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Design of a simple control strategy for a community-size solar heating system with a seasonal storage

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Abstract

The presented paper focuses on the design of different control strategies of a cold climate community-size solar thermal system located in Finland. The system was designed on TRNSYS software in order to perform dynamic simulation. A solar thermal system operating with various control strategies has been designed with an integrated ground source heat pump and a seasonal borehole storage to provide domestic hot water (DHW) and space heating (SH) for community-size demand. The system has two short term storage tanks, a hot tank and a warm tank. The impact of the considered system solutions on electricity consumption has been evaluated and compared as a function of the different collector control modes and different tank configurations (short term tanks sizes). Results have shown that the proposed system was able to provide a 78-83% renewable energy fraction. Total electricity consumption of the heating system varied by 20% between the best and the worst cases. Furthermore, system performance was better when solar energy was mainly stored in the warm tank. During a 5-year simulation, the annual seasonal storage efficiency improved from 0.23 to 0.31, whereas the heat pump electricity consumption reduced from 57.17 MWh to 45.93 MWh. The demand in winter was met mainly through ground heat and the rest was provided by the heat pump compressor. However, the demand in summer was met almost completely by solar energy.

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Keywords: Solar thermal energy; district heating; seasonal storage; system control; solar community

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Nomenclature

BTES	Borehole thermal energy storage	HP	Heat pump
COP	Coefficient of performance	SH	Space heating
DHW	Domestic hot water	ST	Solar thermal

1. Introduction

Buildings are one of the largest energy consumers and emitters of CO_2, representing 40% of the European Union's total energy consumption. Indeed, the Directive 2010/31/EU and the Council on 19 May 2010 of the European Parliament [1] have prioritized the reduction of energy consumption of the building sector, under the "20-20-20" objectives. Similarly, recent developments on the knowledge about global warming have led to explore alternative technologies for cleaner energy production by using renewable sources. Solar thermal system, especially in the building sectors at a community or district scale, is a key alternative technology to achieve this goal, and indeed such systems are spreading in the European countries [2]. Solar communities are a potential approach for heating dominated buildings in cold regions [3]. They are not yet commonly built at high latitudes in cold regions such as Finland. The cold temperature and the low irradiation in winter limit the operation of these systems in building heating requirements; however, solar thermal energy can be used in an effective way by designing such systems smartly. Furthermore, system designs from other countries cannot be transferred directly to a new location [4] [3]. Several crucial factors need to be considered to evaluate the community-sized solar thermal system energy performance in any region. These include the efficient long term seasonal storage, the effective back up system and a good control strategy of the whole system. Hence, a detailed investigation is needed for such system in Finland.

Firstly, in Finnish conditions, seasonal storage is of great importance in order to store energy for winters. The decision to use a type of seasonal storage depends on the climate and the geological situation of the ground. Studies in various countries [5] [6] [7] have shown that higher solar fraction and savings were obtained with systems with underground storage in most cases. All these studies focused on small scale systems and design optimization is needed to make such concept feasible [5] [6] [7] [8]. Recently, a working solar community has been developed at Drake Landing, Canada [9], to evaluate the performance of the system. Space heating is provided thorough BTES (Borehole thermal energy storage) and the system was able to provide 97.6% of solar fraction by the end of 6^{th} year of its operation [10]. Secondly, as system backup, gas and electric boilers have been used widely to overcome the shortcomings of solar thermal energy [9]. Similarly, alternative design is being discussed where a heat pump is used instead of gas boilers [11]. In fact, solar thermal collectors can supply heat to the ground. This heated ground increases the temperature of the evaporator in the ground source heat pump (GSHP), hence, it improves the heat pump efficiency, in addition to provide building heating energy [12]. This technology combination can be particularly attractive in a cold climate.

Lastly, in order to increase the solar fraction of such systems, a good control strategy for the system is required. Numerous studies on model based control strategies for solar thermal plants have been conducted. Improvements were obtained using control based on critical radiations, variable mass flows and the thermo-hydraulic behaviors in the system [13] [14]. Moreover, fuzzy logic and feedforward control have been tested to estimate the daily amount of energy storage and to determine the consumption profile [15]. Similarly, for smaller system's [16] [17] [18], predictive control strategy has been studied where weather forecasts as well as prediction of the user's needs in terms of tapped water were evaluated to operate the auxiliary heater elements in the tanks for a domestic hot water system. Furthermore, design and control of storage tank and its connection with heat pump showed a significant influence on the performance of heat pump and whole system [19]. Detailed studies were carried out for the system performance as function of control strategies and results obtained through simulation showed a reduction of auxiliary energy demand and an increase in solar fraction [20] [21].

In spite of many studies being carried out in the past, however, most of the findings are limited to the particular system configuration considered. Thus, not many community sizes solar heating system has been deliberated. A strong motivation behind this study is to maximize the effective use of the solar energy by giving the priority to building heating energy (domestic hot water and space heating) when solar thermal collectors are used. Therefore an