innovations for affordable, safe, and reliable Solar Cooling systems for the Sunbelt regions were developed. Below are a few key results from this work.

Climatic Conditions & Applications

Generally, the suitability of (solar) cooling systems and the specific applications are highly contingent on geographic location. To establish region-specific prerequisites for solar cooling systems, leveraging geographical data is a logical approach. This necessitates using a Geographic Information System (GIS) that can 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.

GIS software was used to combine geographical data in a way that local reference boundary conditions for solar cooling systems in the Sunbelt regions can be determined and evaluated. 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). As a result, potential sites and economic factors can be considered to identify (future) markets.

Further reading: SHC Task 65 report, *Climatic Conditions & Applications*.

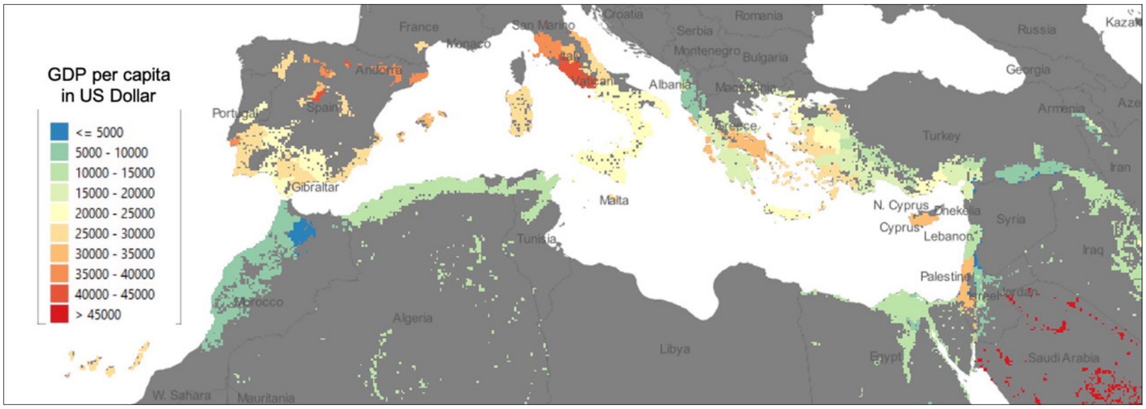

Figure 1. The Mediterranean region was used to identify the potential for a specific Solar Cooling System in building cooling applications. The analysis was conducted on a 10km raster grid, taking into account the Gross Domestic Product (GDP) levels.

Show Cases on System and Component Level & Adapted Components

A number of installed projects were examined to find the constituent elements employed in different solar cooling technologies and their relationships with various variables, including the type of solar collector, climate zone, application, and the components integrated into the systems. Solar cooling is 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 is expected to help expand 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 2 illustrates the demographic distribution of these projects.

The studies conducted included a diverse range of project types. Among these, 50% of the projects are

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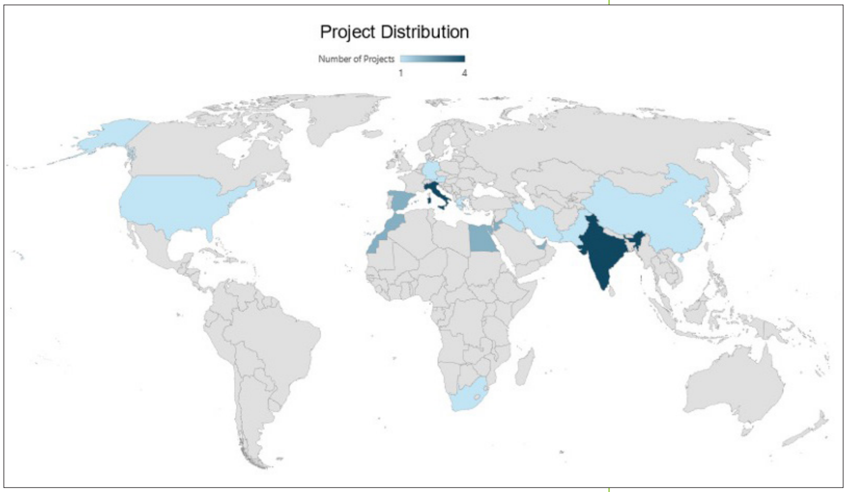

▲ **Figure 2. Case studies located in the Sunbelt region.**

currently in the implementation phase, 25% of the projects are in the conceptual phase, 19% are in operation with established outcomes, 3% are validated concepts, and the remaining 3% have been modeled using simulation tools like TRNSYS, Python, Matlab, or other mathematical modeling techniques. Additionally, the study 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 flat plate collectors and Fresnel collectors are equally prominent at 17% each. The research also indicates that Fresnel 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).

In terms of 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 the process industry. The remaining applications include district cooling, food processing and preservation, and high-rise buildings. This comprehensive analysis underscores the effectiveness and versatility of solar thermal cooling technologies across diverse climatic conditions, paving the way for their broader adoption in various sectors and contributing to sustainable energy solutions in Sunbelt regions worldwide.

For further reading: SHC Task 65 report, *Show Cases on Systems and Component Level & Adapted Components*

Standardized Solar Cooling Kits

For the market uptake of solar cooling, it is essential to have pre-designed and adapted solar cooling kits to meet the market needs of the Global South. Therefore, the Task work 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 are:

- Eight products/concepts were adapted to the constraints of the Sunbelt regions, including information on Sunbelt-specific adaptations or experiences.
- Medium-temperature solar systems used to operate two-stage absorption chillers increases competitiveness.
- Dust accumulation on collector systems can decrease performance by up to 20% per month. To minimize this impact, cleaning the system every 14 days is recommended, reducing the average performance loss to just 5%.

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- Lack of knowledge of design guidelines, including the effects of part load conditions and techno-economic boundary conditions, is a critical issue.
- Heat rejection systems in dry climates present significant challenges

For further reading: SHC Task 65 report, *Standardized Solar Cooling Kits*.

Design Guidelines

A set of design and system integration guidelines for solar cooling projects was developed. To support this effort, a comprehensive questionnaire was created detailing various solar cooling components, design aspects, sizing considerations, and sub-systems such as heat rejection units and cold distribution systems. Data from 10 case studies highlight the performance of solar cooling systems under varying boundary conditions. Additionally, three distinct case studies, each with its own scope and unique characteristics, are discussed in detail in the Task report, *Design Guidelines*.

In summary:

- 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.
- Integrating solar PV with vapor compression chillers is an emerging solution for decarbonizing cooling systems. A comparative analysis considering different load and weather profiles suggests that solar PV cooling can result in a lower levelized cost of cooling compared to solar thermal.
- Hybrid chillers emphasize 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, adopting such systems will be critical in shaping a greener, more energy-efficient cooling future.

For further reading: *SHC Solar Update – July 2024*

Standardization Activities

It's important to have a comprehensive understanding of the significance of standardized actions and key performance indicators (KPIs) in driving advancements in the field of solar heating and cooling systems. Therefore, the importance of standardization in promoting interoperability, ensuring quality, and fostering confidence among stakeholders was examined. In addition, the critical role of KPIs in assessing system performance, economic profitability, and environmental impact were investigated. As a final result, the SHC Task 65 report, *Standardization Activities*, provides a comprehensive roadmap outlining actionable strategies, recommendations, and initiatives to catalyze the widespread adoption of solar heating and cooling solutions. The Australian Standard AS 5389 emerged as a cornerstone for implementing these measures, providing a solid foundation for addressing the specific challenges and opportunities inherent to Sunbelt climates. The proposed list of actions aims to enhance the applicability of AS 5389 to Sunbelt climates by addressing specific challenges and opportunities.

These actions encompass various initiatives aimed at streamlining the integration of solar thermal heating and cooling systems, enhancing industry expertise, and promoting financial mechanisms to support sustainable energy solutions. The six proposed standardized actions to facilitate solar heating and cooling in the Sunbelt region market are:

1. Standardization / Best Practice Design: Develop standardized designs for solar thermal heating/cooling systems to accommodate various collector and chiller technologies and integrate them into existing systems. Standardization can lower initial system costs, increase stakeholder confidence, and promote local component development. Regulatory support, such as an extension of AS5389, is vital to estimate energy savings from these standardized designs.
2. Environment Upgrade Agreements (EUA): Encourage agreements that support environmental upgrades in buildings, potentially including solar thermal systems.
3. Training/Knowledge Dissemination: Promote training and knowledge sharing in the heating and cooling industry to enhance expertise and understanding of solar thermal technology.
4. On-Bill Finance: Explore financial mechanisms allowing customers to finance solar thermal systems through utility bills.
5. Energy Performance Contracts (EPCs) / Pilot Projects: Initiate pilot projects and EPCs to demonstrate the viability and benefits of solar thermal systems.
6. Energy Services Companies (ESCOs): Encourage the involvement of ESCOs in implementing and managing solar thermal projects.

Database for Technical and Economic Assessment

For the successful design of solar cooling systems, it is necessary to have a comprehensive database of technical and economic data for solar cooling components and Sunbelt

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		Cooling demand				Cooling in sectors								Technology								Env.		Scale			
No.	Country/ Institution	Demand analysis	Demand analysis by sector	Demand projection	Demand projection by sector	Domestic refrigeration	Commercial refrigeration	Industrial refrigeration	Transport refrigeration	Domestic A/C	Commercial A/C	Mobile A/C	Other	Solar Thermal	Solar PV	Absorption chiller	Adsorption chiller	Compression chiller	Split units/ heat pumps	Thermal energy storage	Increase of efficiency	GHG emission	potential GHG emission savings	National	Continental/ Regional	Global	Implementation Plan
1	Bangladesh	x	x	x	x	x	x	x	x	(x)	(x)	x	x	o	o	x	o	x	x	x	x	x	x	x	o	o	x
2	Cambodia	x	x	x	x	x	(x)	x	x	x	x	x	x	o	(x)	x	x	x	x	x	x	x	x	x	o	o	x
3	Kenya	x	x	x	x	x	x	x	x	x	x	x	x	o	x	o	o	x	x	x	x	x	x	x	o	o	x
4	Rwanda	o	o	o	o	o	o	o	o	x	o	o	o	o	(x)	o	o	x	x	x	x	(x)	o	x	o	o	x
5	Panama	x	(x)	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	x	o	x	(x)	o	x	o	o	o
6	India	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	o	x	x	x	x	(x)	o	x	o	o	x
7	Barbados	(x)	(x)	o	o	x	x	o	o	x	x	(x)	o	x	x	x	x	x	x	x	x	x	x	x	o	o	x
8	Lebanon	x	x	x	x	x	x	x	x	x	(x)	x	o	o	x	o	o	x	x	x	x	x	x	x	o	o	x
9	Usbekistan	o	o	o	o	o	o	o	o	o	o	o	o	x	x	x	x	o	o	o	(x)	x	x	x	o	o	x
10	UNEP	o	o	o	o	o	(x)	(x)	o	x	x	o	o	x	x	x	x	x	x	x	x	(x)	(x)	x	x	o	x
11	SEIA	o	o	o	o	o	o	x	o	x	x	o	o	x	x	x	o	x	(x)	x	(x)	x	(x)	x	o	o	o
12	EU	o	o	o	o	o	o	o	o	o	o	o	o	x	x	x	x	o	o	x	x	o	o	o	x	o	x
13	IEA	o	o	o	o	o	o	x	o	x	x	o	o	x	(x)	x	x	x	(x)	x	x	o	(x)	o	o	x	x
14	Austria	(x)	o	(x)	o	o	o	o	o	(x)	(x)	o	o	x	(x)	(x)	o	o	o	x	o	o	(x)	x	o	o	o
15	France	o	o	o	o	o	o	x	o	(x)	(x)	o	o	x	o	o	o	o	o	x	x	o	o	x	o	o	(x)

x	The indicator field is mentioned in the roadmap and is assessed/ given a role
(x)	The indicator field is mentioned once or twice, but not further treated
o	The indicator field is not mentioned

countries, supporting extensive assessments and providing insights into future scenarios. The database established allows a solid framework for sensitivity analyses and future scenario planning for solar cooling concepts. An internal Task 65 expert survey shows the average investment costs per kW cold for different system sizes:

- 2,100 €/kW for small ST-based or 1,500 €/kW for small PV-based systems (<10 kW),
- 1,600 €/kW for medium ST-based systems or 1,200 €/kW for medium PV-based systems (10-50 kW),
- 1,200 €/kW for large ST-based systems (50-100 kW) and
- 1,000 €/kW for ST-based systems over 500 kW.

These costs are critical for techno-economic analysis and future scenario planning. Economic parameters influencing key performance indicators (KPIs) include economic base data, consumption-based costs, operational costs, and capital costs. The Climate Profiling Tool helped to assess local weather conditions for solar cooling potential. Life-Cycle Cost-Benefit Analyses (LCCBA) were used to develop business models and financing solutions, emphasizing dynamic cash flow models. Learning curve models showed cost reductions through experience, though their application is limited by data availability for complex solar cooling systems. A detailed economic and financial LCCBA model focused on dynamic cash flow and KPIs such as internal rate of return (IRR), net present value (NPV), and levelized cost of energy (LCoE). Sensitivity and

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risk analyses helped to optimize project outcomes and support financial due diligence. The concept of 'Multiple Benefits of Energy Efficiency' was applied to solar cooling projects to capture additional benefits and drivers.

For further reading: SHC Task 65 reports, *Design Tools and Models* and *Technical and Economic Database for Assessment of Solar Cooling* and news article, *"Overview of Design Tools and Models for Solar Cooling Systems."*

Financing Models

As solar cooling solutions typically require high upfront capital expenditures, several new financing schemes suitable for solar cooling were investigated to provide relevant information. Potential clients may also perceive them as risky 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 – particularly 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 was to establish a common understanding of technical terms and core concepts in economics and financing necessary for developing successful business and financing models for solar cooling. The following topics are covered:

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

This work serves as a basis for better informed discussions among technical and non-technical stakeholders from various disciplines. These are crucial for advancing client-oriented financing and business models to achieve greater market penetration of solar cooling solutions.

For further reading: SHC Task 65 report, *Business Models and Financing Options for Solar Cooling*.

Guideline / Roadmaps & Policy Advice for Sunbelt Countries

To promote solar cooling in the Global South, guidelines and recommendations were developed to create roadmaps and policy recommendations for accelerating and scaling up the adoption of solar cooling technologies. Task experts conducted a literature and roadmap review to gather information and compare exemplary roadmaps and documents addressing cooling demand and solar technologies. The review identified promising methods and opportunities for formulating roadmaps and implementation plans (see Figure 3). The indicated linkage between solar cooling technologies and their potential field of application on a national scale, directly targeting the most fruitful operation, is promising.

Finally, this Task work updated and adapted step-by-step process recommendations for roadmap development and provides a list of policy recommendations to guide policymakers in promoting solar cooling technologies at the national level.

For further reading: SHC Task 65, *Roadmaps for Solar Cooling in Sunbelt Countries*.

Conclusion

Key Messages

The key messages and takeaways from the work of SHC Task 65: Solar Cooling for the Sunbelt Regioins are:

- Designing effective solar cooling systems in Sunbelt regions requires a comprehensive understanding of the climatic conditions to use solar resources for efficient and eco-friendly cooling solutions.
- Further demonstration projects are necessary to gain experience and create confidence in the technology in Sunbelt regions.
- The wide penetration of solar cooling in Sunbelt countries depends not only on the accomplishment of technical barriers.
- Non-technical barriers often play a critical role. Financing, policy advice, and dissemination/communication of success stories are among the important activities for overcoming these barriers.

According to the Cool Coalition report, *Global Cooling Watch 2023*, led by the IFC and UNEP, the cooling market in developing economies is projected to grow from approximately 300 billion to 600 billion USD, or more, by 2050. With billions of people worldwide affected by extreme heatwaves intensified by the climate crisis, improving access to sustainable cooling has become essential.

This highlights the timeliness and importance of this SHC Task. Solar cooling technology's key driver is its potential to reduce greenhouse gas emissions and peak electricity demand, especially in countries with high cooling needs and grid limitations. To tackle this challenge, SHC Task 65 adopted an innovative approach – adapting existing concepts and technologies to the Sunbelt regions, utilizing solar energy (either thermal or photovoltaic).

This article was contributed by Dr. Uli Jakob of Dr. Jakob energy research GmbH & Co. KG and SHC Task 65 Manager. To find more Task results and download free reports, visit the Task webpage.