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Short Communication

Storing Thermal Energy from Solar Collectors for the Needs of a Detached House

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Abstract

This work evaluates the possibility of meeting a single family household's need for hot water and heat year round, using solar collectors as the sole energy source. The main flaw of energetic systems based on solar energy is that the energy supply is usually insufficient in winter, when it is most needed. This work is going to show that, for a house surface of 150 m^2 and base dimension of 10×10 m, it is possible to supply sufficient heat for everyday purposes with solar energy only, using a thermally insulated thermal storage unit of 200 m^3 volume, filled with water or paraffin wax.

Keywords: thermal energy, hot water supply, solar collectors, house

Introduction

Exploiting solar energy is an important task not only due to non-renewable resource shortages, but also for environmental protection. Converting existing solar energy to usable energy in the form of hot water or electricity is still a current topic. However, the main flaw of energy systems based on sunlight is that the energy created directly from thermal energy is insufficient when it is most needed, as in months with low air temperature, while being excessive in the days with high sunlight exposure. To obtain a supply of energy corresponding to the needs of the user, it is necessary to store the excess energy. An analysis of the energy needs of the user and ways to solve this problem are the subject of this thesis.

It has been assumed that solar energy is to provide a full supply of hot water and house heating need for the whole year. The basic assumptions undertaken are that the house for which we are storing thermal energy has a surface of 150 m^2 with a 10×10 meters base dimension. It will be shown that if a thermal storage unit with 200 m^3 volume filled with water or paraffin wax is used, it should be able to supply sufficient thermal energy for a detached house for a full year. This is possible when certain conditions regarding isolating objects thermally, temperature differences in the heat container, and the solar thermal collector are met. Meeting these conditions requires sufficient heat exchange, pump system, relevant system automation, storing material with applicable heat capacity, and other variables. The practical aspects of instilling this idea for a thermal storage unit system used for year-round functioning of the house will be discussed.

The matter being the subject of the analysis is not a new one, in the field of storing thermal energy and exploiting it for use. Considerable attention is given to materials that allow heat storage through various chemical and physical processes [1-7]. Applicable conceptual studies and realizations regarding thermal energy storage are supplied within the article. The main interest of the authors are various materials that can store heat. In the case of buildings, special attention is paid to materials with phase transition in the range of possible temperature changes of the working substance used for heat storage. Usually heat is stored in the walls of the building or in the attic. These are short-term storage units, for which the main objective is to stabilize the

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Table 1. Values of solar radiation energy at the different months in the year for Olsztyn (according to GetSolar data) and necessary energy for heating and hot water for a family house. More explanations of the parameters are in the text.

Month	Radiation (1)	Solar gain (2)	Heating	Hot water	Sun heating and hot water	Energy excess
	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]
January	1633	613	1637	259	1896	-1283
February	4487	2292	1107	234	1341	+951
March	4917	2316	875	259	1135	+1181
April	6979	3841	474	251	725	+3116
May	11312	6529	230	259	489	+6040
June	10930	5649	56	251	307	+5342
July	9988	4116	0.4	259	260	+3856
August	9561	3232	16	259	276	+2956
September	7665	2522	200	251	452	+2070
October	4169	1272	665	259	924	+348
November	1156	187	719	251	970	-783
December	863	185	1521	259	1781	-1596
Total	73660	32754	7500	3055	10555	+22198

temperature. Besides the analysis of the properties of materials, [2, 3, 5, 7] give much attention to constructing thermal storage units and the principles behind building them. Various types of thermal storage units have been built in Europe and the world. Thermal storage units built in Europe are listed in [4], and in particular an object with an underground thermal storage unit supplying power to 52 houses known as Drake Landing Solar Community in Canada is subject to constant analysis. Information regarding current parameters of the system can be found on the internet at *www.dlsc.ca*. A couple of smaller objects powered by solar energy have been realized by the programs IEA Solar Heating and Cooling Implementing Agreement, and information regarding these realizations can be found in yearly reports and other works. These are usually objects with a hybrid system of exploiting solar energy. Practical solutions also use photovoltaic energy and heat pumps. Using solar energy as an energy source backup for buildings has also been attempted in Poland, but this solution is not commonly used. The goal of this article is to introduce the potential of sunlight to produce hot water and heating for a detached house as an autonomic year-round system. A crucial element of the proposed solution is a year-round thermal storage unit.

Energetic Conditions

Energetic conditions related to the energetic supply in the form of hot water and heating will be analyzed assuming a house surface of 150 m^2 with a base dimension of 10×10 m. It has been assumed that the house is of a low-energy type, whose demand for heat is at 50 kWh/m^2/year according to norms, but is not a passive house. It also has been assumed that the roof is at a 45-degree angle, with a one-sided flat surface of 70 m^2 exposed to daylight and completely covered with solar thermal collectors. The solar energy that hits the roof is fundamental for solar thermal collector functioning.

Based on meteorological data and using the program GetSolar professional [version 10.1.1 Author: Dipl.-ing Markus], Table 1 has been created for particular months.

Table 1 in the range solar gain has been created using the data obtained from the GetSolar program, according to company standards, for the city of Olsztyn with latitude 53º5’ and longitude 20º3’. For simulation calculation a vacuum collector with a surface of 69.6 m^2 was assumed. In the calculations for energy demand for heating a house of 150 m^2 at the level of 7,500 kWh/a of the assumed norm for low-energy houses at 50 Wh/m^{2}a, while for heating water 8.37 kWh daily for 3 people using 160 liters warmed from 10ºC to 55ºC was considered as a norm.

The Thermal Storage Unit

From Table 1 it is seen that for the assumed house parameters and collectors with the surface of circa 70 m^2 there exists an excess of heat in many months, especially during the summer. The heat shortage for warming water and the house exist only in the cold months, specifically in November, December, and January. The assumption that a house needs 50 kWh per square meter per year, which is typical for low-energy houses, is essential. Therefore, it should also be assumed that in such a house all outside barriers, which are ground floors, walls, and roofs or flat roofs will be characterized by a heat transfer coefficient of U=0.16-0.20 W/(m²K). It is of course required of outside isolators that they have no thermal bridges. Therefore, continuity of thermo isolation must be preserved in the walls, which have to be dense. This is expected of a house built according to modern technology and norms. If the demand for energy was higher or hot water usage increased, it can be expected that in February, March, and October there would not be a large heat excess and it can be accepted that these months would not contribute much to the positive energetic balance of the house. There would be an excess of thermal energy in the months: April, May, June, July, August, and September. The thermal energy from these months should be stored for around six months, until there is a demand during colder days. Of course energy loss during the storage period is inevitable.

During the months where there is considerable energy excess, in accordance with the data provided in the table, it amounts to 25,860 kWh. During the colder months the energy insufficiency amounts to around 3,662 kWh. The yearly energy excess is 22,198 kWh. This is the energy that can be stored to balance the deficit from the colder months. Assuming a loss of 50% of the stored energy, that leaves about 11,000 kWh to our disposal during the winter months, which greatly exceeds the demand at 3,662 kWh. The parameters of a thermal storage unit capable of storing 20,000 kWh with a 50% loss during a half year period will be analyzed.

The thermal storage unit may be built under the house and it may have the same base dimension of the house and be 2 m deep. Assuming the dimension of the house of 10×10 m, the volume of the storage unit would be around 200 m³. A diagram of the house with the thermal collector and storage unit can be seen in Fig. 1.

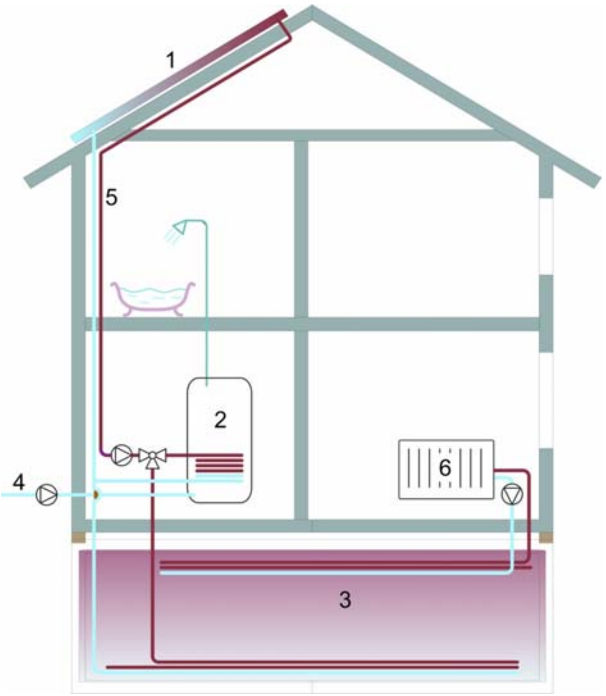

Fig. 1. Diagram of a house with solar thermal collectors and a thermal storage unit installed under the house.
1. Solar collectors, 2. Conversion unit, 3. Storage tank, 4. Cold water, 5. Hot water, 6. Heating

Thermal energy can be stored in many ways. A list of relevant data is included in articles [1-7]. Heat storage units are often filled with paraffin wax with a higher melting temperature of ~60ºC, or water. Filling the unit with paraffin wax has the advantage that heat emittance related to the melting process occurs with a constant temperature equal to the melting temperature and within a long time interval the temperature of the stored energy remains the same. The advantage of a water-filled unit is a slightly higher heat capacity in a unit of the same volume, and the unit can easily be turned into a pool in the case of the user resigning from heat storage. For calculation purposes it will be assumed that the storage unit has the dimensions of 10×10×2 m, which gives a volume (V) of V=200 m³. The unit would be located under the house and does not need to be completely filled, depending on the needs of the user. It is been assumed that the thermal insulation of the unit is d=0.5 m thick. The unit, while completely filled, can collect 22,252 kWh when filled with water, or 24,750 kWh when filled with paraffin wax. It has been assumed that the surrounding temperature is T_0=0ºC, the maximal temperature of the water or paraffin wax does not exceed T_1=70°C, while the specific heat of water is c_w=4,200 J/kg deg, the specific heat of paraffin wax is c_p=2,100 J/kg deg and at the melting temperature of paraffin wax, heat of fusion is c_{tp}=1,500,000 J/kg. It has also been assumed that the density of water and paraffin wax is similar and is approximately ρ=1,000 kg/m³.

The calculations for the heat capacity of the unit for water (in kWh) have been made according to the formula:

$$Q_w\,[kWh] = \frac{V \cdot \rho \cdot c_w \cdot (T_1 - T_0)}{3{,}600{,}000} \tag{1}$$

And for a wax-filled unit phase transition was taken into account:

$$Q_w\,[kWh] = \frac{V \cdot \rho \cdot c_w \cdot (T_1 - T_0)}{3{,}600{,}000} + \frac{V \cdot \rho \cdot c_{tp}}{3{,}600{,}000} \tag{2}$$

From these calculations it can be seen that thermal storage units filled either with water or paraffin wax have similar heat capacity parameters.

It has to be taken into account while calculating that during the first year of exploitation the material filling the unit will be at room temperature (around 20ºC), while after a year it should not be lower than 35ºC (in April). Taking this into account, in the case of water as a storage substance the temperature cannot exceed 100ºC at the end of the storage period (the end of October).

The heat collected in the unit should be stored for about half a year. Every storage unit loses heat if its temperature is higher than the surrounding temperature. From the previous analysis it appears that it is necessary to store around 10,000 kWh for colder days in order to provide sufficient heating and hot water for the house. Taking into account that the heat gathered in the unit will be around Q=20,000 kWh, and assuming a 50% loss rate, the thermal storage unit can lose around Q_s=10,000 kWh of heat during six months.

The surface of the analyzed unit is around S=300 m^2, including the surface underneath the house. A half-year interval is around t=16 mln seconds. Assuming that the heat is lost by the surface of the storage unit, the average heat loss can be quantified so that it corresponds to the assumed heat loss.

Therefore, the power of the loss P_s from one square meter of surface could be:

$$P_s = \frac{Q_s}{s \cdot t} \tag{3}$$

Putting our data into the formula we show that the maximal power of loss by the unit is around P_s=10 W/m^2.

The power of the heat loss from a surface unit through a flat obstacle is dependent on the thermal conductivity λ of the insulating material, its thickness d, and the temperature difference ΔT between the unit and the averaged surroundings, and based on Fourier's formula can be written as:

$$P = \lambda \cdot gradT \tag{4}$$

Assuming the largest *gradT*, which means the one that exists when the storage unit has its highest temperature-namely $\Delta T/d$=140 deg/m (since ΔT=70°C, and the thickness of the insulator was assumed to be d=0.5 m), we receive from the formula, with P_s=10 W/m^2, that the value of the conductivity λ of the material from which the insulator is built should not be lower than 0.07 W/mK.

This is a relatively low value for thermal conductivity. Various materials, as for example glass wool (0.03), styrofoam (0.036), polyurethane foam (0.025), or aero gel (0.017) have a lower thermal conductivity value than 0.07 W/mK. The existence of materials with a lower thermal conductivity value than 0.07 W/mK means that the insulating walls can be thinner than d=0.5 m, and for aero gel they should have to be 0.12 m, for polyurethane foam the thickness of the insulation can be 0.18 m, and for styrofoam about 0.25 m.

The above data has been obtained assuming the most unfavorable conditions. In practice, the necessary thickness of the insulation will usually be lower and will fulfill the necessary conditions completely.

Conclusions

Taking into account the above analysis, it can be ascertained that the goal of providing hot water and heating to a detached house is achievable with current technical solutions. This would allow considerable savings of energy and protect the environment. The cost of this resolution is relatively high, but it shall be expected that the cost of energy will rise, while the cost of installing solar thermal collectors will fall, and taking into account environmental reasons the project might be profitable and attainable.

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