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Energy assessment of solar cooling thermally driven system configurations for an office building in a Nordic country

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HIGHLIGHTS

- We assessed cooling solar-driven thermal solutions for office building in Finland.
- We assessed two connections between storage tank, solar collectors and chiller.
- The parallel connection between solar collectors and chiller showed better results.
- Shaving summer electricity peaks and heating–cooling energy savings are achieved.
- Such cooling technology can potentially allow CHP plants to operate also in summer.

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ABSTRACT

Thermal cooling systems are particularly attractive in locations supplied by district heating based on cogeneration heating plants (CHP). Moreover, solar thermal energy is a major renewable source for the provision of thermal energy, fulfilling demands for space heating, domestic hot water, process heat, and cooling. This energy source can be suitably used also in Nordic Countries.

The presented paper focuses on two configurations of a cooling solar-driven thermal system for an office building located in Finland. Dynamic simulation approach has been used through TRNSYS software. In particular, the configurations differ from the connection between the hot storage tank, the solar collectors and the chiller. Particularly, in the first configuration only the tank can supply the chiller (Case 1), while in the second, the chiller can be supplied either by the tank or the solar collectors directly (Case 2). System performance indexes, in case of district heating as main building heating supply system in winter and as auxiliary heating system for the chiller in summer, have been evaluated as a function of the tank and solar thermal field sizes.

Results show that Case 2 has better performance than Case 1, because of the versatility shown in summer. Particularly, when the solar irradiance is low, Case 2 solutions perform far better than Case 1 solutions, benefitting from the direct connection between the solar collectors and the chiller. This study has highlighted also the potential of this technology in cold climate areas supplied by means of DH based on CHP plants. Indeed, the adoption of such cooling technology, in addition to reduce both heating and cooling consumed energy and to shave summer electricity peaks, can potentially allow some CHP plants to operate also in summer, fulfilling the future energy networks aims: being able to provide electricity, heat and cooling energy.

1. Introduction

Solar energy is a very valuable renewable source for the provision of thermal energy. Particularly, it can be used to supply energy for space heating, domestic hot water, process heat and also space cooling. In accordance with the International Energy Agency (IEA), by 2050 solar technologies could provide approximately 17% of the total energy used for cooling world-wide [1]. This energy source can be effectively used also in Nordic Countries. Indeed, although solar irradiation is lower in Northern Europe compared to South Europe, the difference with central Europe is not large as commonly believed [2]. Important to mention is that, as in other European countries, Nordic Countries are experiencing high peaks of

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Nomenclature

CHP	cogeneration heating plant
COP_{th}	coefficient of performance of the chiller [–]
Cp	heat capacity of the indoor distribution system carrier fluid [kJ/(kg K)]
DH	district heating
DHW	domestic hot water
$E_{i,in}$	final energy consumption (electricity based systems) [kW h]
E_{P1}	final energy consumption of the solar circulation pump (primary side) [kW h]
E_{P2}	final energy consumption of the solar circulation pump (secondary side) [kW h]
E_{P3}	final energy consumption of the circulation pump which supplies the desorber [kW h]
E_{P4}	final energy consumption of the dry cooler circulation pump (chiller side) [kW h]
E_{P5}	final energy consumption of the dry cooler circulation pump (dry cooler side) [kW h]
FC	free cooling
PER	primary energy ratio [–]
PER_{sum}	summer primary energy ratio [–]
PER_{win}	winter primary energy ratio [–]
Q_{CD}	useful cooling distribution system supplied energy (building cooling needs) [kW h]
Q_{ch}	cold energy produced by the chiller [kW h]
Q_{d}	hot energy consumed by the desorber [kW h]
Q_{DH}	district heating supplied energy [kW h]
$Q_{DH,d}$	district heating supplied energy to the desorber [kW h]
$Q_{DH,b}$	district heating supplied energy to the building [kW h]
Q_{HD}	useful heating distribution system supplied energy (building heating needs) [kW h]
$Q_{i,out}$	useful supplied energy [kW h]
$Q_{i,in}$	final energy consumption (non-electricity based systems) [kW h]
Q_{sol}	heat produced by means of the solar thermal collectors [kW h]
$Q_{sol,DHW}$	heat produced by means of the solar thermal collectors for supplying and DHW [kW h]
$Q_{sol,heating}$	heat produced by means of the solar thermal collectors for supplying building heating energy [kW h]
$Q_{sol,chiller}$	heat produced by means of the solar thermal collectors for supplying the chiller (desorber) [kW h]
Q_{WD}	useful water distribution system supplied energy (DHW) [kW h]
SF_{c}	cooling solar fraction [–]
SF_{h}	building heating solar fraction [–]
SF_{h+DHW}	building heating + DHW solar fraction [–]
SF_{DHW}	DHW solar fraction [–]
SF_{tot}	total solar fraction [–]
SHC	solar heating and cooling system
SPF_{el}	electrical seasonal performance factor [–]
$SPF_{el,sum}$	summer electrical seasonal performance factor [–]
ε_{DH}	district heating primary energy factor [–]
ε_{el}	electrical primary energy factor [–]

electricity consumption in summer due to the booming of the installation of conventional vapour-compression cooling chillers [3].

Solar energy can solve this issue. Indeed, it represents an attractive option to decrease the electricity and fossil fuels consumption as well as the dependency of imported energy [4]. Three recent International Energy Agency tasks, belonging to the solar heating and cooling programme, have stressed this concept, focusing on solar cooling systems: Task 38, 48 and 53 [5–7]. They have distinguished solar cooling systems in two categories: solar cooling driven system and PV cooling driven system. The first consists of thermally driven cooling machines coupled with solar thermal collectors, while the second electricity driven cooling machines coupled with PV panels. PV cooling driven systems seem to be now more economically feasible in Europe than the other typology [8,9]. However, if there is no feed in tariff applicable to PV system, both solar cooling typologies have same economic benefits [10]. Solar thermal cooling systems are also very attractive when solar thermal energy is used for other needs (DHW and space heating) [11,12]. Recently the payback time for time for such system has reached 6.75 years [13]. A review of the installed thermal solar cooling systems in the world has been done in IEA SHC Task 38 [14]. It showed the predominance of absorption chiller among the installed solar thermal driven cooling machine. The IEA task also stated the reliability of district heating network as hot thermal back-up source. Moreover, two recent studies concluded that thermally driven cooling technologies are very promising for locations served by means of district heating networks based on cogeneration heating plants (CHPs) [15–52]; which is the typical solution in the Nordic countries. In such places, expanding the cogeneration towards the trigeneration, via decentralized systems, can certainly increase the energy supplied from the CHPs during the summer months in Europe, at the same time improving the overall efficiency of the CHPs and reducing the environmental impact. However, these studies did not consider solar thermal system.

Particular care is needed when assessing energy performance and benefits of solar cooling driven systems. They should be investigated and estimated trough specific key performance indexes: electrical seasonal performance factor (SPF_{el}) and primary energy ratio (PER), as suggested by [16]. Often simulation software are used to carry out energy assessment. TRNSYS software [17] has been used in this study, since it has gained a reliable reputation for assessing the energy performance of the considered cooling technology. It has been positively mentioned also by the subtask c: modelling and fundamental analysis of the IEA SHC Task 38 [5]; where its ability to assess detailed control strategy has been also remarked. TESS library [18] of TRNSYS has been also used to model some components of the system.

The main absorption chiller operating parameters are: the desorber temperature and the cooling temperature achievable by the heat rejection system, which has to remove the excess heat in the condenser and in the absorber [19,20]. Climatic conditions affect both cooling and desorber temperatures, indeed external temperature and solar irradiance represent key variables to consider for achieving good system performance [21]. However, performance strongly depends also on the system schematic and control logic of the whole system [22,23]. The operating temperature of the desorber mainly depends on the chosen control strategy [24]. Usually, the system relies on an auxiliary heater, which supports the system reaching the desired desorber temperature, in case solar collectors cannot [25–32]. Information about tested configurations, main technical system features and findings, in terms of yearly and/or seasonal system performance, of the relevant studies found in literature are listed in Table 1.

Authors have carried out an extensive literature review and they have found that the most used configuration is the series connection between solar thermal collectors, tank and chiller [10,20–22,25–27,33–41]. In such configuration, the absorption chiller is supplied by means of the hot storage tank. The parallel connection between