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A review of thermal energy storage technologies and control approaches for solar cooling

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ABSTRACT

This paper presents a review of thermal storage media and system design options suitable for solar cooling applications. The review covers solar cooling applications with heat input in the range of 60–250 °C. Special attention is given to high temperature (> 100 °C) high efficiency cooling applications that have been largely ignored in existing reviews. Sensible and latent heat storage materials have been tabulated according to their suitability for double effect and triple effect chillers. A summary of system designs for water storage (sensible heat), and phase change material storage (latent heat) has been provided. The article summarizes literature related to solar thermal air-conditioning systems from a material level as well as plant level considerations. This includes evaluating various control strategies for managing the thermal store, that aid in optimal functioning of a solar air conditioning plant. Modeling approaches are reviewed for sizing the solar thermal store, highlighting the large difference seen in specific storage size when applied in different applications.

Contents

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1. Introduction

Solar thermal cooling systems convert incident solar radiation into heat (through solar thermal collectors) and use this heat to generate cooling through a thermally activated cooling device such as an absorption or adsorption chiller, desiccant system or ejector refrigeration system. There is growing interest in solar cooling and an increasing number of installations around the world [1–3].

Unfortunately, solar energy is an intermittent resource. While solar photovoltaic technology is becoming increasingly cost effective at producing electrical energy, it cannot provide “firm” power without the extra cost of battery storage. Consequently, when aiming for a predominantly solar powered electricity grid, system planners must consider the full cost of both (i) energy supply and (ii) diurnal matching with demand, including the resulting extra cost of storage.

In warm climates, where air-conditioning is responsible for a large fraction of greenhouse gas emissions and dominates peak electricity demand [4], solar cooling offers an alternative approach for both reducing emissions and managing solar intermittency. In particular, solar thermal cooling technology offers a much cheaper approach for storing energy, leading to reduced overall system cost.

Just as the low cost of thermal storage is a key justification for concentrating solar power in the wholesale electricity market, low cost thermal storage may prove a key benefit for managing energy flows in the retail electricity market. The use of thermal storage, in a solar cooling system, can also increase the fraction of the total building energy consumption that can be supplied by solar [1,5–7].

This article presents a review of thermal storage media, system design options and controls suitable for solar cooling applications.

Though there have been review papers pertaining to thermal energy storage, they mainly focussed on storage media and heat exchanger design aspects of a solar cooling system [8–10]. There is also a wealth of literature available on thermal storage for solar thermal power generation systems (e.g. [11]).

However, none of these reviews have sufficiently documented the integration aspects of a thermal storage system in the solar cooling plant design, or covered the system control approaches required for managing charging and discharging of the thermal store in order to maximize cooling output and achieve robust operation.

In addition to covering these thermal storage integration issues, this review focuses significantly on thermal storage for high efficiency double effect and triple effect absorption chillers. This is a more recent area of solar cooling research with the potential for improving the overall economics of solar thermal cooling systems, because high chiller efficiency can potentially enable solar collector area to be reduced. White and Goldsworthy [12] highlight the importance of high efficiency chillers as the only way to actually increase the value of collected solar heat, compared with just using the solar heat (as is for hot water or space heating) without further conversion to cooling. However thermal storage becomes more problematic in these systems because expensive pressure vessels are required when using water as the thermal storage medium.

2. Solar cooling system layout and the integration of thermal storage

A typical solar cooling system with an absorption chiller is represented in Fig. 1.

This generic solar thermal cooling system consists of two flow loops separated by the hot thermal storage component. A solar heating flow loop conveys heat from solar thermal collectors to the thermal store. A thermal cooling flow loop conveys heat from the thermal store to the thermal cooling device. When the heat arriving from the collectors exceeds the heat being consumed by the thermal cooling device, then the thermal store is charged. Conversely, when the demand for heat to the thermal cooling device exceeds the supplied solar heat, the thermal store is discharged to match demand.

The storage medium in the thermal store, can store heat in the form of either (i) sensible heat, (ii) latent heat (that involves a phase change of storage material) or (iii) in the form of reversible physio-chemical reactions. Factors such as energy storage density, operating temperature, mechanism of heat exchange and cost play

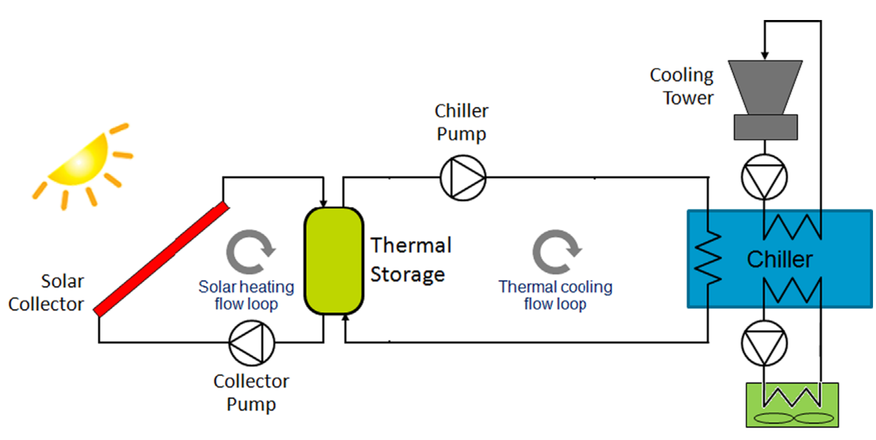

Fig. 1. A generic solar thermal cooling system [13].