Solar Cooling for the Sunbelt Regions

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Abstract

In 2016, air-conditioning accounted for nearly 20% of the total electricity demand in buildings worldwide and is growing faster than any other energy consumption in buildings. The main share of the projected growth in energy use for space cooling comes from emerging economies. 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 introduces the Task 65 and its first results, highlights the ongoing research projects and aims to attract a larger audience to get part of the initiative.

Keywords: Solar thermal cooling, PV cooling, Sunbelt regions, IEA SHC Task 65, MI IC7

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 (OECD/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 (OECD/IEA 2018). 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 day (OECD/IEA 2018). With the increase in demand comes the increase in the cost of electricity and summer brownouts, 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 2019 showed nearly 2,000 systems (IEA SHC 2020). Solar air-conditioning can be achieved by either driving a vapor compression air-conditioner with electricity produced by solar photovoltaic cells or by driving a thermal chiller with solar thermal heat.

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2. Adaption 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 IEA SHC Task 65 is aiming to develop 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 should cover 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 2021).

3. General objectives of IEA SHC Task 65

The key objective of this 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:

- Increase the audience and attention on solar cooling solutions through the combination of MI IC7 and IEA SHC activities and the entire stakeholders.
- Provide a platform for the transfer and exchange of know-how and experiences from OECD countries, already having long experiences in solar cooling, towards Sunbelt countries (e.g. Africa, MENA, Asia, …) and vice versa.
- 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.
- Establishing of 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. First results of the Subtasks

4.1 Subtask A – Adaptation

Different climates found in the Sunbelt Regions are characterised by particular boundary climatic conditions to be considered during the design process (e.g. temperature, humidity, presence of dust, availability of tap water, etc.). The selection and the actual effectiveness of all components and the performance of the solar cooling systems are strongly influenced by the combination of operating conditions such as solar irradiation, ambient temperature, relative humidity, wind, and other parameters. Once the conditions are documented through reliable data, the components and systems can be selected from a specific regional market or/and adequately adapted. In case that component/system cannot be operated under certain boundaries, the operation limits must be documented: a well-documented summary of available procedures, components and systems is a base for promoting solar cooling and demonstrate the current state of the art.

The following results have been achieved in Subtask A so far (October 2021).

A1: Climatic Conditions & Applications

In general, climatic conditions and typical applications for (solar) cooling are strongly depending on the location. Therefore, a geographic information system (GIS) has been used to process this data. GIS is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. Most relevant GIS data are already available from different sources, such as solar radiation data, climatic data, population data etc.

In activity A1, a GIS software is used to combine this data in such a way that local reference boundary conditions for solar cooling systems in the sunbelt regions can be determined. In the scope of this activity A1 these results are used to derive boundary conditions for solar cooling systems and its components. By analysing this data, information about locally applicable solar cooling systems will become available. This aims to understand the reference boundary conditions for adaptation of the components and solar cooling systems (link to Activities A2 and A3). By additional, using population density data, for example, gives a base for future market potential studies on certain products / technologies.

The first steps in Activity A1 has been the evaluation of how to combine and which dates to combine. In a first approach the following conditions and sources are considered:

- Geographic areas that are regarded to require cooling include latitudes between 40°N and 40°S.
- Solar direct normal irradiance (DNI).
- Population density/Built-up areas/Settlement levels.
- Climate zones (Köppen–Geiger climate classification system).

A2: Adapted components

A specific survey has been designed and spread among experts to better understand how to combine the existing components with the climatic boundary conditions and typical applications with the necessary adaptation from the technical point of view. The data are currently under the collection. The elaboration will take into account the involved countries and the Köppen climate classification (Figure 1). Such a climate classification divides climates into five main climate groups, with each group being divided based on seasonal precipitation and temperature patterns. This approach will provide an appropriate qualitative classification of systems and components consequently.

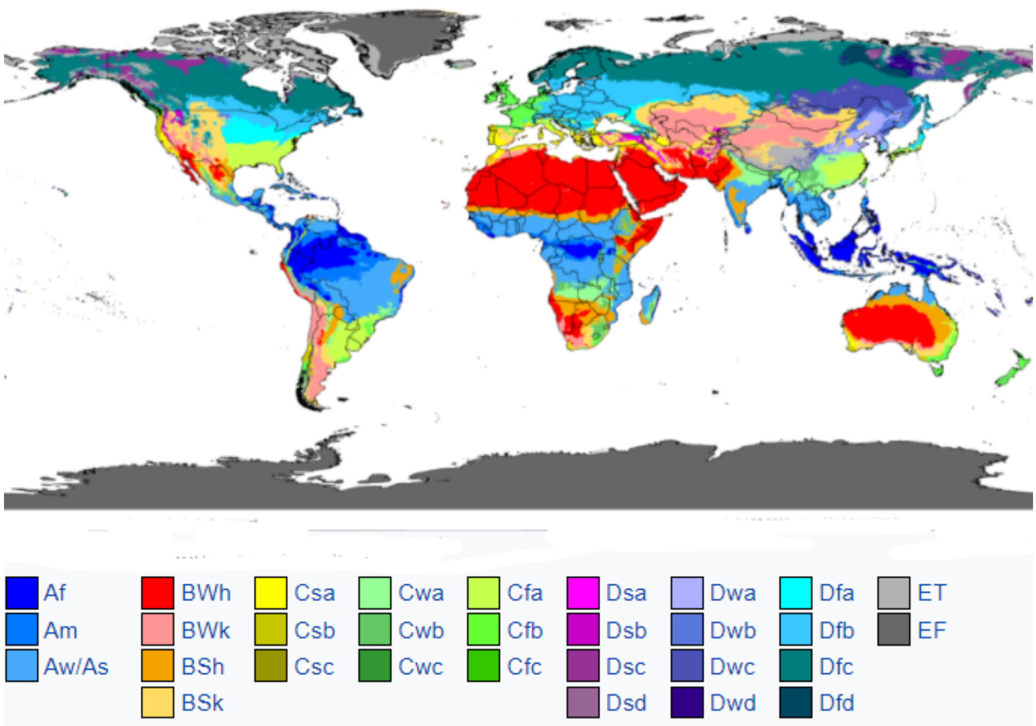

Fig. 1: Updated Köppen–Geiger climate map used for the classification of the data collected

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 technical reliable, economic viable (reasonable), 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.

A first step to enter the specific markets is to ensure know how transfer for current solar cooling system designs and monitoring guidelines. Raising greater awareness for the technology, its technical and economic potential among end users and operators is crucial for further dissemination. Lessons learned through previous programs (e.g. past four IEA SHC Tasks) will be recognized and shortcomings avoided. More challenging climatic conditions require adaptation of components and systems (Subtask A) that leads to new insights and additional lessons learned.

When introducing best practice demonstration sites, the quality of the delivered data must be beyond any doubt. The definition of necessary data quality in terms of resolution and accuracy needs to be provided clearly and checked for each of the solar cooling systems (and single component tests) provided by any participant. A four-eyes principle will be implemented to keep the quality on the self-imposed level.

Future wider implementation of solar cooling systems relies deeply on initial cost optimization. Currently, 40-60% of the life cycle costs can be allocated to these costs. Further important measures are reliable, durable components that reduce the replacement and maintenance costs. Solar cooling systems to date already reached very high efficiencies (e.g. electrical seasonal performance factors > 15, low water consumption for heat rejection, etc.). Correspondingly, the operational costs are low compared to the other costs (Neyer and Koell 2017).

However, that might be changing if challenging climatic boundaries in Sunbelt countries prevent highly efficient solutions. Clear decisions should already be drawn in Subtask A when adapting certain components or systems. Finally, one key towards affordable systems, is extensive standardization work on system (or parts of the systems e.g. collector field, heat rejection, pumps, etc.). Standardizing the design, the manufacturing process, the implementation and the commissioning phase can drastically reduce the initial costs and contribute to competitive

solutions.

When the quality of monitoring data is evident, there is a good base to initiate the improvement of the performance of the demonstration systems accordingly. The comparison of designed and monitored data will lead to lessons learned and to optimization measures. Finally, the economic criteria that will be elaborated together and shared with interested audiences through the dissemination activities.

Achievements for Subtask B to date (October 2021).

<u>B1 & B2: Surveys conducted</u>

Detailed questionnaires were designed and submitted to all Task 65 experts. The expert's feedback will provide an overview of established solar cooling systems and the various components in the Sunbelt Regions and will support the notion to derive integration guidelines for solar cooling projects.

- The implementation of solar cooling systems across the Sunbelt Regions is a key activity among this Task. The collection of system designs and evaluated monitoring data of existing and new demonstration plants is the basis for the calculation of technical and economic KPIs.

  The comparison of calculated, designed, and practical field performance is used to evaluate and improve the performance of the solar cooling plants. Lessons learned can be derived out of the deviation of design and field performances as well as general design rules.

- The large diffusion of solar cooling technology in the market does not depend solely on the technical and economic aspects, but also on the systematic approach for the design and installation of systems in different climates. This will present manageable guidance for easy integration to professionals who are not experts on the specific technology.

  Even though design guidelines are well documented in deliverables of previous tasks (Task 48, 53), the current activity leverages this knowledge to include new concepts, such as a) hybrid cooling systems (including solar thermal, solar Photovoltaic), b) systems for high solar cooling fraction, and c) standard modular packages for solar cooling solutions. This activity is dedicated to keep an eye on the technical research and developments as well as to produce an extensive report on “Good Practice” examples of existing solar driven cooling systems.

<u>B3: Key Performance Indicators</u>

Although the key performance indicator definition was already proceeded often, there is still no standard and during the entire solar cooling community often a mix of non-comparable KPIs is used to express the quality of systems. This is not only confusing for end-users / operators / policy makers but also misleading the discussion among the experts. Thus, first the collection of existing technical and economic KPIs among finalized and ongoing IEA SHC Task but also from other sources is in the focus.

Information collection on definition and update of KPIs for technical and economic point of view for different stakeholders, especially end consumers, operating companies, ESCOs, policy makers, etc. has started.

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.

Assessing solar cooling along the sunbelt countries is further challenging due to different local framework conditions such as energy prices, investment cost of components, energy conversion factors, conventional technical reference systems. A comprehensive database of these technical and economic parameters is crucial to deliver prompt and accurate KPIs. However, beside detailed local results a set of generalized KPIs should be provided under standardized technical and economic boundaries to allow comparison, general conclusions and trend analyse across different solar cooling concepts (e.g. PV vs. ST, SE vs DE, etc.)

A thorough technic-economic-financial analyses based on an LCC assessment allows to answer questions like: (i) Which technical solutions to implement (e.g. higher CAPEX investment in exchange for lower OPEX)? (ii) Influence on cash flows? (iii) Calculation of bids to clients (iv) Effects of equity and debt financing shares? (v) Needs for subsidies/grants? (vi) Which parameters to monitor? Target-performance comparison? (vii) project reporting and decision making (e.g. to management boards, project stakeholders) (viii) financial engineering for reporting, negotiations & due diligence with Financiers (FI) (ix) subsidy or funding demand calculations (amount and timing) for policy makers … and many more.

Several tools, models and methods are available, which need to be screened, evaluated and adapted for solar cooling in sunbelt countries. A great number of these tools and methods are well known or even developed by previous IEA Task participants. However, taking the targeted countries and the number of new interested participants an iteration for reviewing should be set before getting into action of adaptation.

Finally, when all question can be answered satisfactorily with the corresponding tools and KPIs there is a need to show the future perspective of solar cooling. Thus, sensitivity analysis on most critical parameters are of great interest. It is to analyse the potential of future developments of conventional technology, energy prices and optimization potentials of components/systems of solar cooling. These parameters are e.g. investment costs (solar/ conventional), electricity price (energy/capacity), electrical efficiency (solar/conventional), etc.

The following results have been achieved in Subtask C so far (October 2021).

C1: Design tools and models

It is to review and adaptation of tools and models for technical and financial assessment and design for solar cooling and the different project's phases from pre-feasibility to simulation to monitoring. Different solutions are available and of interest among the interested participants (from mobile apps to dynamic simulation models for consultants, manufacturer, researcher, etc.), which need to be discussed and consolidated. Each of the tools and models can support the implementation of solar cooling in sunbelt countries, if it is used target oriented.

The focus in this activity is the documentation of the tools and their specific application, to provide measured data for validation of the tools and the adaptation of selected ones for sunbelt countries. The following sections described the methods applied to achieve the main aim. At the time of writing this report the research based on a literature review has been completed, and a set of questionnaires was developed and distributed among the participants.

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) has been started and is the bases 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 working closely with B3 activity, the review of existing tools (other IEA SHC Task, …) and methods for technical (SPF, PER, fsav, etc.) and economic (LCC/CAPEX/OPEX, LCOH/LCOE, LCCBA 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 adaption of methods and integration of the database (C2) are the core activities. Whereof 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 intermediate and finale results need to be spread across the different stakeholders from end-users, industry, operators, policy makers, etc. across the sunbelt countries and the interested audience. 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 2021), the following results have been achieved in subtask D.

D1: Task65 website established and scientific papers published

A website included into the IEA SHC portal has been created, see https://task65.iea-shc.org/. This website profits from the crosslinks among the participants of Task 65 and benefits from their popularity, resulting in increased page views. This website firstly presents the Task purpose and activities and secondly the Task results. It also lists all Task participants and observers.

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.

Publications so far include:

- Jakob U. and Neyer D. (2020). "Solar Cooling for the Sunbelt Regions – a new IEA SHC Task". Proc. of EuroSun Conference 2020
- Neyer D. and Jakob U. (2020). "Solar Cooling for the Sunbelt Regions – a new IEA SHC Task". Proc. of 6th Yangzi River Delta International Conference on New Energy 2020

D5: Workshops conducted

- SHC Solar Academy Training for CCREE, 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)

D3 & D6: Guidelines and stakeholder engagement

Work has been started on the compilation of new guidelines for solar cooling design with a focus on the specific constraints and opportunities in sunbelt countries. Further, a first round of identifying potential stakeholders in sunbelt countries has been completed, with a milestone achieved in time. The stakeholders shall then be encouraged and assisted in initiating first solar cooling projects in their respective countries.

5. Strong industrial involvement

The IEA SHC Task 65 aims to strengthen the relationships between stakeholders from research and industry and the public to raise awareness of the cooling markets in the Sunbelt countries for solar cooling in future strategies for energy and CO2 reduction in buildings and industrial processes. Therefore, the (existing) technologies need to be adapted to the specific boundary conditions, analyzed and optimized in terms of investment and operating cost and their environmental impact (e.g., solar fraction), and compared and benchmarked on a unified level against reference technologies on a life cycle cost basis.

The strong interest by industry and business is reflected in the number of SHC Task 65 participants from solar thermal collector manufacturers, sorption chiller manufacturers, system suppliers, consultancies, business developers, and ESCOs – overall, 50% of the 77 Task experts are from industry and SMEs.

6. 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, Solar Cooling is still a small niche market with about 2,000 systems deployed globally as of 2020. Due to changing distribution channels and B2B sales of the sorption chillers, the tracking of newly installed solar driven systems is difficult and can only be estimated. Small units with capacity lower than 20 kW are getting more compact (and thus cheaper in upfront costs) and focused the mass markets. The sector of medium to large scale projects, 350 kW - 2,000 kW, is dominated by engineered systems. Still 70% of the small and medium capacity (<350 kW) solar cooling systems worldwide are installed in Europe.

Consequently, the focus on potential markets for solar cooling technologies is becoming more and more important to get out of a niche market. Therefore, the knowhow capitalized in OECD countries (Europe, US, Australia, etc.) on solar cooling, both thermal and PV, has to be adapted and transferred to Sunbelt countries such as Africa, MENA, Asian countries, which are all dynamic emerging economies. For this reason, new developments and innovations for affordable, safe and reliable cooling systems for the sunny and hot climates in the Sunbelt regions worldwide, like Brazil, have been started such as the IEA SHC Task 65 (Jakob et. al. 2020) cover the medium to large size segment of cooling and air conditioning between 2 kW and 5,000 kW.

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