Monitoring Useful Solar Fraction in Retrofitted Social Housing

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Abstract

Registered Social Landlords (RSLs) are responsible for 2.15 million homes in the UK (Department of Communities and Local Government, 2006) and will therefore need to be at the forefront for the drive for sustainable homes if the government's aim of reducing emissions of green house gases by 80% is to be hit by 2050. As it is estimated that 87% of currently existing properties will still be in use in 2050 (Boardman, 2007), retrofitting renewable technologies will be of vital importance if key targets are to be hit. Multiple previous studies have looked at the output of domestic solar hot water (SHW) systems in the UK. However, very few of these assess retrofitted systems in situ, being mainly laboratory based, and none assess how SHW systems perform in social housing. The paper presents a review of domestic SHW performance in-situ based on previous studies and available data sheets, assessing particularly how the in-situ results differ from those in laboratory conditions. A review of modelling techniques in order to predict performance of SHW systems will be included within the paper, as well as models to predict household demand for hot water. The paper presents a detailed methodology of proposed field monitoring of a number of domestic social properties with and without SHW systems. Within this are included details on the background to the project with Gentoo Homes, an RSL in the north east of England, and the research project's aims and objectives.

Keywords: solar hot water, retrofit, social housing, solar fraction, RSL

1. Introduction

1.1 Background and Gentoo project

The UK government is legally bound to cut total greenhouse gas emissions by 80% by the year 2050, as well as achieving a significant cut of at least 34 % by 2020 based on 1990 levels (Climate Change Act, 2008). To make such cuts in emissions it seems likely that a cut larger than the 80% figure will need to be made in the residential sector, so as to mitigate the probable increases in other areas such as aviation (Bows and Anderson, 2007). The government has begun to address the issues of carbon emissions within the housing sector by pushing forward plans to install smart meters within all properties, phase out incandescent light bulbs and running the Low Carbon Buildings Programme (Energy Saving Trust, 2007).

In the UK, the turnover of building stock is relatively slow compared to most developed countries, meaning 87% of current properties will still be in use in 2050 (Boardman, 2007). This makes the retrofitting of energy efficient measures and micro-generation technologies to existing stock essential going forward, if such a reduction in CO2 emissions is to be achieved. The government is introducing a microgeneration tariff in April 2010 for electricity, and a tariff for heat in 2011, in order to make microgeneration in domestic properties more financially viable (Bergman et al, 2009).

Of around 25 million homes in the UK, 2.15 million (around 9%) are in the ownership of registered social landlords (RSLs) (Communities and Local Government, 2006). Because of the number of houses controlled by RSLs it is important that they adopt retrofit carbon cutting measures across a large proportion of their housing stock if government targets are to be achieved. It is also useful for RSLs to be the forerunners of private landlords in retrofitting as they often have a larger skill base and funds within their organisations for the purpose of retrofit, as well as controlling around 9% of the housing stock (Communities and Local Government, 2006).

Gentoo is a RSL based in Sunderland, UK, with a stock of around 30,000 homes and is one of the largest in the country. In September 2008 Gentoo began “Retrofit Reality” a project to retrofit 140 of their homes with carbon saving measures funded in part by a grant from the Housing Corporation (which became the Tenant Services Authority in November 2008 or TSA). Combinations of technologies are being used within the project including A-rated boilers, external cladding, argon-filled double glazing and mains fed showers. 17 of the houses are to be fitted with solar hot water (SHW) systems. It is these retrofitted solar properties which will be the main focus of this paper.

1.2 Previous studies

Domestic hot water accounts for 24.6% of the total primary energy consumption by housing in the UK (BERR, 2008). Yao and Steemers (2005) find that energy usage for domestic hot water depends on many factors, such as the required water temperature, the volume requirement per person and the household size. CIBSE (2007) estimate hot water use to be typically between 30-55 litres per day in the UK at a temperature of 55oc.

Herring et al (2007) state that in 2005 there already existed 82,200 domestic microgeneration systems of which more than 95% were SHW systems. However uptake was largely found to be specific to households with similar age and economic profiles and uptake of the systems was relatively slow due to the cost time and effort associated with their planning, installation and use. Despite this, those who had installed the systems were overwhelmingly happy with the technologies based on consumer research carried out by the Herring et al (2007) study.

Martin and Watson (2002) and Knudsen and Furbo (2004) have undertaken laboratory based studies into the performance of SHW systems. Others, such as Lloyd and Kerr (2008), have carried out research concerning the addition of these low and zero carbon (LZC) systems to houses, both in new build and retrofit scenarios.

Although there have been many studies designed to monitor the output of SHW both in commercial and domestic conditions, Knudsen (2002) and Lloyd and Kerr (2008) found that few tests have been done with the systems in-situ or in what could be considered a "real life" scenario. This meant that few of the vagaries of consumer behaviour and weather impacts had been taken into account and it is these which Knudsen (2002) and Lloyd and Kerr (2008) looked particularly to assess. Jordan and Furbo (2005) and Lloyd and Kerr (2008) perceived many of the influencing factors in the performance of domestic SHW to be attributable to the performance of the storage system.

Andersen (1998) and Lloyd and Kerr (2008) found that the in-situ monitoring of energy output of domestic SHW showed output to be lower than in laboratory conditions, as well as being far more variable. Degelman (2006) used monitoring on a domestic SHW system to show that the system became significantly degraded in performance over time.

Many studies use models to predict solar output from domestic systems (Jordan and Vajen, (2001); Kalogirou and Tripanagnostopoulos, (2006); Lima et al, (2006); Souliotis et al, (2009)). Hobbi and Siddiqui (2009) use a TRNSYS model to advise the design of a domestic hot water system in a cold climate, showing the solar fraction produced. Meir et al (2002) use a TRNSYS model to predict the performance of solar systems before comparing the predicted solar output with actual results from monitoring.

The simulation model used in the predictive element of the study is the Transient Energy System Simulation Tool or TRNSYS. This modelling tool was chosen after careful review of the appropriate literature. The TRNSYS model is used widely in the modelling of solar processes in the academic literature Many studies use models to predict solar output from domestic systems, with the TRNSYS model being the most widely used within the academic literature (Jordan and Vajen, 2001; Kalogirou and Tripanagnostopoulos, 2006; Lima et al, 2006; Souliotis et al, 2009).

Duffie and Beckman (1991) use TRNSYS models for almost all of their workings on solar thermal systems and see it as the most suitable tool for modelling solar output in varying levels of complexity. The TRNSYS software is seen as a powerful tool for research and development, for understanding systems' function and for design. TRNSYS can also be used flexibly with the user's own data for parameters such as weather, which made it an appropriate choice for use in this study. Kalogirou

(2009b) finds TRNSYS models can be validated to an accuracy of 4.7% when modelling a thermosyphon system. Kalogirou uses TRNSYS more than any other system for modelling solar output and cites the flexibility and user-friendly nature of what is a complex tool. Kalogirou frequently uses TRNSYS in his many studies on solar thermal.

1.3 Research project

The aim of the research project is to use an industry standard domestic energy model to predict the performance of solar collectors added to social houses as part of the RSL's retrofit programme. The model will look at domestic hot water energy demand in short time steps, to give hot water daily demand profiles. The model will also predict SHW output from a simulation designed to imitate the "real" retrofitted SHW systems added as part of the RSL's retrofit programme. To do this it can use imported daily demand profiles and imported weather data.

A number of dwellings fitted with SHW will be monitored to determine the performance of the collectors and the solar fraction used by the household. The research project will compare the in-situ results from the monitored domestic SHW systems with the predictions made by the solar collector model and comment on the differences seen between the two sets of results.

Objectives:

- To monitor the performance of in-situ, retrofitted renewable energy sources on domestic housing stock over a minimum of 12 months

- To predict the performance of the retrofitted SHW systems using an industry standard model, TRNSYS, in short time steps

- To analyse the differences between projected and actual performance

- To compare the modelled data with that from the monitored properties, identifying the model accuracy and suggesting amendments to model in order to incorporate observed performance differences

2. Methodology

The methodology essentially takes the form of two streams of work; the monitoring and the modelling aspects, which will ultimately combine so that the in-situ results may be compared to the outputs predicted by the modelling work.

2.1 Monitoring in-situ solar hot water systems

In order to assess the performance and useful solar fraction provided by the SHW collectors, a monitoring system was installed in six retrofitted houses, and in a further two non-retrofitted houses in order to provide baseline data.

The houses were chosen to be as alike as possible (by using relevant data) to ensure that the results from the monitoring was influenced as little as possible by factors not relevant to the study. The building and construction type was taken into account to find similar sized and designed properties. Information from RSL's customer surveys was then used to find households with the same number of occupants, of the same age and occupation patterns. This sample was to represent an "average" household for the size of the properties and the estate in which they were situated.

Within the six solar properties identical monitoring systems were set up. Each system had three heat meters to measure energy supply and demand of the solar collector, the auxiliary boiler and the hot water outflow from the hot water tank. Although sufficient data could be obtained from using just two heat meters, a third was installed as this allowed any system losses to be accurately recorded. The heat meters give a measurement of total energy in the hot water by measuring water flow with a turbine and water temperature with platinum resistance thermometers (PRTs) to give kWh output ($Q=mCp\Delta t$). The heat meters were set up for the domestic scenario, being able to take account of low flow rates, and would pulse a signal to the data logger for each kWh of energy registered through them, periods of hot water usage could then be seen when the information displayed.

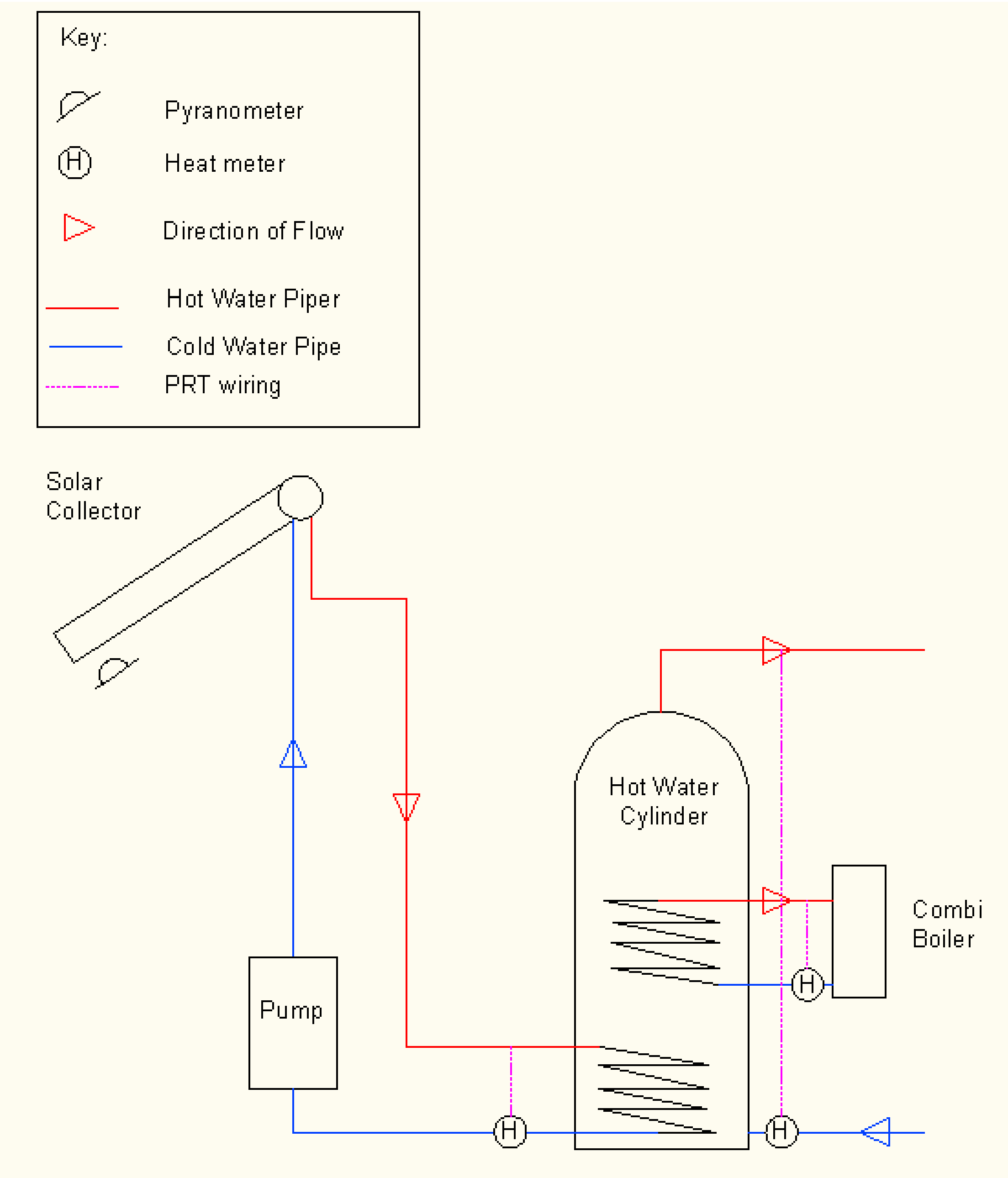
A pyranometer was fitted to the roof of each property at the same mounting angle as the solar collector to measure in plane solar irradiance. As well as this measurement, there was also a weather station set up within half a mile of the properties in order to record local weather patterns in detail. The pyranometers would give details of solar irradiation in half hourly averages, at the angle at which the panel was fitted. The weather station was equipped with a temperature probe for ambient air temperature, a humidity probe for air humidity, two pyranometers to the same specification as those in the properties with one to measure diffuse solar radiation and one to measure horizontal solar irradiance.

All of the measurements were logged to data acquisition units which included GSM modems in order that the data could be transferred remotely without any disturbance to the tenants of the monitored properties.

Alongside the six SHW retrofitted houses, two houses of similar design and occupation were monitored as control properties. These properties had a reduced monitoring system installed with only one heat meter being situated on the boiler outflow to measure hot water consumption.

2.2 Schematic diagram of monitoring system set up

Schematic of monitoring kit for solar hot water properties:



2.3 Modelled data

A model was built in TRNSYS to act as a “base case” from which the various parameters can be tested to see how they affect SHW output. The base case was built from a worked example from CIBSE’s Solar Heating: design and installation guide which allowed a typical SHW system to be built and validated (CIBSE, 2007). The worked example was done using the information in the table below:

Example Energy load	*Energy annum kWh*
DHW usage 120 litres per day	*2267*
Solar pipe losses	*232*
Solar store losses	*295*
Store losses from tappings	*50*
Total DHW load annum	*2844*
Solar fraction at 60^{o}c	*40%*
Solar energy target to collect if optimum	*1138*

Using this worked example and other scenarios from the literature, the model was validated by observing output from the model to be within 5% accuracy of these case studies. The base case model was then used as the basis against which a change in parameters such as collector area, tank size or daily demand profiles, could be measured and the output expressed in terms of a "percentage shift from base case". In order to further validate the model, scenarios were run based on previously conducted studies and the modelled results compared to these, to confirm that the sensitivity of the model was correct.

The weather data used initially in the model comes from the Meteonorm database which provides average weather files based on previously recorded data. As in-situ weather is recorded using the on-site weather station, this data can be added to the TRNSYS simulation.

Once validated, key scenarios are run on the TRNSYS software to imitate likely scenarios in the monitored sample of properties, based on different hot water demand profiles, total daily draw-offs of hot water etc. A system can be designed to be identical to the in-situ system in the sample properties in terms of the sizing of the different components of the SHW system.

2.4 Other data collected

For this project a number of factors about the tenants themselves were recorded. These were; age, work patterns, gender and number of occupants in household, and were taken from the housing association's "customer survey" for 2008.

3. Future work

The ultimate aim of the research project is to use the in-situ results from the monitoring to compare with the modelled data from TRNSYS. The in-situ will be compared with the modelled output and the differences observed and investigated. The source of these potential differences will be considered and investigated and will help form recommendations of improvements to the model. Finally, these improvements will be implemented to the model and an assessment of how close the match between in-situ and modelled is will be made.

In order to do this an exact replica system of the “real” SHW systems must be built within TRNSYS and a number of different scenarios run to give a range of modelled results. Once data is monitored from the in-situ SHW, and a full data set produced for a 12 month period, this data will be input into the model to create hot water demand profiles for each household.

In-situ weather station data will allow real weather data to be added to the model, monitored hot water profiles and loads from the sample 8 households can be added also and thus the accuracy of the modelled output can be improved for a retrofit scenario.

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