Low-Energy House with Heat Storage in the Ground Using Solar Collectors

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ABSTRACT

In recent years, the use of solar collectors to provide additional heat for space heating of buildings, and particularly for hot-water production, has become more common in Sweden. Such systems function well and can cover about 50 % of the total hot-water demand for a residential building having a heat store with a capacity sufficient for a couple of days. The weakness of such systems is that they can deliver the most heat during warm sunny days, when the need for heating is at its lowest. The energy from the solar panels is normally stored in an accumulator tank with a finite storage capacity, which gives very few options for dealing with the surplus.

This paper presents measurements from a new residential building in Sweden—Villa Gustafson—where the major part of the heating is produced by solar collectors operating in combination with a ground heat pump. The surplus from the solar collectors during warm sunny days is stored in the ground beneath the building. During cold weather, this stored heat heats up the building via the heat pump. The system improves the operating conditions of both the solar collectors and the heat pump.

The house was built and the solar system started during the summer of 2008. The paper presents measurements of the system for the first year. The different temperatures to and from the system, as well as the temperature in the heat store beneath the building, were measured, as was energy use. The measured values for the first year (2009), with an average outdoor temperature of 6.7°C (44.1°F), indicate that annual energy use for space heating and domestic hot-water production should not exceed 14 kWh/m^2 (4.4 kBtu/ft^2) per year.

INTRODUCTION

Energy demand for space heating, electricity for building services systems, operational electricity, and domestic electricity in Swedish buildings accounts for almost 35% of the country's total energy use. Several low-energy building concepts have been developed with the aim of reducing this demand. One such concept is the Passive House, for which a formal performance specification for the maximum quantity of purchased energy and maximum installed power demand has been drawn up. In the southern Sweden climate zone, which has a statistically average mean annual outdoor temperature of about 7°C (44.6°F), these values are 30 kWh/m^2 (9.5 kBtu/ft^2) and 10 W/m^2 (34 Btu/[h·ft^2]) per year, respectively (FEBY 2009).

A common way of reducing the need for purchased energy in a building is to collect additional heat via solar collectors and using it mainly for domestic hot-water production. Such systems operate well, with most buildings generally managing to heat all their summertime domestic hot water from this source. Unfortunately, the drawback is that the greatest power is delivered on hot, sunny days, when the need for heating is low (Kjellsson 2004). The heat from the collectors is usually stored in a hot-water tank, with only a limited capacity, which means that there is little application for making use of surplus heat, particularly on hot days with little demand for hot water.

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DESCRIPTION OF THE HOUSE

Bollebygd, 45 km inland from Göteborg in Sweden, is the site of an experimental house—Villa Gustafsson (Figure 1). The building is single-story, with a residential floor area of 222 m^2 (2390 ft^2) and an additional 67 m^2 (721 ft^2) in the form of a garage integrated in the building (Figure 2). The house has a complicated floor plan, with many odd angles and different ceiling heights. Table 1 lists the various parts of the house and their U-factors.

Figure 1 *Villa Gustafson in Bollebygd, seen from the south-west. (Photo courtesy of AB Svenskt Klimatneutralt boende.)*

The average U-factor of the entire building is 0.17 W/(m^2·K) (0.030 Btu/[h·ft^2·°F]). Transmission and infiltration losses amount to 49.2 kWh/m^2 (15.6 kBtu/ft^2) of floor area per year, while the building air tightness has been measured (according to EN 13829) as 0.24 L/s per m^2 at ±50 Pa pressure difference. This value can be compared with that specified in the performance requirements for passive houses in Sweden of a maximum of 0.30 L/s per m^2 at ±50 Pa.

INSTALLATION AND THE HEATING SYSTEM

The house has 29 m^2 (95 ft^2) of solar collectors, mounted on the roof at 20° to the horizontal, and facing to the south. A 900 L hot-water storage tank and a ground heat store are connected to the collectors (Figure 3). A temperature sensor measures the difference between the collectors and the tank/ground heat store. If the temperature of the water in the tank exceeds 70°C (158°F) or is higher than the collector temperature, the water is circulated down to the ground heat store, which means that both surplus heat during the summer and relatively low temperatures during the winter can be utilized. A conventional heat pump with a 6 kW rating extracts heat from the ground heat store. Water from the heat store to the heat pump passes through an exhaust-air heat exchanger, raising its temperature by a few degrees before it reaches the heat-pump evaporator. The heat pump in turn delivers warm water to the house's floor heating system and additional heat to the

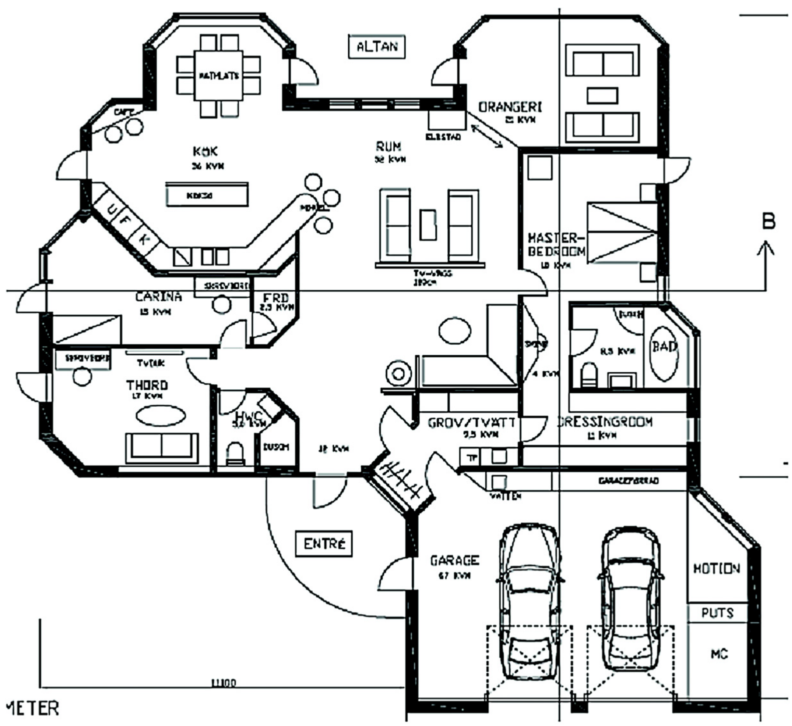

Figure 2 *The floor plan of Villa Gustafson. (Drawing courtesy of Posse Arkitektur AB).*

domestic hot-water heating system. Fresh-air inlets are provided in the outer walls; this air is not preheated.

Ground Heat Store

The ground heat store is located beneath the building's ordinary foundation, close to the rock. The store under the house has a total heat capacity of around 600 MJ/K (167 kWh/K).

MEASURED RESULTS

Temperatures and energy use have been logged since December 2008. Temperatures to and from the heat pump, to and from the exhaust-air heat exchanger, to and from the heat store, temperatures at two different levels in the heat store, at the top and bottom of the water storage tank, indoor-air temperatures, outdoor-air temperatures, to and from the floor heating system, and the domestic hot-water temperature have all been logged (see Figure 3). On the energy side, the energy demand from all circulation pumps, heat exchangers, and the heat pump have been metered and logged.

Figure 4 shows how the temperatures in the heat store, the indoor temperature, and the outdoor temperature have varied, together with energy use, from January 1, 2009 until December 31, 2009. The indoor-air temperature sensor is fitted high up, at about 23 m (6.6–9.8 ft) above floor level, which means that it indicates temperatures that are somewhat higher than in the occupied zone.

The heating system was adjusted in January (week 1–5), which is clearly indicated in the diagram by a reduction in the variations of energy demand, coupled with an absolute reduction of the values. Energy demand in February, March, (week 6–13) November, and December (week 45–51) was about 15 kWh/day (51 kBtu/day). During April, May, June, July, August, and September (week 14–39) it fell to about 3 kWh/day (10 kBtu/day). The measured values for the first year (2009), with an average outdoor temperature of 6.7°C (44.1°F) show that annual energy use for space heating and domestic hot-water production is 14 kWh/m^2 per year (4.4 kBtu/ft^2 per year).

During the first winter (2008–2009), the heat pump has not needed to work with water temperatures to the evaporator below 10°C (50°F), which has resulted in a higher efficiency than normal. The heat pumps coefficient of performance will be evaluated in another project at SP Technical Research Institute of Sweden.

EVALUATION

The underlying aim of the design of the house has been to create an extremely low demand for purchased energy for space heating and domestic hot-water production, while at the same time providing a healthy and low-energy indoor environment without being bound by architectonic constraints or the type of ventilation system. The buyers of the house were free to plan the layout entirely as they wished. As far as energy considerations are concerned, the plan is very demanding: all rooms on a single floor, with lots of angles, windows, doors and different ceiling heights. Nevertheless, despite the complicated architectural design, the house has an exceptionally low purchased-energy demand. Based on measured values from the January 1 to the end of December 2009, the figures for the first winter and summer indicate that the annual energy demand for space heating and domestic hot-water production ought not to exceed 14 kWh/m^2.

System Benefits

- Good utilisation of solar heat, as both surplus heat and low-temperature heat can be used.
- Higher efficiency of the heat pump, as the incoming water to it is at a higher temperature than normal due to the heat stored in the ground.
- Relatively low heat losses from the ground heat store, as the house itself provides insulation above the store.
- No large ground area required for the heat store, as it is situated directly beneath the house's foundation slab.

Table 1. Main Details/Parameters of the House and Thermal Bridges

Part of the House	U-Factor/ Ψ-Value	Area/Length
Walls, lightweight framework with 400 mm cellulose insulation	0.082 W/(m^{2}K) (0.014 Btu/[h·ft^2·°F])	120 m^2 (1292 ft^2)
Roof, lightweight framework with 700 mm cellulose insulation	0.075 W/(m^{2}K) (0.013 Btu/[h·ft^2·°F])	231 m^2 (2486 ft^2)
Ground slab, concrete slab with 300 mm EPS beneath	0.10 W/(m^{2}K) (0.018 Btu/[h·ft^2·°F])	222 m^2 (2390 ft^2)
Windows and doors	1.0 W/(m^{2}K) (0.18 Btu/[h·ft^2·°F])	46 m^2 (495 ft^2)
Corners	0.025 W/(m•K) (0.0044 Btu/[h·ft^2·°F])	29 m (95 ft)
Top plate and ground plate	0.04 W/(m•K) (0.0070 Btu/[h·ft^2·°F])	128 m (420 ft)
Window surrounds	0.051 W/(m•K) (0.0090 Btu/[h·ft^2·°F])	80 m (262 ft)

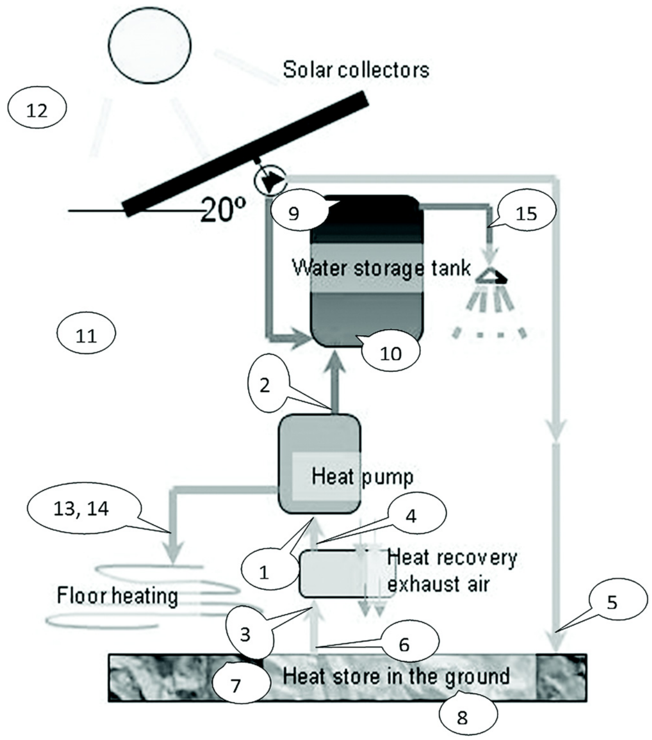

Figure 3 *A schematic diagram of the heating system. The numbers show where the temperatures have been logged: 1) to the heat pump, 2) from the heat pump, 3) to the exhaust-air heat exchanger, 4) from the exhaust-air heat exchanger, 5) to the heat store, 6) from the heat store, 7–8) different levels in the heat store, 9) top of the water storage tank, 10) bottom of the water storage tank, 11) indoor-air temperature, 12) outdoor-air temperature, 13–14) to and from the floor heating system, and 15) the domestic hot water.*

- Considerable architectural freedom offered by the efficient heating system and its high utilisation of solar energy.

System Drawbacks

- As for all low energy or passive houses, the quality of the workmanship when building the house is very important, particularly with respect to airtightness and moisture resistance.
- During the summer, the ground heat store will probably reach a higher temperature, or at any rate the same temperature, as the foundation slab. If this condition persists for too long, there is a risk of moisture in the ground migrating up into the slab and causing problems. Minimizing this risk requires careful design and construction of the foundations, with a diffusion barrier and means of monitoring the heat store temperature. If the slab temperature is 4 K higher than the temperature of the ground underneath it, ground moisture cannot cause a higher relative humidity in the slab than 80%. It is very important that the concrete slab does not contain any organic materials at all.

Potential for Further Development

- Optimization of the system—i.e., adjusting the size of the ground heat store and/or the area of solar collectors.
- Investigation of the effects of siting the heat store outside the house area, or perhaps under only the garage, in order to reduce moisture problem risks.

CONCLUSION

The purpose behind construction of Villa Gustafson has been to create a house with an extremely low demand for purchased energy for space heating and domestic hot-water production, while providing a healthy and low-energy environment without being restricted by architectural constraints or the design of the ventilation system. The house has a complicated one story floor plan, with many odd angles, windows, doors, and different ceiling heights. Nevertheless, despite the complicated architectural design, the house has shown that it needs very little purchased energy. The measured values for the first winter and spring indicate that annual energy use for space heating and domestic hot-water production should not exceed 14 kWh/m^2 per year (4.4 kBtu/ft^2 per year).

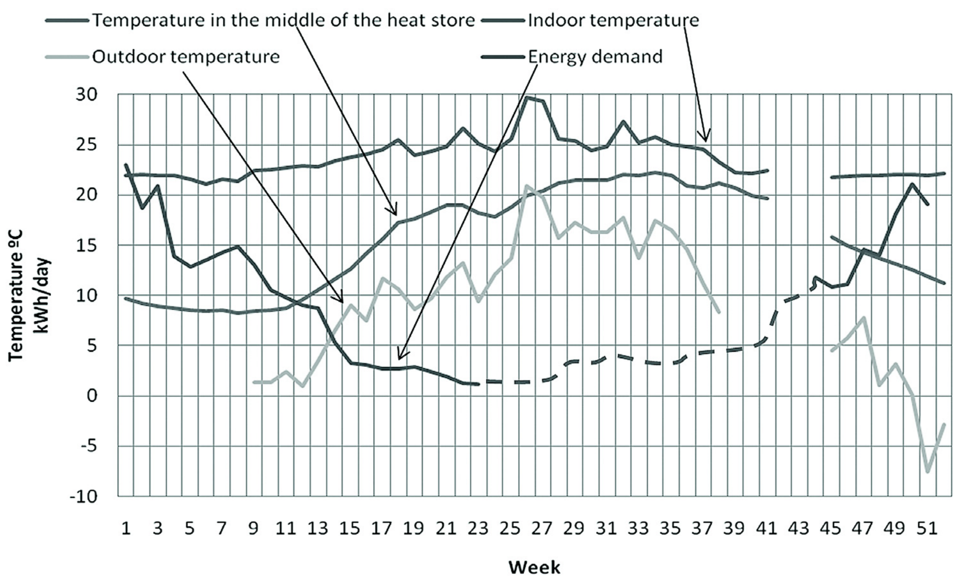

Figure 4 *Weekly mean values of indoor and outdoor temperatures, temperature of the heat store, and energy demand from January 1, 2009 until December 31, 2009. The dashed line for energy demand from week 24 to week 44 is plotted based on manual readings once a month.*

ACKNOWLEDGMENTS

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