# The influence of energy conservation on the performance of solar thermal systems - A cold country case study

Wallin, Jörgen; Bastien, Diane; Claesson, Joachim

*Published in:*
Energy Procedia

*DOI:*
10.1016/j.egypro.2012.11.120

*Publication date:*
2012

*Document version:*
Final published version

*Citation for pulished version (APA):*
Wallin, J., Bastien, D., & Claesson, J. (2012). The influence of energy conservation on the performance of solar thermal systems - A cold country case study. *Energy Procedia*, *30*, 1069-1078.
https://doi.org/10.1016/j.egypro.2012.11.120

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 30 (2012) 1069 – 1078

Energy
Procedia

SHC 2012

# The influence of energy conservation on the performance of solar thermal systems – A cold country case study

Jörgen Wallin [a*], Diane Bastien[b], Joachim Claesson[a]

[a]Royal Institute of Technology (KTH), Brinellvägen 68, Stockholm SE-10044, Sweden
[b] Concordia University, 1455 de Maisonneuve Blvd. West, Montréal H3G 1M8, Canada

## Abstract

The European Union has set a goal that the energy use in the built environment shall be reduced by 41 % to the year 2050 compared to 2005-2006. This could introduce new opportunities for solar thermal systems in cold countries. In such countries, like Sweden and Canada, the economy in solar thermal collector installation projects is often spoiled by the fact that most of heating energy demand of the building occurs during periods when the available solar energy is low.

The present paper investigates the performance of solar thermal systems subjected to different quota between space heating and domestic hot water demand (DHW). This study investigates the performance of a solar thermal system integrated to four different buildings with varying heating loads in two different locations, Sweden and Canada. Models of single family houses are created which are able to simulate the total heating demand with different heating demand profiles but the same DHW demand. Simulations are performed in TRNSYS, an advanced tool used to simulate transient systems. Results indicate that solar combisystems tend to generate more useful energy and therefore be more cost effective when installed in buildings with higher heating demands.

Selection and/or peer-review under responsibility of PSE AG

*Keywords:* Solar thermal collector; economical opportunity; energy conservation

---

* Corresponding author. Tel.: +46 8-790 8653.
*E-mail address*: jorgen.wallin@energy.kth.se

Selection and/or peer-review under responsibility of PSE AG
doi:10.1016/j.egypro.2012.11.120

## 1. Introduction

The European Union has set a goal that the energy use in buildings shall be reduced by 41% by 2050 compared to the year 2005-2006 [1]. This could introduce new opportunities for solar thermal collector installations in cold countries. In cold countries, like Sweden and Canada, the economy in solar thermal systems is often spoiled by the fact that most of heating energy demand of buildings occurs during periods when the available solar energy is low.

In 2000, there was 606,509 $m^2$ of solar thermal collector area installed in Canada and 208,045 $m^2$ in Sweden [2]. However, when considering DHW production and space heating only (i.e. excluding swimming pool heating) the total collector area falls to 72,000 $m^2$ for Canada and 178,045 $m^2$ for Sweden. Consequently, 81% of the installed solar thermal collectors in Canada are unglazed flat plate collectors used for swimming pool heating. The use of glazed flat plate collectors and/or evacuated tubes for DHW and space heating is rather marginal in Canada as well as in Sweden. Nevertheless, the solar thermal collectors installed in 2000 in Canada and Sweden are estimated to avoid annually the emission of 61,969 and 21,678 $t_{eq}CO_2$ respectively.

The present paper investigates the effect on the performance of a solar thermal collector installation by changing the quota between space heating and domestic hot water demand of a building by reducing the heating demand. Four models of single-family houses, which are able to simulate the heating demand with different heating demand profiles, are created. Simulations are performed in TRNSYS [10], an advanced tool used to simulate transient systems, for Stockholm and Montreal.

### *1.1. Stand-alone water based solar thermal collectors*

Solar water collectors for DHW are effective, cost efficient and can significantly reduce $CO_2$ emissions in Mediterranean countries. The energy and $CO_2$ payback time of a thermosiphon solar thermal collector for DHW in Italy can be less than 2 years [3]. In Cyprus, another study [4] found that the energy payback of thermosiphon solar water heaters was 13 months and the payback time with respect to pollutant emissions varied from a few months to 3.2 years, depending on the particular pollutant considered. In addition, the economic payback time was 2.7 year with electricity backup or 4.5 years with diesel backup.

However, solar thermal systems in colder countries, like Sweden and Canada, need frost protection and therefore are usually more complex and need more materials, such as heat exchangers and pumps, so the energy and economic payback time tend to be significantly longer for these countries.

As noted by Gajbert [5], it is reasonable to size a solar thermal energy system to cover about 95% of the DHW during the summer months, for both solar combisystems and solar DHW. This way, overheating problems should be avoided. For a solar combisystem, the collector area and the collector tilt angle should be increased compared to a DHW system to improve the efficiency of the system during the heating season.

A study of 10 Canadian cities has found that the average optimal tilt angle to maximize annual electricity output of photovoltaic (PV) panels is equal to the latitude minus 9.6° [6]. The optimum tilt angle for Ottawa, which is 200 km away from Montreal and at the same latitude of 45°, is 38°. However, installing the solar panel at plus or minus 6° from the optimum tilt angle (32° or 44°) lowers the annual performance by only 0.4%. The performance of solar thermal systems is affected by the loads, therefore these results about PV performance cannot be directly apply for thermal systems, but nevertheless these results offer some insight on the solar resource characterization.

A recent study [7] found that the simple payback time of a solar combisystem with three collectors for the climatic and economic conditions in Montreal is equal to 50.5 years, which is beyond their expected lifetime of 25 years. In addition, the extra cost of installing a radiant floor system (versus baseboard heaters), which is deemed necessary if solar thermal collectors are to be used, is $13,500 and should be considered. However, other studies investigating solar combisystems are using conventional hot water radiators for space heating delivery and do not raise specific issues about the use of water radiators with a solar thermal system [8,9]. Using a radiant floor heating system offers superior thermal comfort and maybe a small heating load reduction compared to water radiators. However, the idea that radiant floors are essential for the space heating delivery of solar combisystems, which is common in North America, is questionable and should be further explored. Using conventional hot water radiators with solar combisystems would greatly facilitate the installation of a solar thermal system in existing houses.

Another Canadian study of a solar thermal system for DHW production made of two flat plate collectors and an additional tank for pre heating found a simple payback of 86 years for their systems [10]. However, the orientation of the collectors, which was set to 20° west of south at a 60° tilt angle, was not optimum and little attention was paid to reduce heat pipe losses and overheating during unoccupied periods.

A large variation of the price of solar thermal systems can be seen between Mediterranean and northern countries. For example a thermosiphon solar system with two flat plate collectors and one 150 l storage tank is estimated to cost 500 euros in Cyprus [4] while a solar combisystem with one flat plate collector and two 300 l storage tanks cost 6200$ CAN [7]. Part of this difference could be explained by the reduced system complexity in warmer locations and because of the state of development of the solar thermal market.

### *1.2. Building-integrated solar water collector*

The addition of solar thermal collectors to buildings could be expensive and may be facing aesthetic issues, especially when large solar collectors are considered. Moreover, the racking system, usually made of aluminum, can represent a significant portion of the cost. Integrating a low cost solar thermal collector within the building envelope has been envisioned to solve these issues. Such integrated collectors typically have lower efficiencies than conventional collectors, but may cover larger areas of façade and/or roof in buildings. In addition, substantial savings may result from displacing the conventional exterior cladding. An interesting colored polymeric solar thermal collector is described in [9]. Such collectors have the potential to be aesthetically pleasant and well integrated, low weight and cost competitive.

## 2. Problem statement and objectives

The heating demand in cold countries is mainly driven by space heating and domestic hot water (DHW) needs. As previously mentioned, there are few solar thermal collector installations for space heating and DHW in cold countries like Sweden and Canada. The main reason for this is the high cost of a solar thermal system. This study analyses the performance of solar thermal combisystems under different heating loads to assess the viability of such systems for existing conventional houses and new high-efficiency houses. Results could be used to identify opportunities for reducing costs of solar thermal collectors and most appropriate applications.

European Union has set a goal that the energy use in buildings should be reduced by 41 % to the year 2050. This means that serious energy saving measures needs to be implemented to reduce the heating demand. This reduction will influence the quota between the amount of space heating and DHW that is being used. The quota between these could influence the efficiency of a solar thermal collector system and its optimum orientation. The objective of this paper is to evaluate if the quota between the space heating and the DHW is influencing the performance of a solar thermal collector installation in order to evaluate if energy saving measures could influence the economy of a solar thermal system. Computer models of buildings with solar thermal collectors coupled with space heating and domestic hot water were created to conduct this study.

## 3. Methodology

Four different models of buildings equipped with solar thermal collectors were built in TRNSYS [11], an advanced tool used to simulate transient systems. TRNSYS comes with many validated sub modules that can be used to create dynamic models of thermal systems. The main modules used to create the building models with solar thermal systems consist of the following:

- Multi zone Building module (TRNSYS Type 56a)
- Climate module (TRNSYS Type 109 with Meteonorm, climate file [12])
- Heat exchanger module (TRNSYS Type 5)
- Solar Radiation Processor: Horizontal Beam and Diffuse Radiation Known (TRNSYS Type 16e)
- Flat Plate Solar Collector with Specified Outlet Temperature (TRNSYS Type 537, TESS [13])
- Storage Tank; Variable Inlets, Uniform Losses (TRNSYS Type 4)
- Auxiliary Heater (TRNSYS Type 6)
- Time Dependent Forcing Function: Water Draw (TRNSYS Type 14b)

The different modules that were used are described in more details in the mathematical reference document of TRNSYS [14].

### *3.1. Buildings characteristics*

Four buildings are created to test how the performance of solar thermal collector systems is influenced by the quota of the heating load and DHW demand of buildings. Two of the buildings are situated in Stockholm, Sweden and two are situated in Montreal, Canada. Two different locations are investigated to see the influence of climate and latitude on the performance of the system. Montreal and Stockholm where selected because both locations have a cold climate with a considerable annual demand for space heating (4,109 Heating degree days [18°C] for Stockholm and 4,753 for Montreal) and different solar resources (annual average solar radiation [tilt=latitude] of 3.20 kWh/m$^2$/day for Stockholm and 3.84 kWh/m$^2$/day for Montreal) [15]. The buildings have similar characteristics but are subjected to different climatic conditions and insulation levels and therefore have distinct space heating loads.

The investigated building is a 126 m$^2$ single-family house with one floor. The new building in Stockholm is representative of a new energy efficient building, built to be slightly better than the new Swedish building code; the old building in Stockholm represents an older building typical of the actual Swedish housing stock. The new building in Montreal is a building created according to the specifications in the new proposed building code for the province of Québec, [16] and the old building in Montreal represents a typical old building in Canada. The space heating demand per square meter of floor area for the four investigated buildings is equivalent to:

- New building Stockholm - 49.5 kWh/m2
- Old building Stockholm - 139.4 kWh/m2
- New building Montreal - 90.8 kWh/m2
- Old building Montreal - 163.2 kWh/m2

### *3.2. The solar thermal system*

The solar thermal collector tested in the simulations is a flat plate collector connected to a storage tank. The volume of the storage tank is changed for every simulation so that the volume is equal to 100 liters per $m^2$ solar collector area (100 liters per $m^2$ area is used as a rule of thumb by many installers in Sweden when designing solar collector systems). Two near optimum collector tilt angles are simulated for both locations to evaluate the influence of the slope on the performance. The two buildings in Stockholm (latitude of 59°) are simulated with the solar collector angle set to 60° and 45°. The buildings in Montreal (latitude of 45°) are simulated with the slope of the solar collector set to 45° and 35°. It is assumed that there are no heat losses in the storage tank, but losses occurring through the heat exchanger are considered. Hot water radiators are used for space heating delivery for all buildings.

### *3.3. Simulations*

The different solar collector areas considered in this study are:

- Base case – No solar collector
- 2.5 $m^2$ solar collector area
- 5 $m^2$ solar collector area
- 10 $m^2$ solar collector area
- 20 $m^2$ solar collector area
- 40 $m^2$ solar collector area
- 80 $m^2$ solar collector area

The area of one flat plate collector is typically around 2.5 $m^2$. The simulation time step is set to one hour and simulations are run for a complete year. The DHW demand is the same for all four simulations, which ensures that the quota between the space heating and DHW is different in the four cases because of varying heating loads. The DHW heating demand is set on a schedule based on a study performed by the Swedish Energy Agency (STEM), where the DHW demand in a Swedish single family house was investigated [17]. The quota between the space heating and DHW for the four buildings is presented in Table 1:

Table 1. Quota between the annual space heating energy and annual energy for DHW

| Building | DHW Quota | SH quota |
|---|---|---|
| New building Stockholm | 40% | 60% |
| Old building Stockholm | 19% | 81% |
| New building Montreal | 27% | 73% |
| Old building Montreal | 17% | 83% |

## **4. Results and discussion**

Table 2 presents the available and useful solar energy and the net space heating and DHW demand for the different buildings and varying solar collector areas. Available solar energy is the amount of energy harvested by the solar collectors and stored in the water tank. Useful solar energy is the amount of solar energy that is used to heat the building and DHW when considering heat losses in the space delivery system. The building heating system also influences the amount of energy that is possible to harvest.

Heating demand is the amount of energy that needs to be supplied for space heating (i.e. the building space heating demand minus the amount of energy supplied to the space heating by the solar collector). Similarly, DHW demand is the total DHW demand minus the heat supplied by the solar collectors.

Table 2. Solar radiation harvested by a solar thermal system for varying collector areas and space heating demands.

| Case 1 - New building Stockholm - 60 ° Collector slope | | | | | |
|---|---|---|---|---|---|
| Collector area | Specific solar energy per collector area | Available solar energy | Useful solar energy | Heating Demand | DHW Demand |
| 0.0 m2 | 0.0 kWh/m2 | 0.0 kWh | 0.0 kWh | 6241.7 kWh | 4148.4 kWh |
| 2.5 m2 | 440.4 kWh/m2 | 1108.8 kWh | 1101.0 kWh | 6225.0 kWh | 3064.0 kWh |
| 5.0 m2 | 425.7 kWh/m2 | 2144.7 kWh | 2128.3 kWh | 5766.7 kWh | 2495.1 kWh |
| 10.0 m2 | 333.8 kWh/m2 | 4159.3 kWh | 3338.0 kWh | 5008.3 kWh | 2043.7 kWh |
| 20.0 m2 | 249.4 kWh/m2 | 7862.3 kWh | 4988.8 kWh | 3958.3 kWh | 1442.9 kWh |
| 40.0 m2 | 161.5 kWh/m2 | 12541.3 kWh | 6459.9 kWh | 3041.7 kWh | 888.4 kWh |
| 80.0 m2 | 93.4 kWh/m2 | 14669.2 kWh | 7468.1 kWh | 2275.0 kWh | 646.9 kWh |
| Case 2 - Old building Stockholm - 60 ° Collector slope | | | | | |
| Collector area | Specific solar energy per collector area | Available solar energy | Useful solar energy | Heating Demand | DHW Demand |
| 0.0 m2 | 0.0 kWh/m2 | 0.0 kWh | 0.0 kWh | 17566.7 kWh | 4148.4 kWh |
| 2.5 m2 | 442.7 kWh/m2 | 1107.9 kWh | 1106.7 kWh | 17533.3 kWh | 3054.0 kWh |
| 5.0 m2 | 421.1 kWh/m2 | 2120.8 kWh | 2105.3 kWh | 17266.7 kWh | 2343.0 kWh |
| 10.0 m2 | 385.8 kWh/m2 | 4124.4 kWh | 3857.7 kWh | 15975.0 kWh | 1882.3 kWh |
| 20.0 m2 | 309.9 kWh/m2 | 7933.4 kWh | 6197.7 kWh | 14116.7 kWh | 1400.7 kWh |
| 40.0 m2 | 227.0 kWh/m2 | 14553.5 kWh | 9079.4 kWh | 11758.3 kWh | 877.3 kWh |
| 80.0 m2 | 149.5 kWh/m2 | 19754.5 kWh | 11959.4 kWh | 9158.3 kWh | 597.3 kWh |
| Case 3 - New building Stockholm - 45 ° Collector slope | | | | | |
| Collector area | Specific solar energy per collector area | Available solar energy | Useful solar energy | Heating Demand | DHW Demand |
| 0.0 m2 | 0.0 kWh/m2 | 0.0 kWh | 0.0 kWh | 6241.7 kWh | 4148.4 kWh |
| 2.5 m2 | 457.1 kWh/m2 | 1175.7 kWh | 1142.7 kWh | 6175.0 kWh | 3072.3 kWh |
| 5.0 m2 | 413.4 kWh/m2 | 2280.2 kWh | 2067.2 kWh | 5775.0 kWh | 2547.8 kWh |
| 10.0 m2 | 332.9 kWh/m2 | 4408.3 kWh | 3328.9 kWh | 4991.7 kWh | 2069.5 kWh |
| 20.0 m2 | 246.1 kWh/m2 | 8279.3 kWh | 4921.2 kWh | 4066.7 kWh | 1402.1 kWh |
| 40.0 m2 | 154.1 kWh/m2 | 12150.9 kWh | 6164.8 kWh | 3275.0 kWh | 950.2 kWh |
| 80.0 m2 | 87.7 kWh/m2 | 14361.8 kWh | 7012.1 kWh | 2666.7 kWh | 711.3 kWh |
| Case 4 - Old building Stockholm - 45 ° Collector slope | | | | | |
| Collector area | Specific solar energy per collector area | Available solar energy | Useful solar energy | Heating Demand | DHW Demand |
| 0.0 m2 | 0.0 kWh/m2 | 0.0 kWh | 0.0 kWh | 17566.7 kWh | 4148.4 kWh |
| 2.5 m2 | 461.0 kWh/m2 | 1173.9 kWh | 1152.6 kWh | 17508.3 kWh | 3054.1 kWh |
| 5.0 m2 | 431.7 kWh/m2 | 2260.3 kWh | 2158.3 kWh | 17125.0 kWh | 2431.7 kWh |
| 10.0 m2 | 387.8 kWh/m2 | 4391.3 kWh | 3877.7 kWh | 15891.7 kWh | 1945.7 kWh |
| 20.0 m2 | 305.1 kWh/m2 | 8404.4 kWh | 6102.9 kWh | 14200.0 kWh | 1412.2 kWh |
| 40.0 m2 | 220.8 kWh/m2 | 14658.8 kWh | 8833.4 kWh | 11958.3 kWh | 923.3 kWh |
| 80.0 m2 | 140.5 kWh/m2 | 19067.4 kWh | 11243.7 kWh | 9816.7 kWh | 654.6 kWh |
| Case 5 - New building Montreal - 45 ° Collector slope | | | | | |
| Collector area | Specific solar energy per collector area | Available solar energy | Useful solar energy | Heating Demand | DHW Demand |
| 0.0 m2 | 0.0 kWh/m2 | 0.0 kWh | 0.0 kWh | 11433.3 kWh | 4148.4 kWh |
| 2.5 m2 | 613.1 kWh/m2 | 1657.9 kWh | 1532.9 kWh | 11425.0 kWh | 2623.8 kWh |
| 5.0 m2 | 566.8 kWh/m2 | 3207.0 kWh | 2834.0 kWh | 10791.7 kWh | 1956.0 kWh |
| 10.0 m2 | 491.5 kWh/m2 | 6231.7 kWh | 4915.1 kWh | 9200.0 kWh | 1466.6 kWh |
| 20.0 m2 | 379.2 kWh/m2 | 11898.8 kWh | 7583.9 kWh | 7116.7 kWh | 881.1 kWh |
| 40.0 m2 | 259.5 kWh/m2 | 19363.1 kWh | 10379.9 kWh | 4783.3 kWh | 418.4 kWh |
| 80.0 m2 | 156.4 kWh/m2 | 23423.2 kWh | 12514.3 kWh | 2841.7 kWh | 225.8 kWh |
| Case 6 - Old building Montreal - 45 ° Collector slope | | | | | |
| Collector area | Specific solar energy per collector area | Available solar energy | Useful solar energy | Heating Demand | DHW Demand |
| 0.0 m2 | 0.0 kWh/m2 | 0.0 kWh | 0.0 kWh | 20558.3 kWh | 4148.4 kWh |
| 2.5 m2 | 620.1 kWh/m2 | 1657.7 kWh | 1550.2 kWh | 20533.3 kWh | 2623.2 kWh |
| 5.0 m2 | 547.1 kWh/m2 | 3182.6 kWh | 2735.5 kWh | 20141.7 kWh | 1829.5 kWh |
| 10.0 m2 | 504.4 kWh/m2 | 6141.9 kWh | 5044.4 kWh | 18466.7 kWh | 1195.6 kWh |
| 20.0 m2 | 405.0 kWh/m2 | 11776.7 kWh | 8099.5 kWh | 15925.0 kWh | 682.2 kWh |
| 40.0 m2 | 290.7 kWh/m2 | 19838.1 kWh | 11626.9 kWh | 12800.0 kWh | 279.8 kWh |
| 80.0 m2 | 186.2 kWh/m2 | 24536.6 kWh | 14897.2 kWh | 9658.3 kWh | 151.2 kWh |

Case 7 - New building Montreal - 35 ° Collector slope

| Collector area | Specific solar energy per collector area | Available solar energy | Useful solar energy | Heating Demand | DHW Demand |
|---|---|---|---|---|---|
| 0.0 m2 | 0.0 kWh/m2 | 0.0 kWh | 0.0 kWh | 11433.3 kWh | 4148.4 kWh |
| 2.5 m2 | 618.4 kWh/m2 | 1690.7 kWh | 1546.1 kWh | 11375.0 kWh | 2660.6 kWh |
| 5.0 m2 | 565.4 kWh/m2 | 3278.6 kWh | 2827.2 kWh | 10716.7 kWh | 2037.8 kWh |
| 10.0 m2 | 482.0 kWh/m2 | 6354.0 kWh | 4819.6 kWh | 9275.0 kWh | 1487.1 kWh |
| 20.0 m2 | 368.4 kWh/m2 | 12095.5 kWh | 7367.3 kWh | 7341.7 kWh | 872.7 kWh |
| 40.0 m2 | 247.7 kWh/m2 | 18939.1 kWh | 9910.0 kWh | 5216.7 kWh | 455.0 kWh |
| 80.0 m2 | 150.2 kWh/m2 | 23071.5 kWh | 12015.0 kWh | 3300.0 kWh | 266.7 kWh |

Case 8 - Old building Montreal - 35 ° Collector slope

| Collector area | Specific solar energy per collector area | Available solar energy | Useful solar energy | Heating Demand | DHW Demand |
|---|---|---|---|---|---|
| 0.0 m2 | 0.0 kWh/m2 | 0.0 kWh | 0.0 kWh | 20558.3 kWh | 4148.4 kWh |
| 2.5 m2 | 613.2 kWh/m2 | 1689.3 kWh | 1533.0 kWh | 20525.0 kWh | 2648.7 kWh |
| 5.0 m2 | 546.7 kWh/m2 | 3253.1 kWh | 2733.7 kWh | 20058.3 kWh | 1914.7 kWh |
| 10.0 m2 | 494.9 kWh/m2 | 6273.3 kWh | 4949.3 kWh | 18508.3 kWh | 1249.1 kWh |
| 20.0 m2 | 393.6 kWh/m2 | 11986.1 kWh | 7872.5 kWh | 16158.3 kWh | 675.9 kWh |
| 40.0 m2 | 279.7 kWh/m2 | 19528.8 kWh | 11189.6 kWh | 13208.3 kWh | 308.8 kWh |
| 80.0 m2 | 178.6 kWh/m2 | 24063.5 kWh | 14289.2 kWh | 10241.7 kWh | 175.9 kWh |

The useful solar energy harvested by the thermal collectors for the investigated cases is presented in Figure 1. For large collector sizes, the efficiency of solar thermal systems is higher for old buildings than for energy efficient buildings. This is explained by the fact that old buildings have a higher heating load and therefore keep the water temperature in the storage tank at lower temperatures, which enhance system efficiency. It would be interesting to evaluate if increasing the storage volume for energy efficient buildings could compensate this effect.

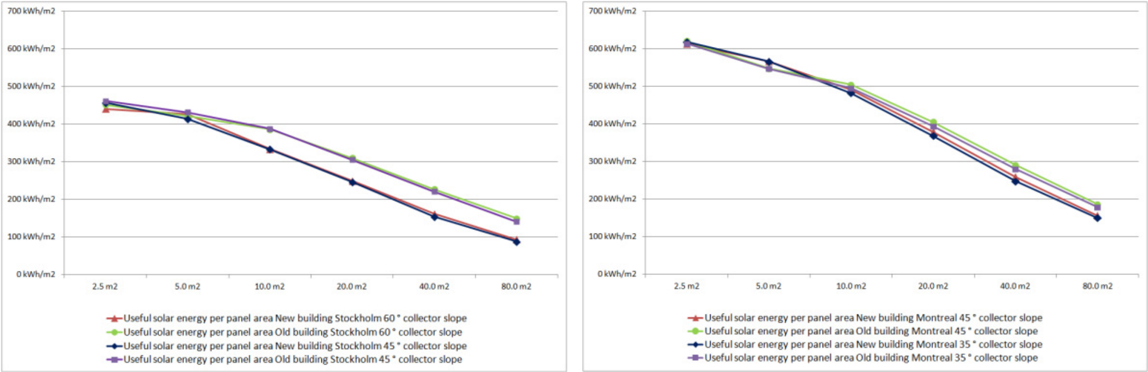

Fig. 1 . Useful solar energy at different collector slopes and different size for Stockholm and Montreal.

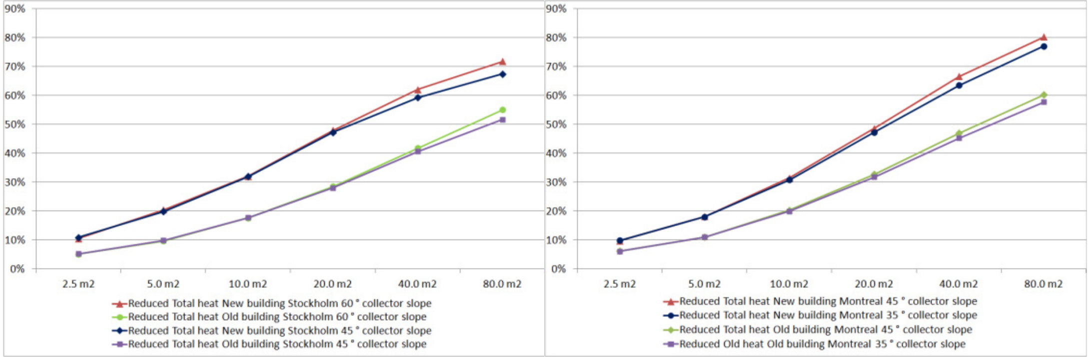

Fig. 2. Fraction of reduction of total heating demand as a function of solar collector area.

Figure 2 shows the fraction of total heating demand reduction for different sizes of solar collectors. Energy efficient buildings are able to supply a significantly higher fraction of their heating needs by a solar thermal system. It can also be seen that when the collector slope is nearly optimal, it has a small impact on the annual performance of the system, especially when the area is small; when the collector area increases, varying the tilt angle exert a stronger influence on the performance. The effect is more pronounced for energy efficient buildings. Analyzing the Figure 3 below gives us additional insight about this behavior:

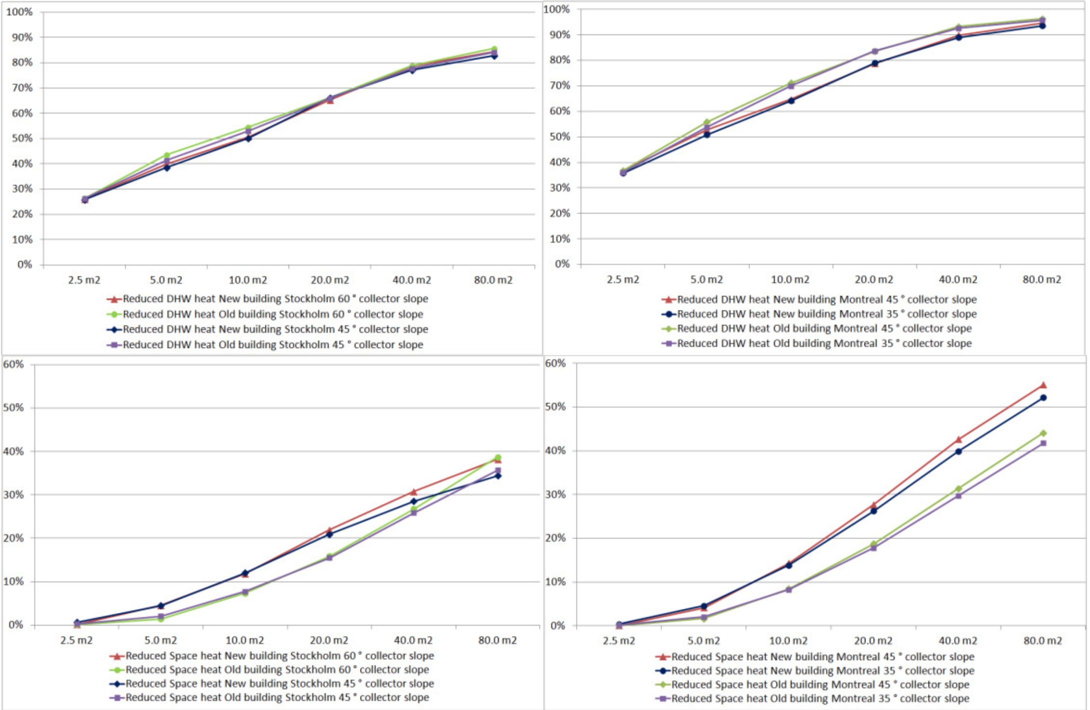

Fig. 3. Reduced heating divided between space heating and DHW heating for all four buildings at different collector areas

From Figure 3, it can be seen that the DHW solar heat is not significantly affected by the collector slope (even though a small influence can be seen for both locations at medium collector sizes). However, the space heating is more affected by the incline of the collector, especially when the collector area gets bigger. The trend noticed in Figure 2 can then be explained by the fact that having a solar collector at a higher tilt angle improves heat production for space heating, which mainly occurs in winter when the sun is low. It can also be seen that the new buildings in Montreal have a larger percentage decrease of heating demand than old buildings, because they have a much lower heating load to start with. This trend can also be observed for buildings in Stockholm; however, for larger collectors, the system performance of the old buildings outpaces that of the new buildings. This could be possibly explained by the storage size of the energy efficient buildings which is not sufficient for such a small heating demand.

The output from the simulation model indicates that the efficiency of the solar combisystems is not very sensitive to the collector slope when it is near optimal since a higher slope favors space heating and a lower slope favors DHW heating. For two identical solar combisystems installed in buildings with different heating loads, the system installed in the building with a higher heating load will produce more useful heat. For instance, a collector of 20m$^2$ installed at 45° in Montreal will produce 7,583.9kWh of useful solar energy in an energy efficient building while the same system installed in an older building will produce 8,099.5 kWh, a 7% increase. The same system installed at 60° in Stockholm will generate 4,988.8 kWh if installed in an energy efficient building and 6,197 kWh if installed in an older building, an increase of 24%. In the Stockholm case presented in Figure 1, an interesting trend can be seen for the new energy efficient buildings. Up to a collector area of 5 m$^2$, the specific useful solar energy decreases roughly at the same rate as the old building but at larger collector areas, there is a more rapid decline of the specific useful solar energy. This is due to the fact that a large part of the available energy is not useful because of the lower space heating demand of the new energy efficient building.

## 5. Conclusion

A simulation model of a solar combisystem was created for four different buildings in two locations for different collector sizes and slopes. The simulation results indicate that the performance of a thermal solar collector is influenced by the quota between the space heating and the DHW. The performance of solar combisystems installed in old buildings tends to be higher than for new buildings, for a given size of storage volume. A solar combisystem installed in a building with a higher heating load will therefore be more cost effective than a system installed in a building with a lower heating demand.

The cost of solar thermal systems needs to be reduced considerably in order to make thermal collectors competitive in cold countries. Looking at the material cost and the simplicity of the system, it can perhaps be argued that the prices of the collectors are set according to the payback in warm countries and not from the production and installation cost of this type of system. The high cost for this type of installation moves the consumers towards other investments. This is unfortunate since a solar thermal collector installation can cover a considerable amount of the heating needed in buildings even in cold countries, as shown by the results presented in this paper. Building-integrated solar thermal collectors should be considered when a large fraction of space heating is to be supplied by solar.

Reducing the energy use in the built environment by 41 % up to the year 2050 requires a shift in the way of thinking. Technologies like solar thermal collectors can play one part to achieve this, but economical hurdles needs to be overcome to make this technology an interesting option. The present investigation clearly indicates that it is technically possible to reduce the annual heating demand by more than the required 41 % set by the European Union. Other energy saving measures that reduces the heating demand will not improve the economical possibility to implement solar thermal panels in the built environment in cold climate countries like Sweden and Canada. Therefore ways to make the collectors cheaper need to be found.

## Acknowledgements

The first author would like to thank the Department of Energy Technology at the Royal Institute of Technology for the support and the trust that I received. Special acknowledgment goes to my supervisor Dr. Joachim Claesson for all the time spent discussing the content of the present paper.

The second author would like to acknowledge support from the Fonds de recherche du Québec – Nature et technologies (FQRNT) for a Doctoral Research Scholarship and Concordia University for a Special Scholarship for New High-Caliber PhD Students, as well as partial support from the NSERC Smart Net-zero Energy Buildings Strategic Research Network.

## References

[1] European Commision, Energy roadmap 2050; Luxembourg: Publication Office of the European Union; 2012.

[2] Weiss W, Faninger G. Solar thermal collector market in IEA member countries.International Energy Agency, Solar and Heating and Cooling Programme; 2002.

[3] Ardente F, Beccali G, Cellura M, Lo Brano V. Life cycle assement of a solar thermal collector. *Renewable Energy* 2005;**30**:1031-54.

[4] Kalogirou S. Thermal performance, economic and environmental life cycle analysis of thermosiphon solar water heaters. Solar Energy 2009;**83**:39-48

[5] Gajbert H. Solar thermal energy systems for building integration, Lund University; 2008.

[6] Paige Kemery B, Beausoleil-Morisson I, Rowlands IH. Optimal PV orientation and geographic dispersion: a study of 10 Canadian cities and 16 Ontario locations. In: The Canadian Conference on Building Simulation, Halifax, Canada; 2012, p.136-49.

[7] Leckner M, Zmeureanu R. Life cycle cost and energy analysis of a net zero energy house with solar combisystem. *Applied Energy* 2011;**88**:232-41.

[8] Fielder, F, Bales, C, Thür A, Furbo S. The actual status of the developement of a Danish/Swedish system concept for a solar combi system. In: NorthSun Conference, Vilnius, Lithuania, 2005.

[9] Furbo,S, Thür A, Bales, C, Fiedler, F et al. Competitive Solar Heating Systems for Residential Buildings (REBUS). Nordic Energy Research, 2006.

[10] Bédard N, Leduc M-A, Bilan d'opération de systèmes solaires thermiques au LTE. L'infobec 2011, p.7-12.

[11] Klein, S.A. et al., 2005. "TRNSYS Version. 16," Solar Energy Laboratory, University of Wisconsin, Madison, Website: http://sel.me.wisc.edu/trnsys

[12]Meteotest, Meteonorm version 6.1 2009, Bern, Switzerland, Website: http://www.meteonorm.com/pages/en/meteonorm.php

[13] Thermal Energy System Specialists (TESS), "http://www.tess-inc.com" and http://www.trnsys.com/

[14] Klein, S.A. et al., 2005. "TRNSYS Version. 16, Matematical reference" Solar Energy Laboratory, University of Wisconsin, Madison, Website: http://sel.me.wisc.edu/trnsys

[15] NASA, Nasa Surface meterology and solar energy; eosweb.larc.**nasa**.gov/sse/

[16] Régie du bâtiment du Québec, Règlement modifiant le Code de construction pour favoriser l'efficacité énergétique, La Gazette officielle du Québec; 2012.

[17] STEM, Mätning av kall och varmvattenanvändning i 44 hushåll (Measurement of tap water and domestic hot ware use in 44 dwellings), ER2009:26, ISSN 1403-1892, 2009