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Financial analysis of an installed small scale seasonal thermal energy store

Shane Colclough*, Philip Griffiths

Centre for Sustainable Technologies, University of Ulster, Newtownabbey, BT37 0QB, Northern Ireland, UK

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ABSTRACT

The financial viability of an installed solar heating system incorporating a Seasonal Thermal Energy Store (STES) for a house constructed to the low-energy Passivhaus standard is analysed. Details are provided of system costs and the recorded performance for the installation which is located in Galway, Ireland, a location which experiences a Temperate Maritime Climate. Using these figures, a financial Life Cycle Analysis has been undertaken to determine the cost effectiveness of the system in providing space heating and domestic hot water.

As part of the life cycle cost analysis the effect of the treatment of the terminal value of the STES was considered. The analysis shows that irrespective of the terminal value attached to the STES, the use of solar thermal energy in combination with an STES offered a more favourable business case than the use of electricity for DHW and space heating over the 40 year time period considered. This shows that a direct space heating and DHW system incorporating STES can be economically viable in a Temperate Maritime Climate in the long term.

1. Introduction

Regulations, such as those mandated as a result of the EU's Energy Performance of Buildings Directive [1], are seeking to significantly reduce the space heating demand of dwellings while increasing the use of renewables to meet the residual energy demand. A study of the performance of houses complying with the (now 20 year old) low energy Passivhaus standard [2,3] provides an insight into the future performance of the now mandated low-energy buildings. A number of studies (for example [4–7]) have documented the performance of the Passivhaus dwelling in various climates. In particular, in the EU funded CEPHEUS (Cost-Effective Passive Houses as EUropean Standard) project, the operation of 221 low energy housing units complying with the Passivhaus standard in five European countries was evaluated [4]. It demonstrated a space heating energy reduction of over 75% compared with building regulations pertaining at the time and over 90% when compared with the typical building stock [8]. When there is a low space heating demand in the dwelling, the opportunity for meeting a significant portion of thermal energy demand (space heating and hot water) with renewable resources such as solar become feasible.

The usefulness of solar energy for heating buildings is a function of the ratio of incidental insolation to heat loss [9]. The profile of the space heating demand is seen to be important. Thus, for example, buildings in cities with excellent solar resources and short heating seasons (e.g. Valetta, Malta) benefit less from solar space heating than those in cities such as Dublin, Ireland which have less available solar energy, but experience a longer heating season, with a relatively mild winter, leading to low peak space heating demands [10].

The falling prices of solar collectors, and the relatively high set cost of installation, allows for excess solar collectors to be added at minimal extra cost thereby significantly increasing the Solar Fraction (SF) of DHW and space heating of a low-energy house, reducing significantly the carbon derived energy demand. Surplus heat generated in summer can be fed to a Seasonal Thermal Energy Store (STES) allowing surplus summer heat to be used in the winter [11].

While much has been written on large communal STES (for example [12–14]) consideration also needs to be given to STES for single dwellings such as that in this study. There are a number of countries in which the largest proportion of newly constructed houses are detached dwellings such as in Ireland where 54.2% (2010), 62.3% (2011), 61% (2012), 57% (2013) of new build are

* Corresponding author.
E-mail address: s.colclough@ulster.ac.uk (S. Colclough).

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detached [15], as has been referred to by other studies e.g. Ref. [16].

A number of papers have focused on the analysis of STES systems in combination with low Energy houses through the use of dynamic building simulation software such as TRNSYS (e.g. Refs. [17–19]), a number of which also undertook financial analysis. However, few examples exist of a financial analysis based on recorded costs and monitored performance of an installation.

This paper analyses the financial viability of the application of a space heating and Domestic Hot Water (DHW) solar thermal installation utilising Seasonal Thermal Energy Storage (STES), to a dwelling complying with the Passivhaus standard in a temperate maritime climate (TMC) based on recorded data, in a location with a four year average Heating Degree Days of 2063 [20].

2. Overview of installation

A Passive House of 215 m^2 constructed in Galway, Ireland in 2006, has a very low predicted space heating demand of 1827 kWh, as determined by the PHPP, when it is used as a residence for a family of four. The house is currently used primarily as an office and show house, but also has periods when it is lived in.

In June 2009, an underground aqueous Seasonal Thermal Energy Store was installed and used to supplement the dwelling's installed electric space heating. Previous publications have provided details for the relative climate, the passive houses construction details, the solar installation, it's operational performance, a Net Energy Analysis and the optimisation of the solar thermal installation applied to the passive house through numerical modelling [21–26].

An Evacuated Tube Solar collector array, of 10.6 m^2 aperture, collects diurnal heat and stores it indirectly in a 300 L DHW (DHW) cylinder ("Tank 1") via a heat transfer coil. Once the temperature of the DHW tank reaches a temperature above which legionella cannot survive (65 °C), a three way valve originally diverted the solar heated fluid via a heat exchanger coil, to a subterranean STES ("Tank 2") of capacity 22,730 L, which is located in the garden. The water in Tank 2 is not circulated and is used purely as an indirect sensible heat store.

In November 2010, this system was modified such that once the DHW temperature exceeds 65 °C, the solar fluid is fed to the space heating system ("Direct Space Heating"), until the house temperature reaches 22 °C, whereupon the solar fluid is fed to the STES. The energy stored in Tank 2 is used in the underfloor heating, which is in the wetrooms, and whole house air duct space heating system via a heat exchanger coil. It also indirectly heats the DHW supply via the preheat coil in tank 2.

Overall the arrangement ensures, a) the SF for DHW is high, b) heat surplus to DHW need is used for direct space heating, c) any surplus heat is stored for winter use rather than rejected (as would be the case in holiday mode), and d) the space heating SF in winter is increased.

The STES storage cycle commences in February with the lowest tank temperature and finishes the following February once the captured summer solar energy has been utilised during the winter period. Due to the design employed, thermal stratification does not occur to any great extent in Tank 2, with the recorded temperature difference between the top and bottom of the tank rarely exceeding 2 °C.

3. System performance & costs

3.1. Space heating

The performance of the system has been monitored since June 2009. System optimisation was undertaken in the first heating season, and the results are thus atypical. In addition, the house was unoccupied or infrequently used for the period June 2011 to October 2013. The overall period for which results are presented here is from March 2010 to May 2011, which represents the most typical system usage pattern.

Fig. 1 shows that the space SF approached 100% for all months apart from January (31%) and February (56%). Thus the space heating needs were met either by direct solar space heating or via stored solar heat for all but two months of the year.

Of the total space heating demand of 1592 kWh between June 2010 and May 2011, only 450 kWh was borne by the electric heating system. The SF over the space heating season was 72%, with 739 kWh (46%) of the total space heating demand being met by direct solar space heating via the heat exchanger coil in the HRV System and the wet underfloor heating system, with the remaining 406 kWh (26%) provided by the seasonally stored heat. It is noted that the Passive House Planning Package (PHPP) forecast an annual space heating demand of 1832 kWh, 236 kWh above the recorded space heating demand over that period. The PHPP, while not a dynamic building simulation tool, has received extensive validation and the PHPP model is accepted as an accurate predictor of space heating demand. The lower than predicted space heating demand may be due to the fact that internal temperatures of less than 15 °C were experienced for 15 days due to the house being unoccupied for part of December and January. Temperatures across Ireland dropped to record lows in December 2010. Apart from December and January the internal temperatures always exceeded 17 °C, even during periods when the house was unoccupied.

Fig. 2 shows the breakdown on a per month basis between electric heating, direct solar space heating and stored solar space heating for the heating season 2010 to 2011. It can be seen that the STES made a significant contribution in October, November and December, but was depleted by January 2011. In 26 November 2010 the solar heat system was adapted to provide a connection to the existing HRV system in the house as described earlier. This enabled solar heat collected by the 10.6 m^2 solar array to be used to directly heat the dwelling rather than via the intermediary of the STES, the effects of which are clearly visible in Fig. 2.

3.2. DHW consumption

The domestic hot water consumption recorded at the site was low at 852 kWh. This reflects the use of the building as an office/showhouse during the period analysed rather than a domestic dwelling and also a low occupancy level. The total solar contribution to DHW was 792 kWh for the period SF of In the following analysis, the recorded domestic hot water consumption has been used.

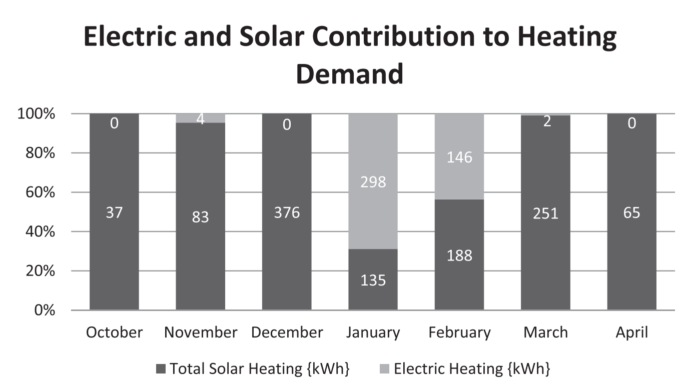

Fig. 1. Space heating demand for heating season analysed showing solar fraction.