Renewable Energy 107 (2017) 147–155

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Energy and emission analyses of solar assisted local energy solutions with seasonal heat storage in a Finnish case district

Satu Paiho*, Ha Hoang, Mari Hukkalainen

VTT Technical Research Centre of Finland Ltd, P.O. Box 1000, FI-02044 VTT, Finland

ARTICLE INFO

Article history:
Received 11 January 2016
Received in revised form
10 January 2017
Accepted 2 February 2017
Available online 4 February 2017

Keywords:
District energy
Solar energy
Seasonal heat storage
Ground source heat pump
Energy analysis
Nearly zero energy building (nZEB)

ABSTRACT

Pilots for the seasonal thermal energy storage of solar energy on a local basis are few in Finland, even if international demonstrations show that the utilization level of solar energy can exceed 50% of the annual local heat requirement in similar climate zones. This study presents options for heat and electricity generation based on local energy systems and utilizing seasonal thermal energy storages. Energy needs and production on Vartiosaari district in Helsinki in Finland were explored as a case area. The project studied the impacts of introducing solar thermal energy on local energy self-sufficiency and emissions from heating energy supply, if excess solar heat in the summer is stored using borehole thermal energy storage or tank storage for use in the winter. Around 60% self-sufficiency in heat production would have been achieved in the scenarios studied. In addition, carbon dioxide emissions could be reduced by around 50%, and sulphur dioxide and particulate emissions by up to 70% compared to the business-as-usual situation.

1. Introduction

Anderson et al. [1] show that research on energy use in the built environment is often divided between the building and urban scale leading to several potential problems. For example, an analysis at the individual building level often treats the building as a stand-alone object, isolated from its context within the built environment while in reality buildings are connected to their surroundings through physical means (e.g., infrastructure) as well as through their users (e.g., residents). Similarly, definitions and studies of nearly zero energy buildings (nZEBs) often neglect the surrounding district [2]. However, district level analyses and initiatives can better support applying higher-level environmental and other targets, such as implementing coordinated actions to integrate renewable energy [3] or reducing carbon emissions [4].

District-level experiments from Sweden have obtained interesting results, e.g. Refs. [5,6]. In Stockholm, the Hammarby Sjöstad district has a well-known integrated infrastructural system entitled the Hammarby Model, created to handle energy, waste, water, and to generate secondary energy possible to reuse within the district [5]. The district is far from self-sufficient in terms of locally generated secondary energy but it supplies the district with 22% of the district heating needed, 24% of the district cooling needed, and 5% of the electricity needed. Since the Växjö municipality has a goal to be fossil fuel free by 2030 it imposes specific energy requirements beyond the Swedish building code while selling plots for new residential buildings [6]. In the Östra Lugnet new residential area the Växjö municipality attached a condition that the new buildings must be connected to the municipality-owned local biomass-based district heating system that produces both heat and electricity. Measurements from Östra Lugnet area show that houses with a higher specific energy use e.g. those with district heating system can have lower primary energy use and CO_2 emissions than a house with lower specific energy use e.g. one with air-source heat pump [6].

According to Lund et al. [7], the 4th Generation District Heating (4GDH) systems provide the heat supply of low-energy buildings with low distribution losses in a way in which the use of low-temperature heat sources is integrated with the operation of smart energy systems. Already now large scale solar systems and seasonal heat storage are proven supporting technologies with district heating, e.g., [8–12]. However, they are not piloted at the district-scale in Finland.

Xu et al. [9] and Pinel et al. [13] review all three available technologies for seasonal heat storage: sensible heat storage, latent heat storage and chemical storage. Sensible heat storage is a comparatively mature technology. Water, rock-sort material and ground/soil are frequently used as storage materials. Latent heat

* Corresponding author.
E-mail address: Satu.Paiho@vtt.fi (S. Paiho).

http://dx.doi.org/10.1016/j.renene.2017.02.003
0960-1481/

Nomenclature

BTES	borehole thermal storage
COP	coefficient of performance
nZEB	nearly zero energy building
STES	seasonal thermal energy storage
SunZEB	solar-based Zero Energy Building
SunZED	solar-based Zero Energy District
TTES	tank thermal energy storage
4GDH	4th Generation District Heating
2012	district built according to the 2012 Finnish building codes

and chemical storage, still being in the development phase, have much higher energy storage densities than sensible storage, which means that they can remarkably reduce the storage volume, and they seldom suffer from heat loss problems [9]. The heat loss problem with seasonal storage can be reduced by low-temperature storage but a heat pump is then recommended to adjust temperatures according to the buildings' energy use [14].

Based on a review of several realised seasonal sensible heat storage projects [9], the solar fraction has had quite large variations, being between 16 and 81%. In German examples the combination of central solar heating plants with seasonal heat storage enabled solar fractions of even over 50% [10]. In a Swedish area comprising 50 residential units, called Anneberg, low-temperature space heating with seasonal ground storage of solar heat was designed resulting in a solar fraction of about 70% [11]. In Drake Landing Solar Community in Canada, the solar fraction of 97% was detected in the fifth operation year with a solar thermal system with borehole seasonal storage to supply space heating to 52 detached energy-efficient homes through a district heating network [12]. A simulation study from Finland [15] shows that high solar fractions (up to 96%) can be achieved also in Helsinki with lower temperature heating systems such as underfloor heating and/or with houses built to meet the Passive standard.

Finland is one of the few countries in the EU that has taken hardly any direct subsidies into use for solar energy [16] and where the utilization rate of solar energy is quite low. In 2012, only about 14 GWh of solar heat and about 5.5 GWh of solar power were produced in Finland [17] while in the same year in total over 19 TWh of district heating and over 14 TWh of electricity were produced for use in residential buildings [17].

City of Helsinki produces about 5% of the total greenhouse gas emissions causing climate change in Finland [18]. In 2013, the major greenhouse gas emitters in Helsinki were district heating, transport and consumer electricity [19]. According to the strategy programme of Helsinki [20], the carbon dioxide emissions in the city of Helsinki are targeted to be reduced by 30% from the level of 1990, by 2020. One of the proposed measures is to change the production structure of electricity and heat of Helen, the municipal energy company in Helsinki, so that renewable energy sources will account for approximately 20% by 2020. In 2014, the share of renewable energy in Helen's production was 7%, the majority of which was hydropower [21]. In 2013, in the entire urban area of Helsinki, electricity consumption was around 4540 GWh/a, district heat consumption about 6470 GWh/a, and district cooling consumption approximately 116 GWh/a [22]. As a long term goal, Helsinki plans to become a carbon neutral and climate resilient city by 2050 [23].

This paper aims to support the climate goals of Helsinki by analysing the energy and emission impacts of local renewable energy solutions including seasonal heat storages in a residential case district, called Vartiosaari, in Helsinki. The land use planning for the area is currently on-going and initial energy analyses are needed to continue the detailed planning. In addition, the study targets on supporting energy solution planning by providing the space requirements of different solar system and seasonal heat storage alternatives.

The remaining sections of this paper are organized as follows. Section 2 describes the principles used in the analyses and systems analyzed. Section 3 introduces the energy demands of the case district. Section 4 presents the main findings of this study, Section 5 discusses the findings, and Section 6 concludes the study.

2. Principles of the analyses and analyzed alternatives

The main objective of this research was to prepare district scale energy analyses of a residential district utilizing local energy sources and seasonal thermal energy storage. A new neighborhood area under planning in Helsinki, called Vartiosaari, was selected as the case district.

The general methodology of the energy analyses is presented in Fig. 1. The analyses were performed for two different kinds of building stocks (phase 1) - one stock containing buildings built according to the 2012 Finnish building codes, and the other stock corresponding to SunZEBs (solar-based zero energy buildings) in a SunZED (solar-based Zero Energy District) concept. The SunZED concept is a combined district heating and cooling system, which functions in the urban infrastructure and enables recycling of energy flows [24]. A special feature of the concept is that excess heat from the buildings during summer time is recovered through district cooling and a heat pump technology. This recovered heat is recycled to the district heating network, mainly for the heating of domestic hot water.

Typical SunZEB concept buildings were earlier specified in Ref. [24] and these were utilized in the analyses. The heating, cooling, and electricity demands of the district for both building stocks scenarios were calculated, including the heat distribution losses in the district heating network. It was estimated that the losses are 5% in the district heating network because it is a low-temperature district heating network. In 2013, a typical value for heat distribution losses in the district heating network of Helsinki was 6% [25]. The losses in the district cooling network were not considered since the focus was on heating.

In the second phase of the analyses, the seasonal heat storage technology was selected. Calculations were made for both borehole and tank storage systems. In the case of the borehole thermal storage, a ground source heat pump was utilized to produce the remaining energy demand, which could not be produced by solar collectors. In addition, the ground source heat pump was needed to adjust temperatures for the low temperature heating in the buildings. With the tank thermal storage, solar assisted district heating was utilized. In both cases, the heat was distributed through the district heating network.

In the third phase, the effect of having various amounts of different solar energy technologies on the energy balance of the district was calculated. The production potential of solar heat and power is based on hourly measurements from the Helsinki area. The utilized annual production was 500 kWh/m^2 for the solar collectors [26] and 120 kWh/m^2 for the solar panels [27].

In the fourth phase, these results were reported by means of energy production self-sufficiency, remaining energy demands (to be produced by some other means), and environmental emissions (CO_2 and SO_2 equivalent emissions and small particulates) to air. The emissions were calculated for the year 2030, which was the estimated construction year for the area. The initial emission