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Economic and energy analysis of three solar assisted heat pump systems in near zero energy buildings

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ABSTRACT

The European Union's directive of the energy performance of buildings makes energy systems with local energy generation interesting.

To support local energy generation the government has appointed a commission to investigate the possibility to implement net metering for grid connected PV-systems.

In this paper three different systems are simulated and analyzed with regards to economics and energy: a PV-system and a heat pump (alternative 1), a heat pump and a solar thermal system (alternative 2) and a heat pump, a PV-system and a solar thermal system (alternative 3).

System alternative 1 is profitable with daily net metering and monthly net metering and unprofitable with instantaneous net metering.

The solar electrical fraction of the system is 21.5%, 43.5% and 50%, respectively.

System alternative 2 is unprofitable and has a solar electricity fraction of 5.7%.

System alternative 3 is unprofitable and has a solar electricity fraction of just below 50.

The conclusion is that a PV system in combination with a heat pump is a superior alternative to a solar thermal system in combination with a heat pump.

1. Introduction

In the Europe union (EU-27) the household sector accounts for almost 27% of the total European final energy consumption [1]. This is an important reason for the European commission to adopt the directive on the energy performance of buildings [2] as one of several measures to reach its 20–20–20 goal.

The European Union's directive on the energy performance of buildings will lead to more local energy generation in the future and more energy efficient buildings. Solar energy is regarded as one of the most promising ways for local energy generation. Partly because of this the Swedish government has appointed a commission which will produce proposals on how to facilitate the use of net metering for locally produced electricity in buildings.

In Sweden today one common way of reducing the amount of purchased energy in new buildings is to install a ground source heat pump in combination with a well-insulated building envelope and mechanical ventilation with heat recovery. In Sweden approximately 340,000 ground source heat pumps has been installed the last decade according to the Swedish Heat Pump Association [3].

Because of this it will be more common with energy systems that combine solar energy with ground source heat pumps and heat recovery ventilation.

Earlier studies with solar assisted heat pumps have mainly focused on complex systems with PV/T hybrids or solar thermal collectors acting as the source for the heat pump evaporator [4–6]. Other studies have focused on standard heat pumps and solar thermal systems [7].

In this paper three less complex solar assisted heat pump systems will be simulated in the program Trnsys [8] and analyzed with regards to economics and energy consumption. The different systems are PV-system, solar thermal system and a combination of a PV-system and a solar thermal collector system.

The aim of the work presented in this article is to find the system which is most cost effective and has the highest solar energy fraction.

2. Methodology

The energy simulations are performed in the transient simulation program Trnsys. The simulation interval is set to 3 min and two years, 17,520 h, are simulated.

The Trnsys models are built up with so called decks in Simulation studio which is the graphical user interface of Trnsys.

Each Trnsys model consists of identical decks with exception of the different solar energy systems analyzed. A short description

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Table 1
Main Trnsys type in the simulation deck.

Trnsys type	Description	Comment
Type 56	Multi zone building	
Type 927	Ground source heat pump	Based on external data file for Premiumline EQ C6
Type 534	Heat storage tank	Heat pump internal tank
Type 557a	Borehole	
Type 194	PV-module	5 parameter model
Type 539	Flat plate solar collector	
Type 760	Air–air heat recovery	

of the most important types used in this work is summarized in Table 1.

All results from the energy simulations are exported and further processed and used in the economic calculations.

The analysis is based on the annuity method because of its ability to compare systems with different economic lifespans.

The revenues from the different system alternatives are converted to net present values by multiplying the revenues with the discount factor (DF) defined by:

$$\mathrm{DF} = \frac{1}{(1+i)^t} \quad (1)$$

The accumulated net present value (NPV) revenues are then converted to an annuity defined by:

$$(\mathrm{NPV} - C_i) \times \frac{i \times (1+i)^z}{(1+i)^z - 1} \quad (2)$$

where i is the interest rate, t is the economical lifespan and C_i is the investment cost.

In the economic calculations the investment cost only includes the solar energy systems and not the ventilation heat recovery and ground source heat pump systems.

A sensitivity analysis is done in order to evaluate the impact of different electricity price changes on systems profitability.

3. The simulated building and technical installations

3.1. The building

The simulated building consists of one zone and one story with a living space of 138 m^2 which is maintained at 21 °C. The building has floor heating embedded in the building foundation which consists of a concrete slab on grade with a total insulation thickness of 300 mm.

In the building walls the insulation is 350 mm thick and the roof has an insulation thickness of 370 mm.

The *U*-values of the different building elements can be seen in Table 2.

Four inhabitants, two children and two adults, live in the building.

The energy system of the building consists of three main parts: household electricity, the production of domestic hot water and space heating and heat recovery ventilation. The part of the three systems investigated that are identical to each other will be described in this section. Another important factor is how different measuring schemes influence the size and the economics of the PV-system. The different schemes will be explained in detail in Section 4.

Table 2
U-values for the different building components used in the simulation.

Building component	*U*-value (W/(m^2, K))
Ceiling	0.106
Outer walls	0.102
Ground floor	0.103
Windows	0.81

The total energy demand for the building with household electricity included is 19,880 kWh/year. The same building with a ventilation heat recovery unit installed has a demand of 16,920 kWh/year purchased energy and with ventilation heat recovery and ground source heat pump the purchased energy demand is 10,157 kWh/year. In Fig. 1 the energy demands per month is shown and in Table 5 the building total energy demand for the different combinations of technical installations are summarized.

3.2. Heat pump

The heat pump used in the simulations is based on a commercial available model made in Sweden by Bosch Termotechnik AB. The model used is an IVT Premiumline EQ C6 which has a heating capacity of 5.8 kW.

It has a 225 L internal double jacketed storage tank with an inner domestic hot water tank of 185 L.

The domestic hot water production is prioritized which means that no heat is supplied to the building when the temperature in the tank is below 47 °C which is the set point temperature minus a 3 °C hysteresis. The temperature probe which is measuring the domestic hot water is located approximately 20 mm from the bottom of the tank and on the outside of the tank. A zone valve switches the heated media to either the outer compartment of the domestic hot water tank or to the floor heating system.

Once every week the domestic hot water temperature is raised to 65 °C to avoid growth of the Legionella bacteria. This is partly done with the heat pumps internal electric heater. The heat pump heater is limited to 3 kW which is one-third of the heater potential and will only be active when the domestic hot water is raised to 65 °C.

The domestic hot water consumption in the building is 66 L per day and person and the annual energy amount needed for production of domestic hot water is 4675 kWh.

The tapping cycle is based on EN 16147:2011 [9] tapping cycle M which is a cycle with 23 draw offs a day. Previous studies have shown that the number of tapings and the time of occurrence are of importance for the storages performance as shown by Fiala [10]. An evaluation of different tapping cycles will be done in the future to improve the domestic hot water part of the model.

The required temperature lift of the main water varies with the season, in summer the minimum lift is 42 °C and in winter the maximum lift needed is 49 °C. The variations can be seen in Fig. 2.

The heat pump is connected to a 150 m deep borehole on the heat pump cold side and to the building floor heating system on the hot side. It is dimensioned for monovalent operation which means that it is able to cover 100% of the building heat load. The borehole is dimensioned so the exiting fluid temperature never is below 0 °C.

The heating is regulated by a linear temperature curve based on the heating system forward flow temperature and outdoor temperature. Maximum forward flow temperature to the floor heating system is 33.5 °C.

The temperature differences are within the manufacturers recommended 2–5 °C for the cold side fluid and 7–10 °C for the hot side fluid.

Two circulation pumps are integrated in the heat pump. On the hot side the circulation pump is frequency controlled and the speed is regulated to keep the temperature difference over the heating