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10 key principles for successful solar air conditioning design – A compendium of IEA SHC Task 48 experiences

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ABSTRACT

The results of past and ongoing activities, in successive IEA SHC (solar heating and cooling) Tasks, suggest enormous potential for solar cooling technologies to reduce greenhouse gas emissions. However, solar thermal cooling still faces barriers to emerge as an economically competitive solution. IEA SHC Task 48 was introduced to gather learnings from existing installations, and to find technological and market solutions, which could enable industry to deliver solar thermal driven heating and cooling systems that are efficient, reliable and cost competitive.

The selected experiences of these research activities were clustered into 10 qualitative key principles for successful design and operation of SHC systems. Three existing systems are fully discussed in a solar cooling design guide (Mugnier et al., 2017). This paper aims to introduce these key principles in its general format. The background to the qualitative statements is explained, supplemented with examples from the context of Task 48 and compared with recent literature. Furthermore, a survey was conducted among SHC experts, who provide an assessment of the importance of the principles.

The result shows that all principles have their eligibility. However, it turns out that there are three main categories of principles: (i) essential, (ii) important and (iii) controversial. Following the key principles is not a guarantee, but they can support researchers, designers and contractors to implement solar heating and cooling systems successfully.

1. Introduction

Solar Driven Heating and Cooling (SHC[1]) Systems are a promising solution to cover the rising demand of air-conditioning. Due to its potential to reduce greenhouse gas emissions, solar driven systems are included in the International Energy Agency (IEA[2]) SHC Strategic Plan Key Technologies (Murphy, 2009). Several IEA SHC Tasks related to solar air-conditioning have been completed and supplied a considerable collaborative international effort to develop this technology from fundamental R&D, to demonstration projects, and to market introduction.

During operation of IEA-SHC Task 25 (1999–2004) an outlook for solar cooling was delivered to initiate industrial development and encouraging maturation of the technology. Tools and methods to support market introduction of the emerging technology were created during Task 38 (Henning, 2006). The efficiency and reliability of the latest generation of solar cooling systems (at that time) were evaluated and demonstrated – pilot installations were analysed in detail. Data analysis from these installations has shown that under certain conditions and with a considerable effort during design, installation, commissioning and operation, the technology is reliable, promising and competitive in terms of energy performance and environment amenity.

The number of commercial deployments has increased steadily, and interest in solar air-conditioning (SAC[3]) has grown over the last years. A survey by Mugnier and Jakob (2015) has estimated the number of worldwide installations at nearly 1200 systems in 2014. The installation growth is shown in Fig. 1.

However, this promising technology was perceived to face two main issues: (1) a general lack of economic competitiveness – as is the case

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[1] SHC – Solar Heating and Cooling.
[2] IEA – International Energy Agency.
[3] SAC – Solar air-conditioning.

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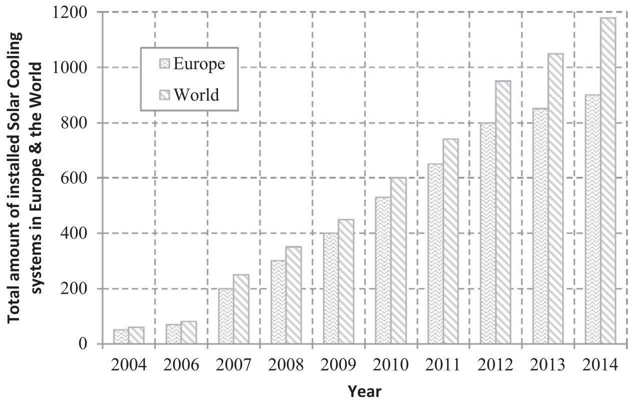

Fig. 1. Estimated number of solar cooling systems worldwide (Mugnier and Jakob, 2015).

for many renewable energy technologies unless incentives are in place; and (2) lack of proven record of long term energy performance and reliability. Consolidating previous enhancements, made under Task 25 (Henning, 2009) and Task 38 (Henning, 2006), Task 48 (Mugnier, 2011) was established to address these barriers and support the development of the growing solar cooling industry.

2. Methodology

This section contains background about the work and focus of IEA SHC Task 48, resulting in 10 comprehensive key principles in Mugnier et al. (2017). Complementing this general overview is a recent survey of solar cooling experts to gather their opinion and evaluation of the 10 key principles. The main reason for conducting the survey is to get broad, international feedback about complications experienced during implementation of solar thermal cooling, and to identify work on further optimization of design attributes for ongoing research work.

2.1. General Task activities and work

IEA SHC Task 48 "Quality Assurance and Support Measures for Solar Cooling" was a project conducted by a group of researchers and practitioners from 9 countries (Australia, Austria, Canada, China, France, Germany, Italy, Singapore and USA). It aimed to find solutions to enable industry to deliver solar thermal driven heating and cooling systems that are (i) efficient, (ii) reliable and (iii) cost competitive. These three major targets were achieved through the following activities, grouped into four subtasks (Fig. 2):

(1) Development of tools and procedures that characterize the performance of the main components of SAC systems (Calderoni et al., 2016)

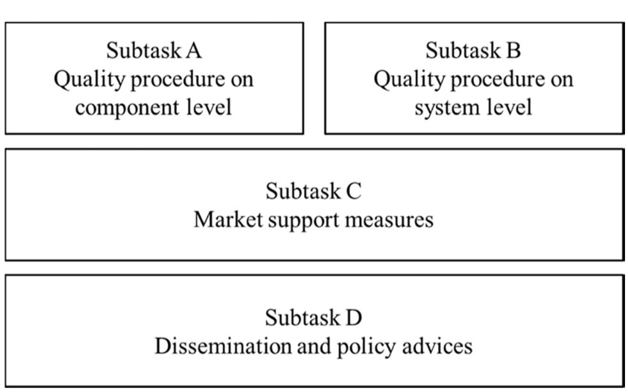

Fig. 2. Schematic of the main activities in IEA SHC Task 48 (Mugnier, 2016).

(2) Creating practical and unified procedures for specifying the best technical configurations for complete integrated SAC systems (Morgenstern et al., 2016).
(3) Development of standards and procedures to identify and validate the quality of SAC systems under different scenarios (Neyer et al., 2016a).
(4) Production and dissemination of information to promote solar thermal driven cooling and heating systems (Jakob et al., 2016)

The scope of the Task includes the technologies for production of cold water (e.g. Melograno et al., 2015) or conditioned air by means of solar thermal heat (e.g. Calderoni, 2015). It starts with the solar radiation reaching the collector, includes auxiliaries (Helm et al., 2015), heat rejection (Fedrizzi et al., 2014) and ends with chilled water and/or conditioned air transferred to the application. While the cold distribution system in the building, and the interaction of the building with the technical equipment, is not the main topic of the Task, this interaction was discussed in specific cases, where necessary. Systematic characterization of SHC systems (Menegon and Fedrizzi, 2015), assessment of technical and economic performance (Neyer et al., 2015b) and best practice examples (Selke and Frein, 2015) were collected.

Main technical key figures (defined by Neyer et al. (2015b)) to express the quality of SHC systems are the non-renewable primary energy ratio (PER_{NRE}[4]), the non-renewable primary energy savings ($f_{sav.NRE}$[5] – comparison of PER_{NRE} of SHC System with PER_{NRE} of a reference system) as well as an electrical equivalent seasonal performance factor (SPF_{equ}[6]). From economic point of view, the main key figure is defined and expressed as CostRatio (CR[7]). Under the consideration of specific investment, replacement, operation- and consumption-based costs, the annualized costs for the entire SHC system and the defined reference system are calculated by using the annuity method. Based on these costs the levelized life cycle cost (levelized cost of energy: LCOE[8]) are computed. To avoid a discussion of absolute costs the CostRatio is calculated following Eq. (1).

$$CR = \frac{LCOE_{SHC}}{LCOE_{REF}} \tag{1}$$

The CostRatio is defined as the relation of levelized life cycle cost of the solar heating and cooling system to an equal capacity business as usual reference system.

The IEA SHC Task 48 was completed in summer 2015. 20 final deliverable reports and tools have been completed in different activities by Task 48 experts. The full content of the reports is available online at the Publications or Tools Section of the Task 48 website (http://task48.iea-shc.org/; Mugnier, 2011).

After several years of active research and analysis of commercial systems, Task 48 has demonstrated that solar heating and cooling systems can be financially attractive in certain applications under certain boundary conditions. Analysis of the total annualized life cycle cost of good practice solar heating and cooling installations was performed by Neyer et al. (2015a) and Neyer et al. (2016a) using standardized cost assumptions. Ten systems, representing a wide range of alternative combinations of applications and designs, were analysed. The majority of the plants and their solar yields are used in multiple way (heating (SH[9]), cooling (C[10]) and domestic hot water (DHW[11])). Those, which are used for cooling only over the entire year, are marked as "C only". If the system is designed to cover 100% of the loads, it is summarized

[4] PER_{NRE} – Non-renewable primary energy ratio.
[5] $f_{sav.NRE}$ – Non-renewable primary energy savings.
[6] SPF_{equ} Electrical equivalent seasonal performance factor.
[7] CR – CostRatio.
[8] LCOE – Levelized cost of energy
[9] SH – Space heating.
[10] C – Cooling.
[11] DHW – Domestic hot water.