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Performance analysis of a novel control system for solar collectors coupled with sorption chillers

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ABSTRACT

This paper presents work on a holistic approach for improving the overall design of solar cooling systems. Newly developed methods for hydraulics and control were used to redesign an existing pilot plant. Measurements taken from the newly developed system show that target temperature control leads to an 81% increase of the Solar Cooling Efficiency (SCE) factor compared to the original pilot system. In addition to the improvements in system design, new efficiency factors for benchmarking solar cooling systems are presented. The Solar Supply Efficiency (SSE) factor provides a means of quantifying the quality of solar thermal charging systems relative to the usable heat to drive the sorption process. The product of the SSE with the already established COP of the chiller, leads to the SCE factor which, for the first time, provides a clear and concise benchmarking method for the overall design of solar cooling systems.

Analyse de la performance d'un nouveau système de régulation des capteurs solaires couplés aux refroidisseurs à sorption

Mots clés : Énergie renouvelable ; Capteur solaire ; Système à sorption ; Conception ; Performance ; COP

1. Introduction

As the world's population continues to grow, its hunger for energy is becoming more acute, thus putting an unsustainable strain on fossil fuel resources. One of the main contributors to this problem is the demand for cooling in buildings. Renewable alternatives include solar-driven cooling systems. Generally, there are two different kinds of solar cooling methods: (i) electrically-driven solar cooling systems, for example, compression chillers driven by PV generated

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Nomenclature

COP [–] Coefficient of performance for cooling applications, ratio of cooling output to the driving heat input
SSE [–] Solar supply efficiency, ratio of direct usable solar energy to total solar output
SCE [–] Solar (supply) cooling efficiency, ratio of cooling output to total solar output

Subscripts
PLC Programmable logic controller
VSHP Valve storage heat primary side
VSHS Valve storage heat secondary side
HT High temperature
MT Medium temperature
LT Low temperature

electricity; and (ii) thermally driven solar cooling systems, for example, sorption chillers driven by heat generated by solar thermal collectors (Hartmann et al., 2011).

For the electrical systems, small-scale split-units are widely available and are mostly driven by fossil generated electricity. Due to their widespread use, these compression chillers are comparably cheap and easy to install. It is also possible to power these chillers using PV generated electricity. However, the high exergy content of electricity makes this an undesirable solution. Instead, electricity should be used only for those applications for which there is no alternative, such as, electrical motors, computers and illumination (Marletta et al., 2008).

Solar-driven sorption chiller systems offer the potential to save significant quantities of primary energy. Even if supplemented with a fossil-based system, primary energy savings from 38% to 53% are achievable (Pietruschka et al., 2010). However, compared to electrical systems, the thermal systems are not yet established within the market (Langniss et al., 2007). Currently, very few systems have been installed around the world (Sparber et al., 2009). Such systems still require a significant investment of effort in order to ensure reliable and efficient operation (Jakob, 2010).

The wide range of components available leads to a variety of possible implementations and many unresolved problems. This requires a holistic approach to their design in order to realise the basic idea of solar cooling. In addition to the use of renewable energy sources, sustainable and market needs have to be considered.

Previous investigations into solar cooling systems have focused mainly on the system components such as the chiller, the collector, or the heat rejection system, and therefore have not considered the relation between supply and demand of an overall energy system about which there is limited published work. However, this correlation is extremely important for a highly efficient system with good control.

This paper presents a newly designed state-of-the-art solar-driven cooling system which has been developed by taking a holistic view of the supply and demand sides of the energy system. This has been done by combining a generic design for hydraulics with a newly developed solar cooling system controller (Jakob and Saulich, 2008).

Section 2 describes a pilot plant built in 2007 and the redesigned system of 2010. By identifying comparable operating conditions, the performance of both systems is compared in Section 3, using newly defined efficiency factors. Section 4 contains the conclusions regarding the performance of the newly developed concept.

2. Methods

2.1. *Solar cooling pilot system, Rimsting 2007*

In 2007 a pilot plant was built in Rimsting, Germany to provide the cooling load for a single-storey office building occupied by the company SolarNext AG. Commissioning took place in March 2007.

2.1.1. *Description of 2007 pilot plant*

The main heat source for driving the single-effect absorption chiller is a solar thermal plant with a gross collector area of 37 m^2. This is supplemented with a 30 kW oil-fired boiler (Fig. 1). The flat plate collectors were connected to three parallel groups with six collectors in series in each. The pipe connections were arranged according to the Tichelmann-system (same length, same pressure drop and same flow rate for parallel collector groups).

The solar thermal plant was extended in 2008 by a further 36 m^2 of vacuum tube collectors. Here, seven collectors in series were connected to three parallel groups.

One primary pump supplies both collector areas with antifreeze fluid. As an active protection against overheating, an additional fan coil was installed outside the building within the primary solar circuit. In the case of no heating demand in summer, this meant that the generated solar thermal energy would not cause any damage to the plant by overheating any components.

A plate heat exchanger separates the solar fluid from the heating circuit water. The secondary solar pump transports heating circuit water from the bottom of the hot water storage tank, through the heat exchanger and back to the top of the storage tank.

To store the solar thermal energy, two tanks, each with 1000 L capacity were installed in parallel. For charging the hot water storage, the tanks were hydraulically separated via six 2-way valves into three levels (‘top’, ‘middle’ and ‘bottom’) which can be charged separately by opening and closing appropriate valves.

Discharging of the solar loaded hot water storage tanks was managed by a return flow boost of the oil-fired boiler. This means that the return flows of heating circuit or sorption chiller supply were switched to the bottom of the storage tanks. Via the top of the storage tanks the solar thermal heated water flows to the return inlet of the oil-fired boiler. In the case of insufficient heating, the pre-heated water is heated further using the oil-fired boiler to provide the necessary heat demand.