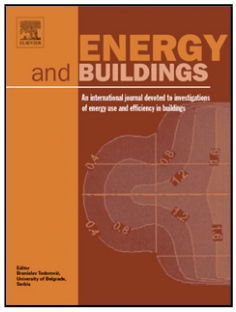

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Potential for reliance on solar water heating throughout the summer in northern cloudy climates

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Abstract

In latitudes between 50° and 60°north domestic hot water is frequently provided by the house's central heating boiler. These are run for short periods in the summer just to provide hot water, this tends to be inefficient. In places with a constant solar climate it should be possible to rely on solar energy to provide domestic hot water, however many northern cities have a large daily variation in solar radiation. The potential of solar water heaters to meet the hot water demand of a household throughout the summer period in a wide range of cities was investigated. Hourly solar irradiation and air temperature values for a typical year are used to calculate the efficiency of a commercially available solar panel and estimate the energy collected each hour. The hot water is stored with daily extraction varied to correspond to different levels of occupants. The heat loss from the store is also calculated and used to find the optimum area of solar collector for a given store size. It was found that it should be possible to provide domestic hot water by solar panels for the period when space heating is not required in all location considered.

Keywords

solar water heating; domestic hot water; northern climate; summertime usage; thermal stores

1 Introduction

The practicality of using solar water heating to augment existing water heating systems in Northerly latitudes (50° and above) has been established. This normally involves the use of an auxiliary water heater to boost the temperature on cloudy days [1,2] or the running of central heating boilers for very short times to top up the temperature in the domestic hot water tank to supplement the solar heating on dull days [3]. Although some gas boilers and electric heaters can work efficiently for short duration runs the same is not true for low carbon heat sources like biomass fired boilers or micro CHP units. This leads to the conclusion that solar water heaters cannot be used efficiently in combination with low carbon heating systems. Consequently a different implementation strategy should be employed when using solar water heaters in combination with low carbon heat sources. It has been show previously [4] that it is possible for a typical solar water heater to provide adequate

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hot water without auxiliary heating on a number of days in the year in Northern Ireland a region that is not known for its sunny weather.

This paper investigates the possibility of using suitably sized solar water heating systems with heat stores to provide all the hot water demand throughout the summer period allowing the alternative heating system to be switched off for the season. It is reasonable to assume that this can be done in areas where there is consistent sunshine but this is not the case for many northern cities. In these cases it may be possible to heat more water than is required on sunny days and store it for use so on cloudier ones.

As location that experience changeable weather patterns are being considered it is desirable to use hourly irradiation data rather than averaged data. The availability of solar energy in the latitudes considered is highly seasonal so although some of the results are given for a complete year the systems considered are designed for summer duty. For the purpose of this analysis summer is considered to start four weeks after the spring equinox and continue until four weeks before the autumn equinox i.e. days 109 to 242.

2 Background

2.1 Domestic Hot Water Demand

The consumption of Domestic Hot Water (DHW) will vary across cultures. The IEA Solar Heating and Cooling programme - Task 32 published a model of a reference heating system for a typical European house [5]. This included an estimate for DHW, although unfortunately it was not characterised by the number of occupants so it is too general to use for a study that concentrates on DHW heating. There have been several attempts to estimate or measure the typical DHW demand of a British household but most report the data in terms of volume flow rather than heat. The Energy Saving Trust carried out a survey which measured both flow and temperature [6] so it gives indication of the DHW heat requirements.

The EST survey reported that the average hot water delivery temperature was 52°C. The temperature of the cold water feed to the boiler was also measured and was found to vary from 10 to 20°C depending on whether the boiler was supplied directly from the incoming main or from a storage tank. The average water supply temperature was 15°C. To raise water from 15°C to 52°C requires

155kJl^{-1} which gives: $Q=4.34+6.2N$ MJd^{-1}

Where Q is the heat supplied per day. It should be noted that the survey data used to derive this equation reported a wide range of usage between similar households and there is a possibility that a real household could use twice the energy calculated by this equation.

2.2 Available solar energy

The amount of solar energy available at a given location and time principally depends on the orientation of the collector, elevation of the sun in the sky and the degree of cloud cover. This varies over the year and throughout the day. There have been many attempts to model solar radiation

patterns [7] however there are also some measurement based weather data series for typical years. These use historic data adjusted to give hourly data readings that could have reasonably been encountered in the last 30 years. The use of these data series avoids the need to estimate the hourly cloud cover. Measured solar radiation data is reported in three formats, horizontal radiation (or global horizontal radiation) which is the total radiation falling on the horizontal plane of the earth, beam radiation which is the radiation that falls on a plane normal to the sun's beam (this plane changes orientation throughout the day) and diffuse radiation which is the radiation falling on the horizontal plane of the earth that is not the direct result of beam radiation i.e. all the solar energy that hit the earth after being scattered by clouds and atmospheric dust.

The US Department of Energy runs a web site [8]which contains typical year data for a large number of locations. The total horizontal, beam and diffuse radiation received during the summer for northern cities have been taken from this web site and are shown in Figure 1 along with their annual total horizontal radiation. The cities in Figure 1 are in order of their latitude which is shown after the city's name.

Figure 1 Annual solar radiation received by different cities

As would be expected those in the south are generally sunnier than the north but this trend is less pronounced in the summer than for the year as a whole. This may be a consequence of the summer days being longer in the north than in the south.

The total horizontal radiation figures do not give an indication of the cloud cover that a location experience. This can be inferred from the ratio of diffuse radiation to beam radiation. Brussels receives the highest proportion of diffuse radiation of any city considered and Vancouver the lowest. The daily horizontal solar radiation received in these cities is shown in Figure 2. As they are on similar latitudes the differences in their total summer radiation shown in Figure 1 must be due to different amounts of cloud cover.

Figure 2 Impact of cloud cover on summer radiation

Both cities experience a large daily variation in the level of radiation. However the occurrence of more than a few consecutive days with low radiation in summer is low in both locations.

2.3 Radiation on an inclined plane

In most cases the collectors are mounted on south facing sloping roofs so the total energy on an incline plane needs to be calculated (I_N). The beam (I_B) and diffuse (I_D) radiation need to be considered separately, there is also a requirement to consider radiation that has been reflected from the earth's surface onto steeply inclined collectors (I_R).

2.3.1 Direct Beam

This will depend on the angle between the sun's ray and the collector so

$$I_N = I_B \cos(\Theta)$$

Where Θ is the incident angle between the sun's ray and the normal of the collector surface.

θ varies throughout the day its calculation is explained in a number of text books, and papers [9,10,11] .

2.3.2 Diffuse radiation

Diffuse light is the result of the some of the direct beam being scattered as it passes through the atmosphere so it is reasonable to assume that it can come from any direction. This is the basis for isotropic sky models of solar radiation [7]. Using the isotropic sky model the diffuse radiation can be calculated by:

$I_S=I_D(1+\cos(\beta))/2$

Where I_S is the diffuse radiation on the collector and β the angle between the collector and the earth's surface or tilt angel

2.3.3 Reflected light

Not all light is absorbed by the ground; some is reflected back to the sky and so could irradiate a collector which was tilted above the horizontal. The proportion of light reflected back is called the albedo. This varies with the type of ground surface. Natural Resources Canada [12] suggests that a value of 0.2 is used if the air temperature is above freezing.

The isotropic sky model uses the following equation for reflected radiation

$I_R=I_G\alpha(1-\cos(\beta))/2$

where I_G is the total radiation on a horizontal plane.

2.4 Collector tilt angle

To collect the maximum amount of solar energy from a fixed collector, it should be orientated towards the strongest beam experienced over a year. That is, a tilt angle equal to the suns zenith angle on a summer's day. The zenith angle at noon is the latitude minus the declination that is between 28° and 38° for the cities in Figure 1. The summer irradiation has been calculated for different tilt angles at Vancouver and Brussels. These have been plotted in Figure 3 to see if the different proportion of bean radiation affects the optimum mounting angle. As both of these cities are in the south of the region being considered the data for Anchorage and Oslo has also been plotted to see the impact of latitude on optimum mounting angle.

Figure 3 Impact of tilt angle on annual radiation on an inclined collector

In all cases the level of radiation does not appear to vary greatly over the range of inclinations used for roofs of flat or pitched roof (0° - 50°). The output of Vancouver peaks with a tilt angle around 30° and Anchorage peaks around 40° which supports the assumption that the tilt angle should be the latitude minus the maximum declination. The higher level of diffuse radiation received by Brussels and Oslo tends to reduce the impact of changes in tilt angle.

3 Solar hot water system model

The average summer irradiation for the cities in Figure 1 was 2600 kJm^{-2} and the average ratio of beam to diffuse radiation was 1.343. St Petersburg experiences conditions that are the closes to the average conditions of the cities considered (summer irradiation of 2582 kJm^{-2} and a beam to diffuse ratio of 1.331) so it was decided to use its data to represent a typical city. A spread sheet model for a house experiencing the weather conditions of St Petersburg with south facing solar panels mounted at an optimum tilt angle of 37° and variable sized thermal stores was developed. The auxiliary DHW heating that would be needed to maintain an acceptable water temperature was calculated. In order to investigate the impact of variation in solar panel performance with irradiation and air temperature hourly data was used. The solar panel area was increased until the maximum temperature at any hour of the water in the store was reached 90°C. This was done to ensure that maximum use could be made of the storage capacity without the risk of boiling the water. 90°C is of course too hot for use for DHW but thermal stores are fitted with temperature regulator valves that automatically mixes the hot water from the store with cold water to get an acceptable temperature before it enters the DHW system.

On each hour the following parameters were calculated:

- The efficiency of the solar panel based on the recorded ambient air temperature with the fluid exit temperature assumed to be equal to the store temperature from the previous hour plus 10°C (to allow heat transfer through the solar heating coils in the heat store).
- The energy collected by the panel based on its efficiency and the calculated irradiance for that hour.
- The net energy stored once the additional energy from the panel and store losses have been accounted for.
- The temperature of the store at the end of the hour.

As the system considered used large stratified thermal storage tanks which held more than one days water consumption it was decided to model the hot water extraction as a single demand taken at 12:00 each day. The stores energy level would be reduced by the daily DHW demand and the energy required from an auxiliary heater to return the store temperature to a minimum acceptable temperature of 40°C calculated.

3.1 Solar panel performance

Solar water heaters collectors are tested according to EN 12975-1, 2:2006 this uses the following equation to describe the variation of efficiency with irradiation and temperature:

$$\eta_{dt} = \eta_0 - a_1 dt G^{-1} - a_2 dt^2 G^{-1}$$

where

$\eta_{\Delta t}$ is the efficiency at a given temperature difference

η_0 is the efficiency when the fluid leaving the heater is at ambient temperature

Δt is the temperature difference between the fluid leaving the heater and the ambient temperature

G is the irradiation

a_1 and a_2 are constants determined by measurement under test conditions.

There are many types of solar water heaters and it is important to choose the correct technology for a specific application. As it was intended to look at applications where the stored water temperature would be considerably hotter than the ambient air it was decided to only consider the use of evacuated tube water heaters as these have lower losses under these conditions than other types of solar collectors.

Table 1 shows typical performance with some equipment currently available on the market taken from their manufacturer's web sites [13,14,15,16] This is not a comprehensive market survey but Table 1 indicates that there is not a lot of difference in performance between different manufactures equipment.

Table 1 Solar panel characteristics

In order to investigate the impact that loss of efficiency at higher water temperatures it was decided to use the characteristic for the SunnPro unit's as they appear to be slightly more temperature sensitive than the others.

The Hot Water Association heat store specification indicates that the solar collector fluid should be 10°C above the stored water temperature for the solar heating heat exchange to work at as designed [17](The Hot Water Association 2010).

The heat storage capacity of a heat store depends on the maximum and minimum acceptable water temperatures. It is assumed that the heat store temperature is going to vary between 90°C (to avoid boiling the store's contents) and 40°C (the assumed minimum acceptable hot water supply temperature) so the heat transfer fluid from the solar panel will need to be between 50 – 100°C.

3.2 Heat store losses

When water is drawn from a heat store it is replaced by cold feed water at the bottom of the tank. Thermal stratification ensures that there is a supply of hot water at the top of the tank so that around 50% of the tanks capacity can be taken from it before the discharge temperature reaches an unacceptable level [17]. However over time the temperature in the tank will equalise; so a uniform average temperature can be assumed when calculating the heat loss from the thermal store. This will have to be provided by the solar water heater in additional to the DHW load. The Hot Water Association standard for heat stores quotes the following equation for calculating the maximum permitted heat loss from a heat store installation in a new building:

$$Q_{HL\text{-}MAX} = 1.28 \times [0.2 + 0.051 \, (V_T)^{2/3})]$$

Where $Q_{HL\text{-}MAX}$ is the maximum permitted daily heat loss from a thermal store in kWh with an initial store temperature of 75°C and a total storage capacity of V_T litres. The rate of heat loss will be proportional to the difference in temperature between the store and the ambient air so:

$$\Delta Q/\Delta t = K \, (T_w - T_a)$$

Where K is a constant for the heat store, T_a is the ambient air temperature around the store, and T_w is the temperature of the water in the store.

The maximum losses are specified for a 24hr period from an initial storage temperature of 75°C with an ambient air temperature of 20°C. Given that the temperature drop after 24 hours is not that large it is reasonable to assume a constant rate of heat loss over the period so:

$\Delta Q/\Delta t = Q_{HL\text{-}MAX}/24 = K((T_{w,o}+T_{w,24})/2)-T_a)$ or

$K = Q_{HL\text{-}MAX}/24((T_{w,o}+T_{w,24})/2)-T_a)$

4 Results of modelling

4.1 Impact of storage capacity

It would be expected that a system with high storage capacity should be able to smooth out the daily variations in radiation and provide DHW for more days than a system with lower capacity. The model was run with the store capacity from 300 litres to 1200 litres, in each case the solar collector area adjusted so that the maximum water temperature at 90°C. The incidence of different auxiliary heat input required to maintain an acceptable DHW temperature throughout the 135 day summer period is shown if Figure 4.

Figure 4 Auxiliary water heater duties for different thermal store size

The DHW load for a household of four is 29MJ but the water heater must also be able to provide the losses from the thermal store. The difference in performance shown in Figure 4 is not just the result of the different store size. The additional buffering provided by the larger store allows a larger area of collector to be used without unacceptable water temperatures being reached as shown in Figure 5.

Figure 5 Maximum collector area that can be installed for a given capacity thermal store

It is not surprising that a larger collector area will allow sufficient solar energy to be collected to satisfy the DHW loads on more days of the year as is shown in Figure 6. There is clearly a limit to the benefits that can be made from increasing the solar collector area. The reason for this can be seen from Figure 2, there are a few periods with very low irradiation levels if the solar collector was sized to provide DHW over these periods the store temperature limit would be reached during sunny spells.

Figure 6 Maximum collector area that can be installed for a given capacity thermal store

4.2 Impact of changes in occupation levels

From Figures 4,5 and 6 it was concluded that the most appropriate size system for a house with four occupants in St Petersburg would consisting of a 6 m^2 collector and 700 l thermal store. Its performance throughout the summer is shown in Figure 7.

Figure 7 Auxiliary water heater duties for different occupation levels

Although four occupants is frequently considered to be a typical family in the developed world according to the "Housing in England" survey (anon,2009) [18] only 7% of English households have more than four occupants and 64% have less than three so the characteristic for 2 occupants is likely to be representative of a typical households. Increasing the occupancy level increases the duty of the auxiliary heater but it is clear that the solar water heater supplies the majority of the summer DHW in all cases. The system is sized to give a maximum water temperature of 90°C with 4 occupants. If the house has 6 occupants the maximum temperature reached was 83°C and it reached 96°C with just 2 occupants.

4.3 Impact of tilt angle

Figure 3 indicates that the amount of harvestable solar energy is not particularly sensitive to collector inclination. There are many buildings with flat roofs or south facing walls which may be considered as possible location for solar water heaters. In practice manufactures recommend limits to the inclination of their panels SunnPro recommend that the SP series mounting angle should be in the range 15^o - 75^o. The model was rerun with the appropriate solar radiation figures used for tilt angles of 15^o and 75^o. The maximum area of collector that could be installed while avoiding excessive water temperature in a 700l thermal store was separately calculated for each of the tilt angles. The auxiliary DHW requirements of the three systems are shown in Figure 8.

Figure 8 Performance of systems sized for different tilt angles

All of the systems could be considered as the main DHW system in summer. However this is achieved by using different areas of collectors which are given below:

- 6.1m^2 for a 15° tilt,
- 5.9m^2 for a 37° tilt,
- 8.9m^2 for a 75° tilt.

It has been found that solar collectors integrated into walls can improve the walls insulation and reduce summer solar gains [19] which could offset the additional cost of the larger collector.

4.4 Impact of location

The model was rerun using Vancouver and Brussels climates to investigate the impact of variations in the solar climate. The store size was set to 700l and the collector adjusted to give a maximum water temperature of 90°C. The Brussels system did not perform as well as the others so the Brussels model was rerun with a 1000 l store. Results for the three locations are plotted in Figure 9.

Figure 9 Auxiliary water heater duties at different locations

The collector areas of the following systems are given below:

- St Petersburg 5.8m^2
- Brussels 700l store 5.9m2
- Brussels 1000l store 7.1m^2
- Vancouver 4.4m^2

As may be expected the higher sunshine levels in Vancouver give the best performance but it is possible to design a suitable system for all of the locations.

4.5 Use of unsupported solar heating in summer

There will be an ambient air temperature where the solar gain input to a building and heat released by activities carried out in a building will match the heat loss from the building. This is known as the balance point temperature [20] and is typically 15.5° for UK houses. At this temperature the buildings do not need space heating. To see if the solar water heaters can cope without additional heat input from the buildings heating system the models for St Petersburg with a 700 l store and Brussels with a 1000 l store were rerun with the auxiliary heater disabled. The results are shown in Figures 10 along with the ambient air temperature.

Figure 10 Water storage temperatures with no auxiliary heating throughout the summer

From the air temperature plots it is likely that space heating will be needed up to day 150 until around day 240. The DHW temperature at St Petersburg and Brussels are show in Table 2.

Table 2 summer performance of solar water heaters

The hot water consumption survey [6] reported that 80% of DHW systems delivered hot water with a temperature in the range 44-60 °C. From Table 2 it would appear that the St Petersburg system could supply this for the period when space heating was not required but he Brussels system would need some auxiliary heating system available. However from Figures 9 and 10 it would appear that this would only be needed on a few days a year.

4.6 Minimum water temperature

There is a concern that DHW systems need to be periodically run at temperatures above 60°C to prevent Legionella bacteria growing [21]. Figure 10 shows that this requirement is met in both locations.

5 Discussion

5.1 Solar heating season

One would expect to have more solar heating available in the summer than the winter. There appears to be little available solar energy 50 days each side of the winter solstice however there is a dramatic change in available energy in the four weeks around the equinoxes and sufficient available solar energy to provide the domestic hot water needs of a household in summer. These large seasonal variations mean that summertime data should be used when designing a system rather than annual values. Figure 10 show that for the portion of the year when heating is unlikely to be required the DHW temperature will be at acceptable levels without any auxiliary heating in St Petersburg. Whereas in Brussels there would be a few day in the period when space heating was not required when the hot water would be tepid without the occasional use of auxiliary water heating .

5.2 Regional variation

It is clear from Figure 1 and 2 that most northern cities have exploitable solar energy in the summer period. This potential is demonstrated in Figure 9, the critical factor is the degree of cloud cover rather than the latitude of the location. Even in cloudy location suitably sized systems can supply the bulk of the DHW load throughout the summer. Sites that have a wide variation in daily radiation will need larger thermal stores than ones with more consistent solar climates.

5.3 Tilt angle

The performance of a roof mounted south facing solar panel is not particularly sensitive to the actual angle of inclination (see Figure 3). It is noticeable from Figure 1 that many cities received a significant proportion of diffuse radiation. The collection of this is maximised by having a horizontal collector. This may explain why for the cloudy cities of Brussels and Oslo the panel with the maximum summer irradiation were mounted at a tilt angle less than the optimum angle for beam radiation. The good performance of horizontal and shallow inclined panels means that solar water heaters could be considered for properties with flat roofs rather than just those with south facing roofs.

Panels mounted with a high tilt angle were found to produce the highest number of days on which solar water heating can supply the DHW demand. This mounting arrangement captures beam radiation when the sun has a high zenith angle and reflected radiation; as such it is essential that the installation has a clear view of the horizon and the ground. The intensity of early morning and reflected radiation is low and there may be issues with the fluid in the panels reaching sufficient temperature to transfer heat to a thermal store. More experimental work may be needed to how well this configuration performs in practice.

5.4 Storage capacity

Increasing the storage capacity should increase the number of days when solar water heaters could satisfy the DHW load. This is contrary to the findings of Yohanis et al [4] , who were simulating the performance of a solar panel and hot water tank and concluded that increase in tank size did not increases the number of days that the DHW demand could be met by solar water heating. The difference between these findings may be explained by the fact that Yohanis et al increased the tank capacity while using the same size solar panel; thus increasing the losses from the storage tank without increasing the energy input. The difference in losses between a 100l thermal store and a 300l one is equivalent to increasing the occupancy by two people. From Figure 7 it can be seen that

increasing the occupancy level by two without increasing the panel size does reduce the number of days that the solar water heating system can satisfy the DHW demand.

In this paper the solar collector was sized to provide a peak water temperature while providing the DHW load and storage losses. Figure 5 clearly shows that the area of solar collector that can be used in a given property is directly proportional to the capacity of thermal store used. To summarize the larger the store the larger the collector area that can be used and the more days in a year the solar water heating can be relied on. However there appears to be a practical limit to the number of days that solar energy can be depended on irrespective of the size of system installed.

5.5 Practical sizing

The systems considered have been sized for a given consumption. It is likely that there will be a large variation in daily consumption from day to day and between households. Insufficient load causes a rise in the peak water temperature; excessive load causes an increase in the use of the auxiliary water heater. It is likely that there will be times when the house is unoccupied so the solar DHW system will need to have a strategy to limit the maximum stored water temperature. This is normally achieved by switching off the solar collector pump once the maximum water temperature is achieved this is acceptable providing the fluid temperature remains below its maximum stagnation temperature (200 °C for the SunnPro panels). An alternative strategy may be to have a small portion of the top of the thermal store occupied by phase change material that melts around 90°C. Occasional increases in occupancy could be accommodated by additional running of the auxiliary water heater.

5.6 Rating of Auxiliary water heater

Figures 4, 7 and 9 show that if auxiliary heating is required on summer days it is often at a low level. A low capital cost solution to provide an auxiliary DHW system in the summer may be to use a low power electric immersion heater to maintain a minimum tank temperature (for the rest of the year the central heating system can provide the auxiliary DHW load). The auxiliary water heater should only cut in if the water temperature is unacceptable cool and it should cut out again as soon as it is acceptable so that the water in the store can take up heat from the solar collectors. If short immersion elements are mounted in the top of the tank they will only heat the top layer of water, this will help maintain a satisfactory DHW supply while still keeping the average temperature low.

5.7 Impact of electrical consumption

Solar water heating systems which employ thermal storage tanks are likely to have to be pumped systems. The parasitic energy requirements of a number of systems were measure during field trials [22] and found to be between 4.2 - 9.1% of thermal energy collected (although one installation included an integrated PV panel which generated sufficient electricity to power the installation). By comparison gas fired central heating boilers when operating in the summer have a parasitic electricity consumption of 2% of their hot water production [23]. Consequently a solar DHW system is likely to use more electricity that a gas fired system so the simple solar fraction does not give a true representation of the carbon saving. To do this the primary energy needed to produce the electricity used by the solar DHW system needs to be calculated. The exact value will depend on the mix of plant that was generating at the time; this will vary between counties, throughout the day and from day to day. On a summer's day in the UK the marginal power is likely to come from a gas fired combined cycle gas turbine power station. On average these achieve a gross efficiency of 43%

when supplying domestic consumers (average power plant efficiencies from DUKES table 5.10 [24] with an 8% allowance for transmission and distribution losses), so each kJ of parasitic power needs 2.3 kJ of primary energy in the form of natural gas to produce it.

If the gas DHW system was replaced by a solar one it would have an additional electrical parasitic load of 5% of the thermal load. If this was provided by mains electricity this would represent around 12% of the thermal energy collected by the system. Consequently if the primary energy used to produce the parasitic power is considered, the maximum solar fraction is actually 88% rather than 100%.

5.8 Economic considerations

An economic analysis has not been included in this paper as this is the subject of further work covering the economics of using a cluster of micro-generation technologies. It is recognised that the systems sizes proposed in this paper are larger than those used for systems that are designed to augment the DHW system in the summer. From the St Petersburg model the system with100l store had an annual solar fraction of 33% which would be typical of a system that was designed to augment the existing DHW system. The 600 l one had a solar fraction of 52%. A report into the cost of systems installed under the "The Low Carbon Buildings Programme" [25] reported a wide spread in the installed cost of solar hot water systems but they found the following weak correlation to output for system with outputs from 0.5 to 10 MWh/year:

cost = 540Q + 2900

where the cost is in £ and Q is annual output in MWh/year

The 300l system in St Petersburg collected 1.7MWh/year of heat where the 700l one collected 2.2MWh/year this is an output increase of 29% the corresponding increase in the installed cost of the solar collector would be 7%. Consequently if it is finically viable to install solar water heating the value of the extra energy collected by the larger system is likely to cover the additional cost of the larger solar panel installation and thermal store.

6 Conclusions

The low strength of the winter sun in northern latitudes means that it cannot be considered as the main source of DHW heating in winter. However it has been shown that a suitably sized system can provide the bulk of the DHW demand during the summer period with only a minimum use of auxiliary water heating. This could have considerable operational advantages for combined heat and power plants, biomass boilers and district heating systems as they could be shut down for the summer rather than be left running for short periods to provide DHW loads.

In the summer time the inclination of a solar panel was not found to be critical. Horizontal (or minimally inclined) panels could also be used in situations where a south facing roof is not available.

In some locations a vertically mounted solar panel will provide the highest solar fraction but a disproportionate increase in panel area is needed to achieve this.

After allowance has been made for the primary energy used to provide the electric power used by the system solar water heating could provide 9.5% of domestic heat consumption in a typical UK

house from a renewable source. The EU has a target for 20% of energy to come from renewable sources by 2020; it is clear that a much wider adoption of solar water heating could make a major contribution towards achieving this for the domestic sector in Northern Europe.

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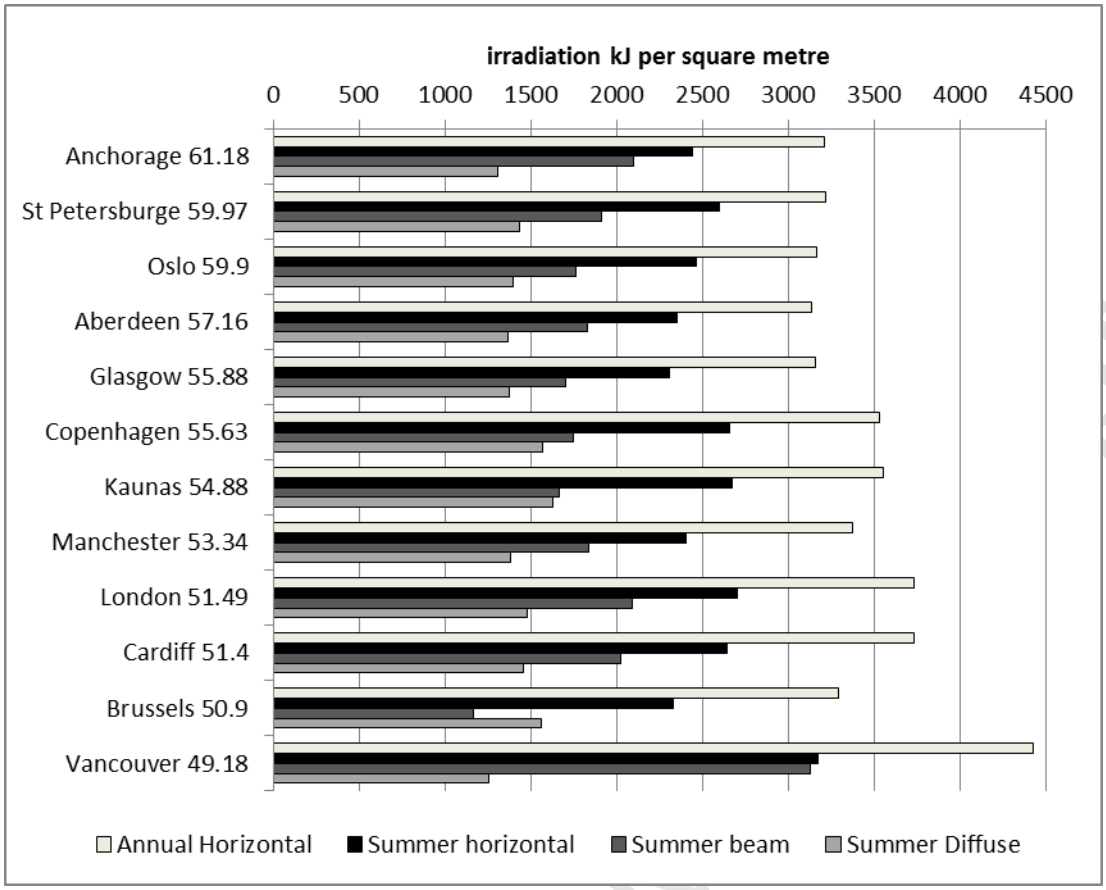
9 Figure captions

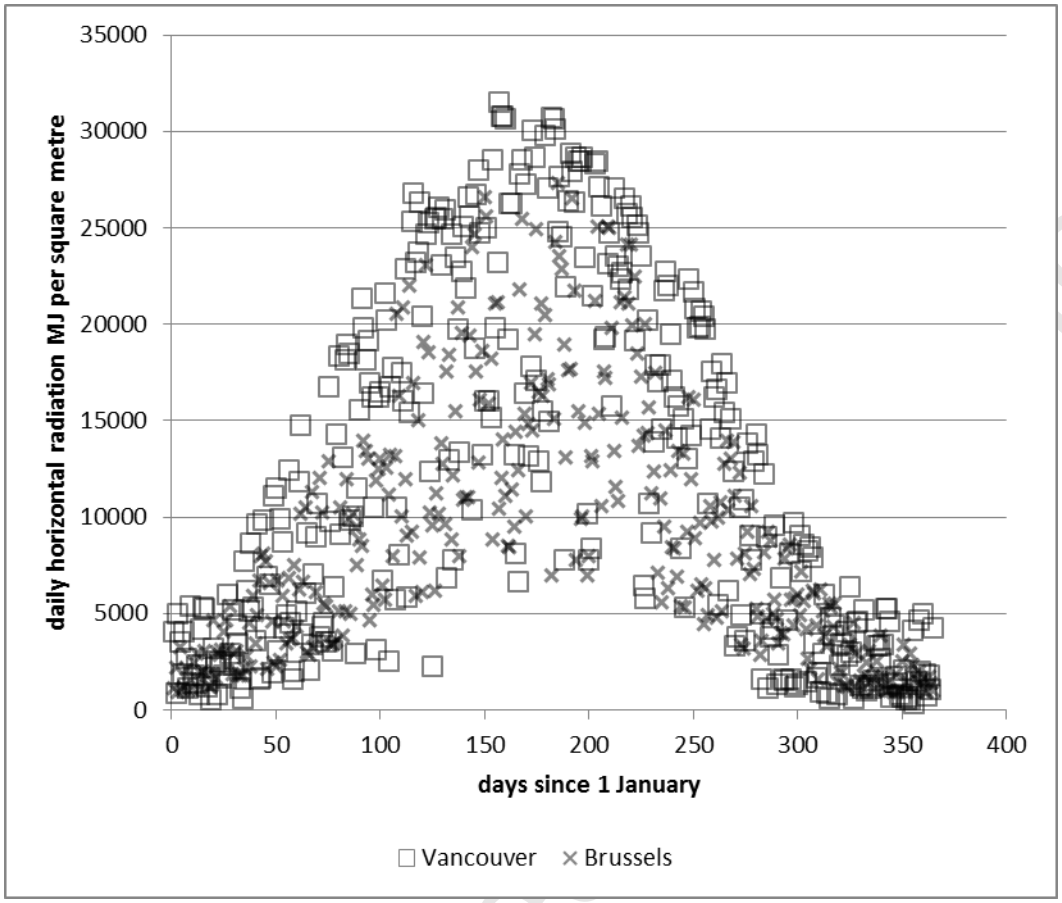
Table 1 Solar panel characteristics

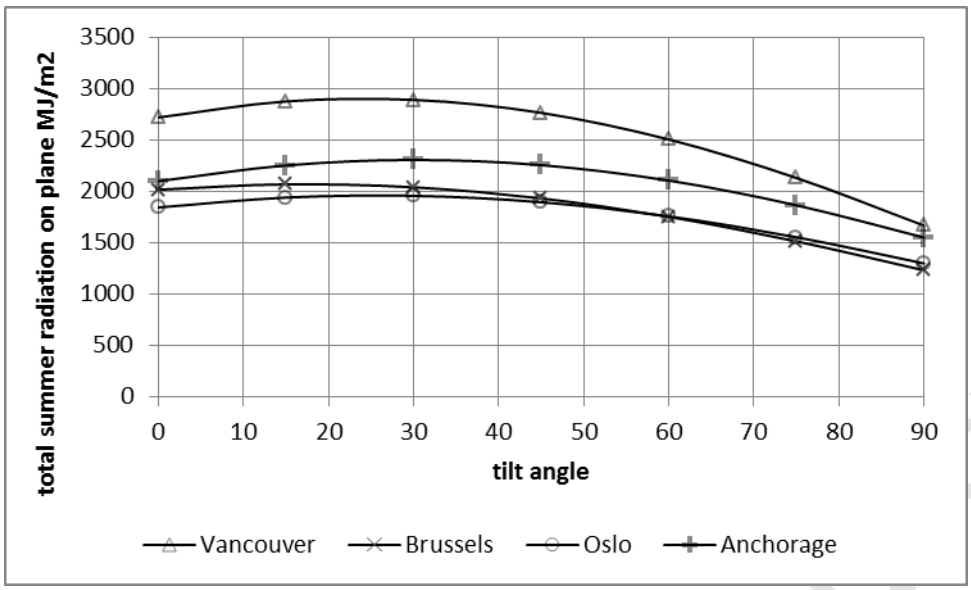
Manufacturer	η_o	a_1	a_2
SunnPro SP series	0.73	1.53	0.017
Solar Tube Company	0.65	1.49	0.014
Solar UK LaZer2	0.753	1.54	0.0099
Solarplusgreen TZ58/1800-20R	0.71	1.529	0.0166

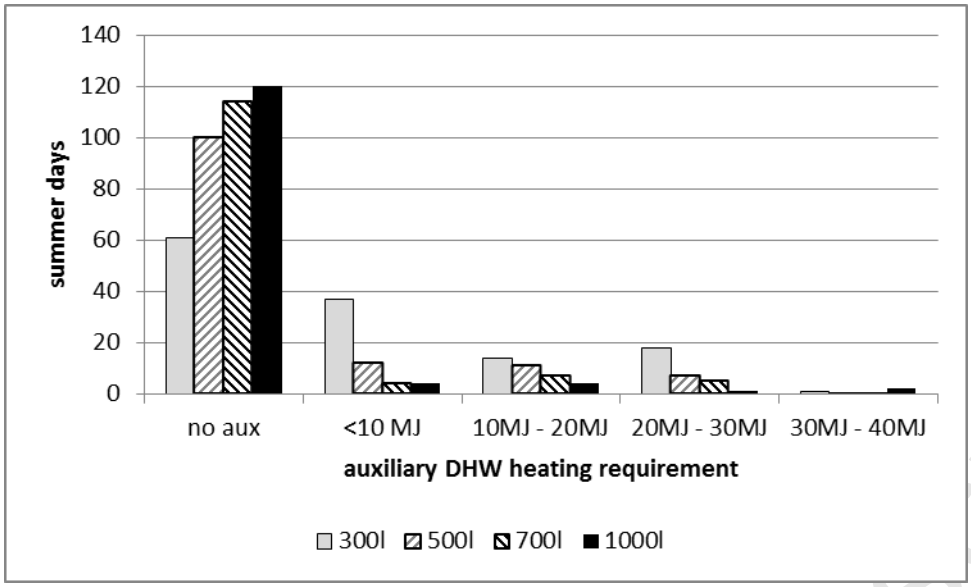
Table 2 summer performance of solar water heaters

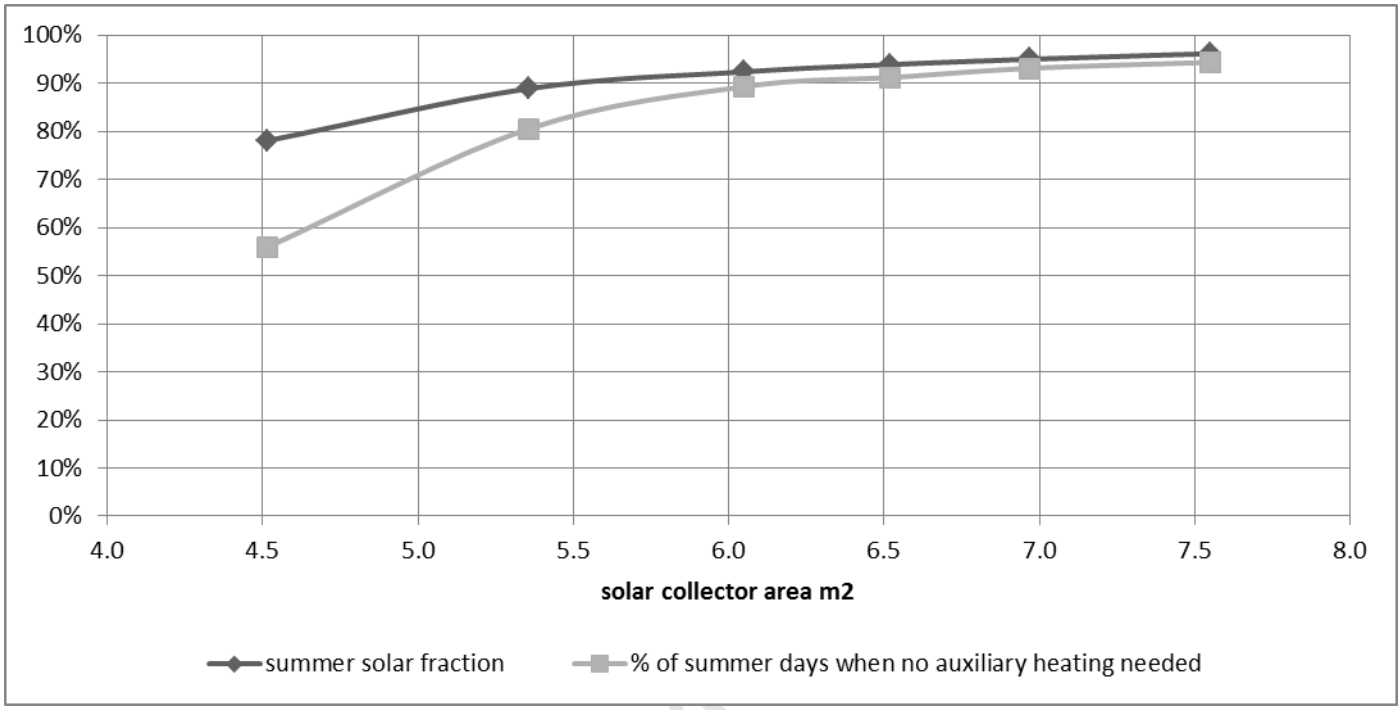
	minimum temperature	average temperature	standard deviation
St Petersburg	34.7	62.7	10.4
Brussels	29.2	46.4	13.6

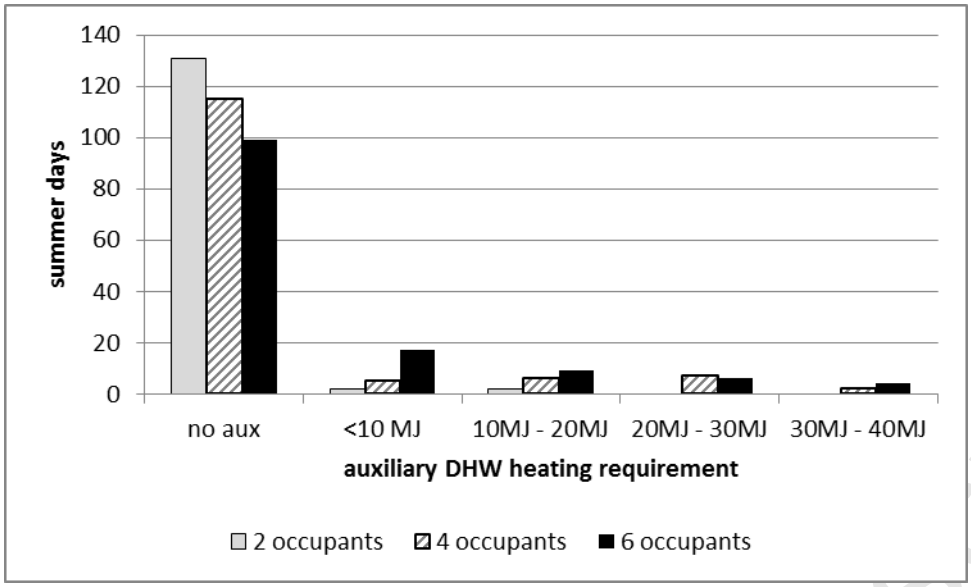


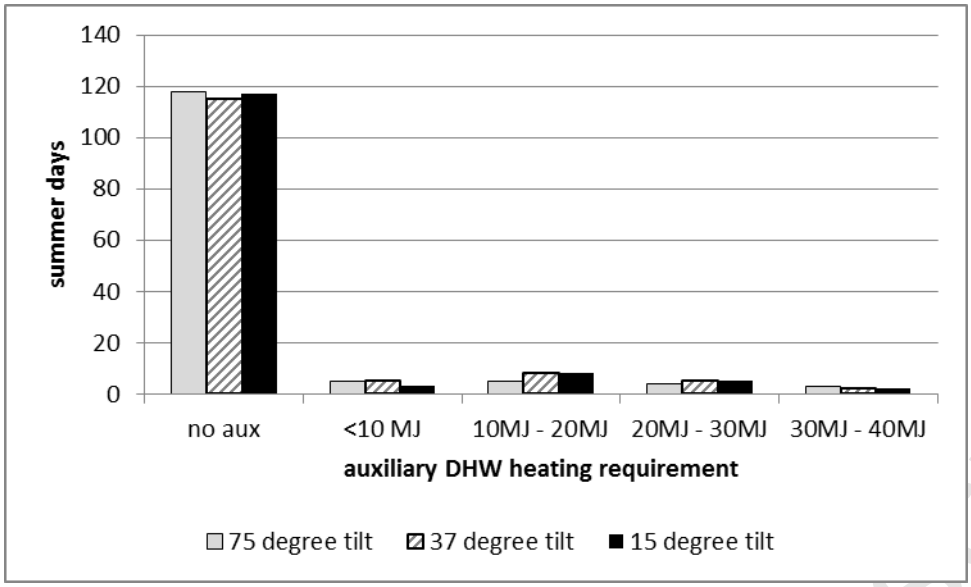


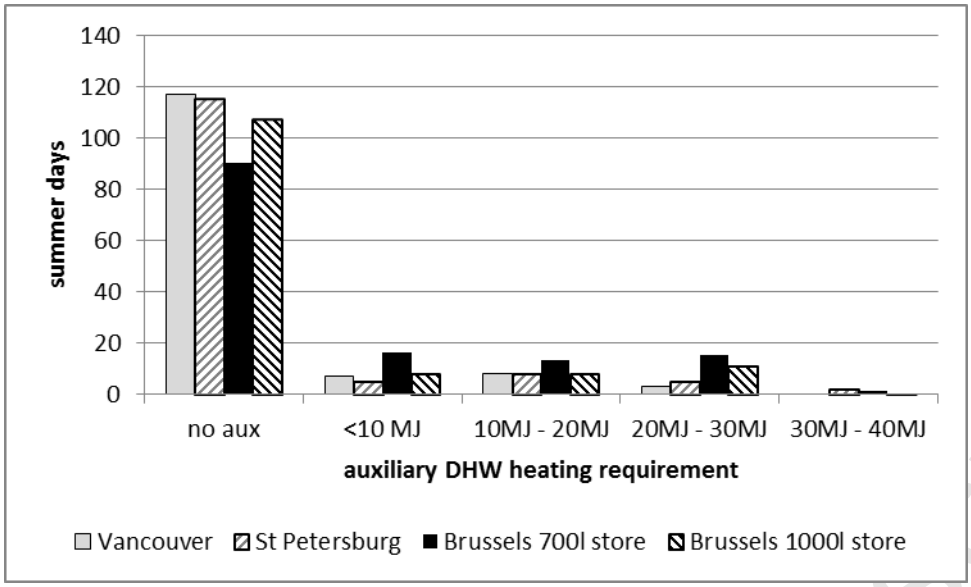


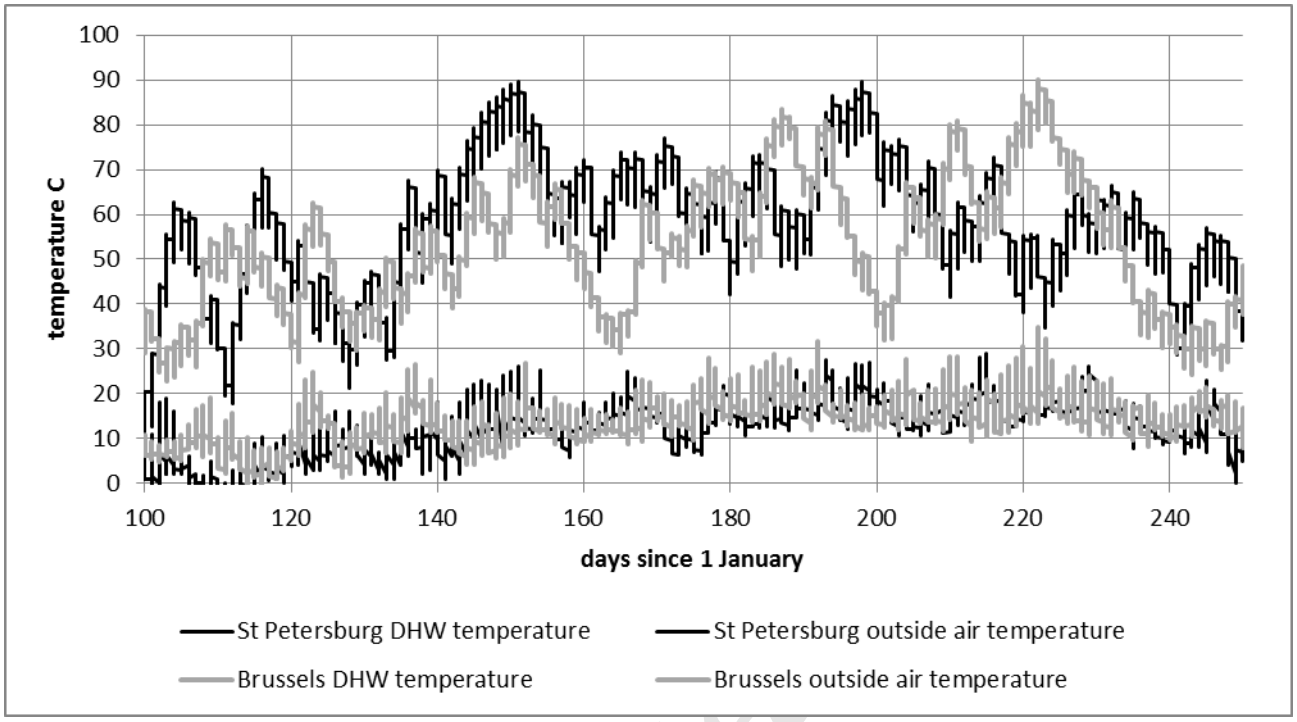












Highlights

- Hourly solar data used in simple model of solar water panel and thermal store.
- Heat stores allow larger solar panels to be used.
- Surplus heat from sunny days stored for use on cloudy ones.
- Solar water heating could be sole means of water heating even at latitudes 50° to 60°.
- 12 cities between Anchorage, St Petersburg, Brussels, Vancouver considered.