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Published version

O'FLAHERTY, Fin, PINDER, James and JACKSON, Craig (2012). Evaluating the performance of domestic solar thermal systems. In: Retrofit 2012, Salford, UK, 24-26 January 2012.

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Abstract:
The paper reports the findings of a two year case study into the performance of solar thermal hot water (STHW) systems installed on new build properties in South Yorkshire, UK. All properties were fitted with 12 No. flat-plate solar thermal panels, covering 4.67 m^2 and designed to supply, on average, up to 1064 kiloWatt hours (kWh) of solar energy output per annum. The case study concentrates on properties with high occupancy levels: an arbitrary level of 87% was chosen which enabled ten properties to be considered.

The results show that there is a significant difference in performance across the selected STHW systems and none of the systems achieved the design specification. The average gas energy displaced was only 5% with a solar fraction (including losses) of just 19%. However, the STHW systems (along with the installed photovoltaic systems) working to their full capacity have the potential of generating 29% of the average household energy demand per annum.

Keywords:
carbon reductions, household load, solar efficiency, solar fraction, energy displaced

1 Introduction

Solar thermal hot water (STHW) systems offer an opportunity to reduce carbon dioxide (CO_2) emissions from homes and contribute to the UK Government's target of generating 15 percent of the UK's energy supplies from renewable sources by 2020 [DCLG, 2009]. However, there are many variables that can have an influence on the performance of STHW systems, thereby limiting their ability to save on water heating bills and contribute to carbon reduction targets. This paper explores the impact of STHW's in a domestic setting, based on an evaluation of STHW systems installed in a social housing scheme in South Yorkshire, UK. The scheme of 23 three-bedroom super-insulated homes fitted with renewable energy technologies was completed in September 2007. All of the homes are fitted with solar photovoltaic (PV) and STHW systems, but this paper focuses primarily on the performance of the STHW systems.

2 Literature Review

The UK Government's 2006 review into the sustainability of existing buildings in the UK [DCLG, 2006] found that 152 million tonnes of carbon (MtC) were emitted from the UK's building stock in 2004. In total, 27% of this figure, or 41.7 MtC, was attributable to the housing stock. Domestic emissions will have to fall by 33.4 MtC to 8.7 MtC by 2050 if the housing sector is to reduce emissions by 80% to meet overall carbon emissions targets.

As of 2008, there were around 100,000 STHW systems installed across the UK [Element Energy Ltd., 2008], although new systems were only being installed at a rate of a few thousand per year. For instance, just 4,000 STHW systems were installed in the UK in 2006. Despite STHW technologies being available for many decades, there are very few publications that focus on the performance of STHW systems in-situ. Relatively few STHW systems that have been installed are subjected to detailed monitoring and data from those monitored systems are not often publicly available. As a result, there is a lack of understanding of the costs of the energy generated by these systems [Bates *et al*, 1999].

3 Case Study Detail

The case study scheme consists of twenty three properties, five of which are detached and eighteen semi-detached. All properties had 4.67m^2 (4.12m^2 based on aperture area) of STHW on a roof pitch of either 40° or 27°. The systems used in this study are indirect, using a heat transfer fluid (glycol), and active (forced circulation via a pump). The pump in the system is programmed to switch on when a temperature differential of 5°C is sensed between the lower store temperature in the bottom of the cylinder and temperature of the glycol in the solar panel. Properties also benefited from the installation of either 58 or 72 solar PV tiles and their short-term performance is considered elsewhere [O'Flaherty *et al*, 2009].

4 Research Methodology

The solar energy, in kWh, was manually recorded from a Resol Deltasol BS Plus solar controller in the pump station kit in each property. The design specification included a temperature sensor on the return pipe near the cylinder with a flow temperature sensor installed near the solar collector. Flow rates were factory set at 6 litres/min. All pipework was fully insulated to minimise heat losses. For a combined cylinder system (i.e. water is pre-heated in the bottom of the cylinder before being heated to the required delivery temperature by an auxiliary boiler), the most accurate method of calculating the solar energy is to consider the collector heat output in kWh [Energy Savings Trust, 2001]. However, standing and pre-heat losses may occur in the cylinder and these are ignored in this calculation. As it is difficult to measure the pre-heat losses in a combined cylinder system [Energy Savings Trust, 2001], the measured solar energy figures presented in this paper are higher than is actually the case, but these losses are estimated in Section 7.1 when calculating energy savings.

Solar energy datum readings were taken upon commissioning the systems in August or September 2007 with final solar energy readings taken two years later. These readings were validated via independent sensors which were installed on STHW systems in two properties and this is described in Section 6. Financial limitations meant that only two properties could be independently monitored.

5 Findings and Discussion

Table 1 gives details of the solar systems, energy outputs and energy consumption over the two year monitoring period for ten properties with high occupancy levels. The property identification is given in col. 1. The solar energy output, recorded as described in Section 4, is given in col. 2. Two roof pitches were used in the design of the properties (27° and 40°) and these are shown in col. 3. The monitoring duration for each property is given in col. 4 and varies slightly due to the inability to gain access to some properties on the date of the second anniversary of commissioning. The occupancy dates are given in col. 5 and relates to when at least one person was living in the property. The occupancy dates are converted to percentage occupancy in col. 6. For simplicity, the number and type of occupant is not considered, nor is the time of the year to which the occupancy relates. A more accurate calculation would prove to be very difficult since some properties are rented and the number and type of occupant can change on a regular basis. The cylinder hot water temperature from a typical winter's day in November/December 2008 are given in col. 7 and will be used to possibly explain differences in performance in Section 5.1. Gas and electricity consumption in kWh are given in cols. 8 and 9 respectively. The electricity consumption was taken from the calibrated household electricity meters in kWhs but units of gas consumed were recorded in m^3 from the calibrated household gas meters and converted to kWhs using a standard procedure as shown in Equation 1:

Gas (kWh) = Gas units x volume conversion factor (1.0226400) x calorific value (31.3241) ÷ kWh conversion factor (3.6) Equation 1

5.1 Variation in Solar Energy Outputs

Referring to Table 1, there is a significant difference between the best and worst

Table 1. Solar thermal hot water monitoring data

1	2	3	4	5	6	7	8	9
Prop. ID	Solar Energy Output (kWh)	Roof Pitch (°)	Monitoring Duration (Yrs)	Occupancy dates	Occupancy (%)	Cylinder hot water temp (°C)	Gas usage (kWh)	Electricity usage (kWh)
V	1,990	27	2.02	15/10/07 - end of monitoring	95	24.5	6,371	5,230
R	1,166	27	1.99	27/10/07 - end of monitoring	92	42.9	9,948	3,137
B	961	40	2.04	15/10/07 - end of monitoring	92	45	18,517	pre-pay
P	947	27	2.04	20/11/07 - end of monitoring	87	35.5	10,366	4,353
I	677	27	2.04	15/10/07 - 13/11/08; 15/12/08 - end of monitoring	87	42.7	13,881	6,081
F	549	40	2.08	1/11/07 - end of monitoring	90	49.7	14,904	12,710
K	495	27	2.15	15/10/07 - end of monitoring	87	50.2	12,867	8,166
T	476	27	1.99	15/10/07 - end of monitoring	94	64.9	16,097	6,470
S	437	27	2.03	15/10/07 – 24/05/2009; 1/06/09 - end of monitoring	91	58.4	15,901	6,851
O	200	27	2.11	15/10/07 - end of monitoring	88	58.4	8,729	4,734
Av:	790				90		12,758	6,414

performing STHW systems for high occupancy properties. The best performing STHW system generated 1990 kWh during the monitoring period whereas the worst system generated only 200 kWh. It is also obvious in Table 1 that none of the STHW systems achieved the design specification of 2,128 kWh of solar energy (1,064 kWh/year - design calculations were not available from the designer to check this specification).

The performance of STHW systems is very much dependant upon sufficient usage of hot water from the cylinder. Allen *et al* [2010] report that while the volume of hot water used by the households is known to vary widely, even between otherwise similar households [BSI, 1989], an Energy Saving Trust study [2008a] confirmed that STHW performance is primarily dependent on the number of occupants. Therefore, if some properties have higher occupancy levels and a higher number of residents, they are likely to use more hot water, hence the heat transfer cycle is repeated more often, assuming of course their is sufficient heat in the collector from solar gain. However, a key reason why none of the STHW systems achieved the design specification is that each property is fitted with an electric shower over the bath, meaning that hot water usage from the cylinder will be significantly reduced.

The variation in individual performance is mainly due to householders working with their solar hot water systems and using their boilers in partnership with the system. It was shown that householders who do not alter their boiler timings or patterns of hot water demand will have a lower performance, whereas properly timed and controlled input from the subsidiary heating system will lead to enhanced performance [Powell and Monahan, 2009].

To complement the above theory, Figure 1 provides a relationship between the measured solar energy over the two year monitoring period (Table 1, col. 2) and the cylinder hot water temperature on an arbitrary winter's day in November/December 2008 (Table 1, col. 7). The cylinder hot water temperature for an afternoon at this time of the year was chosen as it is unlikely that the STHW system will provide sufficient energy to heat the water to a usable temperature, hence auxiliary boiler input will be required. Referring to Figure 1, the properties with higher solar energy outputs appear to have a lower cylinder hot water temperature and it is likely that these households alter the boiler timings to provide hot water as and when required as opposed to continuously maintaining the water at a high temperature. This would enable the STHW system to work at every opportunity. The properties with highest cylinder hot water temperatures generally exhibit lowest solar energy outputs and these can be considered as homes where the boiler timings are not altered and the STHW system is competing with limited success against this auxiliary heater.

5.2 Efficiency of STHW Systems

The solar irradiation available to a STHW collector varies with its azimuth, pitch and geographical location [Allen et al, 2010]. The location of the STHW panels in South Yorkshire in the UK would mean annual global irradiation of approximately 950 kWh/m^2 of panel on a horizontal surface, assuming no shading [Suri et al, 2007]. For a typical UK roof pitch of 15–50°, and for SE to SW facing installations, the energy available will be increased by approximately 10–15% from these values [BSI, 1989], meaning at least 1,045 kWh of global irradiation per m^2 of panel. This value also corresponds to 20 years of solar irradiation data proposed by Page and Lebens [1984].

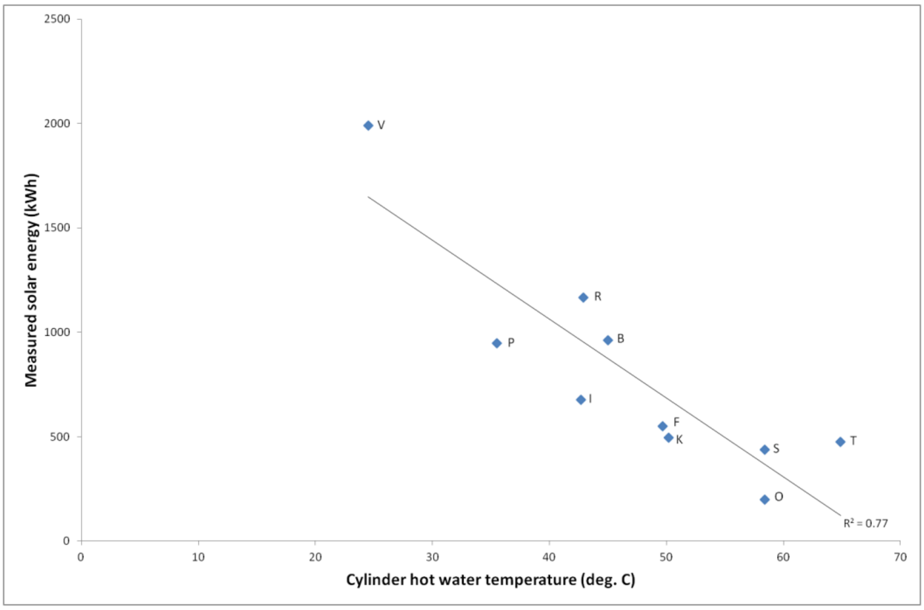

Figure 1. Measured solar energy versus cylinder hot water temperature

Therefore, the annual gross solar resource available to the 4.67m^2 collectors was estimated as 4,880 kWh/year. The best performing system (Property V) generated 1,990 kWh over two years (on average 20% gross efficiency per annum), the worst performing system (Property O) generated only 200 kWh over the same time period (on average 2% gross efficiency per annum). The average efficiency was only 8%. The gross efficiency in this study compares unfavourably to a previous study where it ranged between 22-39% (average: 32%) [Martin and Watson, 2001]. When used to calculate efficiency, gross area provides less favourable results for collectors [Martin and Watson, 2001]. However, to enable comparisons to be made with other studies, the gross collector area was used as opposed to the aperture or absorber area to calculate performance data. In one previous study [Bates *et al*, 1999], it was observed that there was a striking variation in the parameters monitored in each STHW system - some organisations were not necessarily aware of what parameters should be monitored and why they should be monitored. Performance data based on gross area were available for all studies and, hence, were used to compare performances here (Section 6.1).

6 Validation of Data

Two properties had additional monitoring equipment installed to independently monitor the performance of the solar thermal hot water system in the present study. However, these properties remained unoccupied for a substantial part of the two year monitoring period and are, therefore, excluded from Table 1. The intermittent data collected during times of occupancy was used to validate the readings from the solar controllers. This involved installing two brass body paddle wheel flow meters (Burkert S030) on the flow and return pipes to measure the quantity of glycol passing through the system. These were accompanied by a pulsed output flow transmitter (Burkert 8035) which enabled the flow to be logged by a data logger (model R-Log GPRS). Settings were based on the pipe size and material of the flow meter, with a K factor of 49.03 being used to signify 49.03 pulses being recorded for every litre of glycol circulating around the system. The flow and return temperatures were also monitored using two PT100 temperature sensors. The logger was programmed to continuously monitor at two minute intervals and send the data on a daily basis at midnight via GPRS.

However, the data logging system did not perform as expected and there were time periods when the data were not sent via GPRS. Despite many attempts to rectify the problem in conjunction with the suppliers, both data loggers in the properties were eventually changed but this only partially solved the problem, the logging system in one property became more reliable but the logger in the second property continued to malfunction. In addition, it was noticed over time that the paddle wheel flow meter also exhibited signs of malfunction and a possible reason for this was that tiny fragments in the glycol (e.g. burrs from the copper pipework during installation or other contaminants from storage vessels) accumulated at the paddle wheel causing it to stick; this was also evident in other similar flow meters being used by the authors elsewhere. Since manual readings were taken on a random basis from the solar controllers, the aim was to match time periods where both manual and logged data were available to enable a comparison to be made for verification purposes. A three week period in July 2008 was selected for this from one of the properties when manual and logged data periods corresponded and the paddle wheel meter was working freely.

The logged data (vol. of flow, flow and return temperatures) were analysed using a Heat Transfer Analysis method. Data were analysed to determine the quantity of energy transferred to the water in the cylinder and Equation 2 was used for this purpose:

$$Q = (\rho)(V)(C_p)(\Delta T) \qquad \text{Equation 2}$$

where ρ = density of the glycol, kg/m^3

C_p = Circulating fluid coefficient, J/kgK

V = volume of flow, m^3, obtained from the number of pulses recorded by the data logger (49.03 pulses per litre)

ΔT = Difference in flow and return temperatures, K, recorded via temperature sensors

A full detailed analysis of this procedure is outside the scope of this paper. Referring to Table 2, the two types of readings are given in col. 1 followed by the solar energy outputs under consideration in cols. 2 and 3 from the manual data. Col. 4 shows the difference in solar energy output during the three week period: 175 kWh for the manual readings (col. 3 - col. 2) and 189 kWh for the heat transfer analysis. This gives a difference of 14 kWh or 8% between the two. It can, therefore, be considered that the manual data presented in this paper reflects fairly accurately the performance of the solar thermal hot water systems being monitored, as a difference of 8% is within normal research error parameters.

7 Benefits of STHW Systems

The average solar energy output in properties with occupancy levels above 87% (ten properties) were used to estimate the impact of the STHW systems in reducing carbon emissions. The average generation from these ten properties (Table 1, col. 2) is 790 kWh or, if divided equally between years one and two for the purpose of analysis, 395 kWh per annum, well below the design specification of 1064 kWh per annum. However, the average occupancy level was 90% (Table 1, col. 6) so the average generation of 395 kWh is slightly underestimated.

Table 2. Validation of solar thermal hot water monitoring data

1	2	3	4	5
	Reading 1 4/7/08, kWh	Reading 2 25/7/08, kWh	Solar energy kWh	Difference %
Manual readings*	427	602	175	8
Heat Transfer Analysis**	-	-	189	

** from the solar controller ** from independent flow meters and temperature sensors*

7.1 Useful Energy Savings (Energy Displaced)

An estimate of the energy savings due to the performance of the STHW systems is given in Table 3. Referring to Table 3, the property ID is given in col. 1 and the solar energy output is given in col. 2. The primary circuit losses avoided are given in col. 3 and are based on the fact that the boiler operates less frequent and runs for less time to heat the solar pre-heated water. Heat losses from the pipework connecting the boiler to the cylinder are, therefore, avoided and are added to the energy benefit of having the solar heating system [BRE, 2008]. In this analysis, an allowance of 5% for pipe losses is made [Energy Saving Trust, 2003]. The excess cylinder losses are given in Table 3, col. 4 and are based on not all solar energy input to the cylinder being useful. Higher heat losses are evident from the cylinder due to the solar system holding the cylinder at a higher temperature for more of the time during the summer months than a conventional heating system would [BRE, 2008]. In this analysis, the excess cylinder losses are estimated at 20% [Energy Saving Trust, 2001] although a more complicated analysis based on U values was conducted by Cruickshank and Harrison [2010]. In reality, the solar energy input to the cylinder that is not used, for example when the properties are unoccupied during holidays, should not be counted towards energy savings [BRE, 2008], but due to the complexity of monitoring this, it is excluded from the analysis.

Table 3. Displaced energy and CO_2 savings

1	2	3	4	5	6	7	8	9
Property ID	Solar energy Output (kWh)	Primary circuit losses avoided[a] (kWh)	Excess cylinder losses[b] (kWh)	Useful solar energy benefit (kWh)	Gas energy saved (kWh)	Parasitic electricity[c] (kWh)	Energy displaced (kWh)	CO_2 savings (kg)
V	1,990	100	-398	1,692	1,879	-70	1,809	316
R	1,166	58	-233	991	1,101	-41	1,060	185
B	961	48	-192	817	908	-34	874	153
P	947	47	-189	805	894	-34	861	150
I	677	34	-135	575	639	-24	615	107
F	549	27	-110	467	519	-19	499	87
K	495	25	-99	421	468	-18	450	78
T	476	24	-95	405	450	-17	433	76
S	437	22	-87	371	413	-15	397	70
O	200	10	-40	170	189	-7	182	32
Av:	790 (395/yr)				746 (373/yr)		718 (359/yr)	125 (63/yr)

[a] *estimated at 5% from Energy Savings Trust, 2003*

[b] *estimated at 20% from Energy Savings Trust, 2001*

[c] *estimated as 3.75% of gas energy saved from Building Research Establishment, 2008, 2009*

The useful solar energy benefit is shown in col. 5 (col. 2 + col. 3 - col. 4). In addition, the boilers fitted to each property will have an efficiency of less than 100% but since they are new boilers, they are assumed to have an efficiency of 90% for the purpose of this analysis. The useful solar energy benefit in col. 5 is corrected for the boiler efficiency giving the gas energy saved in col. 6 [BRE, 2008]. However, the solar controller and pump use electricity to circulate the heat transfer fluid around the loop. In previous studies, this averaged 4% [BRE, 2008] and 3.5% [BRE, 2009], so an average of 3.75% is used. This parasitic electricity is shown in col. 7, Table 6 and is subtracted from gas energy saved (col. 6) to give the energy displaced in col. 8. The average fuel energy displaced from the ten high occupancy properties is 359 kWh/year (col. 8).

7.2 Carbon Reductions due to STHW

A kWh of solar energy generated in place of gas eliminates 0.18 kg CO_2 [DEFRA, 2010], assuming the natural gas-fired boiler is used to heat the water and not the immersion heater. A kWh of electricity generates 0.32 kg CO_2 [DEFRA, 2010]. Applying these values to col. 6 (savings) and col. 7 (emissions), Table 3 respectively, gives the net CO_2 savings in col. 9. Referring to Table 3, col. 9, there are, on average, 63 kg of CO_2 saved per annum per property. There are approximately 24.8m domestic properties in the UK [Technology Strategy Board, 2007] and the carbon savings required by 2050 is 33.4 MtC, or approximately 1.35 tons per property if the Government's 80% reduction target is to be met by 2050. The average solar thermal performance in this study saved only 0.063 tons, or 5% of the target per property.

However, a $4.67m^2$ STHW system generating on average only 395 kWh per annum (Table 3, col. 2) has a gross efficiency of approximately 8%, hence more savings can be made with better performances and consideration of the criteria responsible for performance (e.g. ensuring showers are fed from the cylinder, use of hot-feed washing machines, residents understanding the technology better etc.). Application of renewable energy technologies will help in meeting this target but as a minimum, design specifications must be met. Low cost, non-technological changes, for example, changing peoples' behaviour by using more energy efficient white goods, installing more insulation for energy conservation, installing energy efficient boilers, switching off or using standby mode on TV or audio appliances etc. will contribute significantly to this target.

7.3 Impact of STHW Systems on Household Load

The average gas consumption in the Yorkshire and Humber region of the UK is 18,500 kWh per annum (2007 figures) [DECC, 2007] and 3,300 kWh per annum for electricity for a medium sized house, Table 4, cols. 1 and 2 [Lynas, 2008]. Referring to Table 1, the average gas consumption for the ten properties with occupancy levels greater than 87% is, on average, 6,379 kWh per annum (12,758 kWh over two years). Since the occupancy levels varies for these properties from 87% to 95%, an estimation of gas usage assuming 100% occupancy can be made by simply uplifting each individual property's usage on a pro-rata basis for the purpose of comparison. This would give an average gas consumption of 7,079 kWh (14,158 kWh over two years, Table 4, col. 3). However, the STHW system, on average, has displaced only 359 kWh per annum for, on average, 90% occupancy (Table 3, col. 8). Again, for the purpose of comparison in Table 4, this figure is uplifted to 399 kWh on a pro-rata basis if normalised to 100%

Table 4. Energy displaced per annum due to renewable energy technologies

1	2	3	4	5	6	7
Energy	Average use	Average imported energy[a]	Average energy displaced[b]	Average energy demand	Regional/ national comparison	Average energy displaced[b]
	kWh	kWh	kWh	kWh	%	%
Gas/STHW	18,500	7,079	399	7,478	- 60	5
Electricity/PV	3,300	3,570	902[c]	4,472	+ 36	20
Totals	21,800			11,950		

Table 4 (cont'd). Energy displaced per annum due to renewable energy technologies

1	8	9	10	11	12
Energy	Hot water demand	Solar fraction (incl. losses)	Actual renewable energy[d]	Actual renewable energy	Potential renewable energy
	kWh	%	kWh	%	%
Gas/STHW	2,091	19	2,203	18	29
Electricity/PV	-	-			
Totals					

[a] *based on 100% occupancy for ten properties for gas, nine for electricity* [b] *based on ten properties and gas assumed for water and space heating, 100% occupancy* [c] *assumed as 50% of PV energy used in the home and 50% exported to the grid* [d] *assumes 100% of average PV energy generation (1,804 kWh)*

occupancy (Table 4, col. 4), and if it is assumed that gas is used to meet the hot water and space heating needs in these properties, the total average energy demand is 7,478 kWh (7,079 + 399 kWh, Table 4, col. 5). This is 60% below the regional average (Table 4, col. 6). The average energy displaced (399 kWh) equates to only 5% of the gas energy demand for space and water heating, as shown in Table 4, col. 7.

Applying a similar analysis to the electricity usage for comparison, the average consumption of grid supplied electricity per annum of nine properties under consideration (one property had a pre-pay meter so cannot be included) is 3,207 kWh, or 3,570 kWh if normalised to 100% occupancy on a pro rata basis (Table 1, col. 9; Table 4, col. 3). In addition, the ten properties generated, on average, 3,605 kWh of electricity through the photovoltaic system over the two years (the photovoltaic systems were switched on continuously in these properties so were unaffected by occupancy), or, on average, 1,803 kWh per annum (for simplicity, the two year performance of the PV arrays is considered elsewhere, O'Flaherty, 2009). It is assumed that 50% of the electricity generated through the photovoltaics was used in the home and 50% was exported to the grid - some residents received payments from the energy supplier based on this assumption (the scheme only included generation and import meters, an export meter was not installed and in addition, this agreement was prior the Feed-in-Tariff being introduced). The average household consumption for the photovoltaic generated electricity is, therefore, 902 kWh (1803 kWh x 50%, Table 4, col. 4). This gives a total household electricity consumption of 4,472 kWh (Table 4, col. 5), or 36% above the national average of 3,300 kWh (Table 6, col. 6). The average electricity displaced by the PV generation is 20% (Table 4, col. 7). The analysis, therefore, shows that the properties clearly benefit from being super-insulated as gas consumption is well below the regional average (60%) but electricity consumption is over a third higher than the national average, possibly due to the installation of the electric shower and perhaps due to the use of the auxiliary electric immersion heater on occasions. However, the total average energy demand for the properties is 11,950 kWh (Table 4, col. 5), or 55% of the average use of 21,800 kWh (Table 4, col. 2)

Hot water accounts for around 15 to 20% of a household's energy bill annually [Energy Savings Trust, 2008b]. Since the average energy consumption for these properties was 11,950 kWh, hot water demand equates to 2,091 kWh (assuming 17.5% of the consumption is due to hot water needs, Table 4, col. 8). Therefore, in this study, the STHW systems provided, on average, a solar fraction of only 19% of the hot water needs of the properties per annum (based on fuel energy saved and 100% occupancy, Table 4, col. 9, the solar fraction is 21% if based on the solar energy delivered to the cylinder and normalised to 100% accuracy). The STHW suppliers estimated that 4.67m^2 of solar panels should meet up to 60% of the household hot water demand per annum but this was not the case in this study. Residents need to better understand the operation of their renewable energy technologies to ensure maximum performance.

7.4 STHW as a Renewable Source

It was stated in Section 1 that the UK Government has a target of generating 15% of the UK's energy supplies from renewable sources by 2020 [DECC, 2009]. It was shown in Section 7.3 that the average energy demand of the properties under consideration was 11,950 kWh (Table 4, col. 5). Since the renewable energy systems on average displaced 2,203 kWh of energy (399 kWh for the STHW and 1,804 kWh for the PV systems using 100% of actual generation and 100% occupancy, Table 4, col. 10), the proportion of renewable energy generated by these properties was 18% of the total energy demand (Table 4, col.11). If the 15% target was applied to each individual property, then these properties, on average, exceeded the target by 3% despite the poor performance from the STHW systems. For the purpose of comparison, if the STHW systems provided their full specified 1064 kWh (taken as fuel energy saved as opposed to solar energy output), in addition to the 3.02 kWp photovoltaic system [O'Flaherty, 2009] generating its specified 2,400 kWh of electricity, then approximately 29% of the energy needs of these properties would be, on average, met by renewable sources (Table 4, col. 12). This highlights the needs for these renewable energy technologies to be fully functional to ensure the best possible chance of meeting UK emissions reduction targets.

8 Conclusion and Further Research

The following conclusions can be drawn from the analysis presented in this paper:

- None of the STHW systems monitored in this project achieve the design specification of 1064 kWh of solar output per annum. The systems in properties with a high occupancy level had an average solar energy output of 395 kWh (8% solar efficiency)

- Only 5% of the average total gas energy demand for high occupancy properties was displaced by the STHW systems and on average, only 19% of the gas supplied hot water energy demand was met (solar fraction = 19% including losses)

- The fuel energy saved due to the installation of the STHW systems was, on average, 359 kWh/yr based on an average 90% occupancy. This led to average CO_2 savings per property of only 63 kg

- Residents need to understand how to get the most out of these technologies. For instance, the STHW systems should be used to compliment the energy provided by the auxiliary boiler/immersion heater and not operated in competition with them.

- Cylinder water usage will be significantly reduced if the property is fitted with an electric shower instead of relying on the STHW system to heat the water.

- Adopting a 'fit and forget' approach in renewable energy technology schemes is not sustainable. Systems should be monitored to ensure they are working at their optimum and low performing systems should be re-commissioned. Fully functional renewable energy systems in this study had the opportunity of displacing up to 29% of the property's energy demand if they met their full design specification. In this study, 18% of the energy demand was provided by renewable energy technologies.

9 Acknowledgements

The authors' wish to acknowledge the financial support received for the Economic and Social Research Council's Business Engagement Opportunity Scheme and the Eaga Charitable Trust. The contribution of South Yorkshire Housing Association and Rotherham Metropolitan Borough Council is also acknowledged.

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