One Passivhaus' Search for Zero Carbon

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1 Introduction

Dynamic Building Simulation Modelling has demonstrated that Temperate Maritime Climates experienced in cities such as Dublin, Ireland offer the greatest opportunity for solar assisted space heating in Europe. This paper validates a simulation result by reviewing the actual solar heating results achieved in a house located on the west coast of Ireland which is built to Passivhaus standards. It also demonstrates the maximum Solar Fraction (SF) achievable for the house through the use of a TRNSYS model validated using data gathered on site.

Figures are presented giving the extent to which solar energy assisted in approaching zero carbon heating in the Passivhaus under study. Finally, Life Cycle Cost and Energy Analyses are carried out for the Solar and ISES installation.

2 Description of Installation

A 215m^2 (TFA) detached Passivhaus coupled with a solar installation comprising

- 10.6 m^2 evacuated tube solar array
- 300l Domestic Hot Water (DHW) tank,
- 23m^3 aqueous Inter Seasonal Energy Store (ISES) and
- combined underfloor and Heat Recovery and Ventilation (HRV) space heating system

has been monitored since June 2009. This is the showhouse for Scandinavian Homes, a builder of Passive and Low Energy houses. See Fig 1.

Solar heat is first used to meet the DHW requirements, and then the space heating requirements (either via the wet underfloor heating system or via the heat exchanger (HX) in the HRV system). Any surplus solar heat is diverted to the ISES.

Key performance data was recorded and used to validate a TRNSYS model.

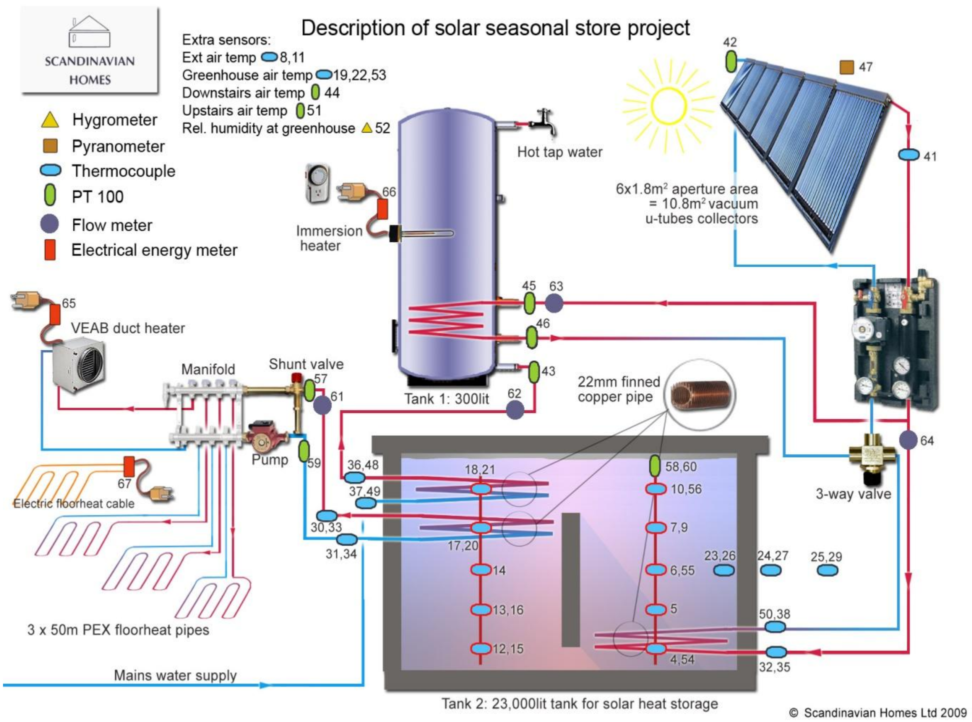

Fig 1. Diagram of monitored Solar Installation

3 System Performance

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.

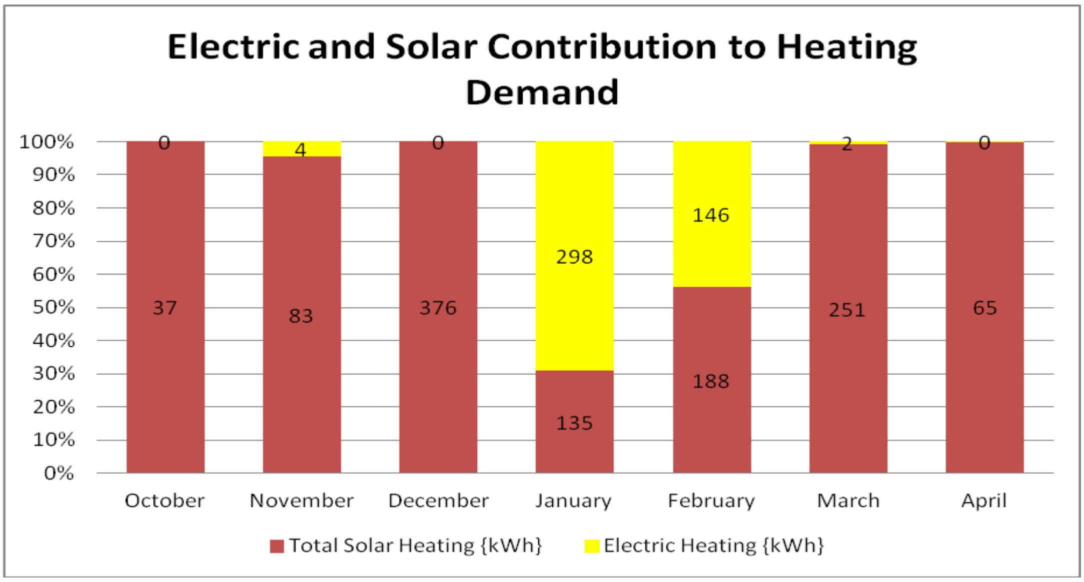

Fig 2 Space Heating Demand for Oct 2010 to Apr 2011 with Solar Fraction per Month

The SF over the heating season was 72%, with 739 kWh (46%) of the total space heating demand being met by direct space heating, and the remaining 406 kWh (26%) by means of inter seasonally stored heat. It is noted that the Passive House Planning Package (PHPP) forecast that the annual space heating demand would be 1832 kWh, 236 kWh above the recorded space heating demand. In addition DHW demand projections were significantly higher than the 705kWh recorded. This reflects use of the building as an office/showhouse rather than a domestic dwelling and also a low ocupancy level. It should also be noted in the analysis that temperatures of less than 15°C were experienced for approximately 15 days due to the house being unoccupied for part of December and January. Thereafter the internal temperatures always exceeded 17°C, even during periods when the house was unoccupied.

Fig 2 shows that only January and February required a statistically significant amount of electric heating, demonstrating that 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. It is noted that the space SF approached 100% for all months apart from January (31%) and February (56%).

Fig 3 shows the breakdown on a per month basis between electric heating, direct solar space heating and stored solar space heating for the heating season '10 to '11.

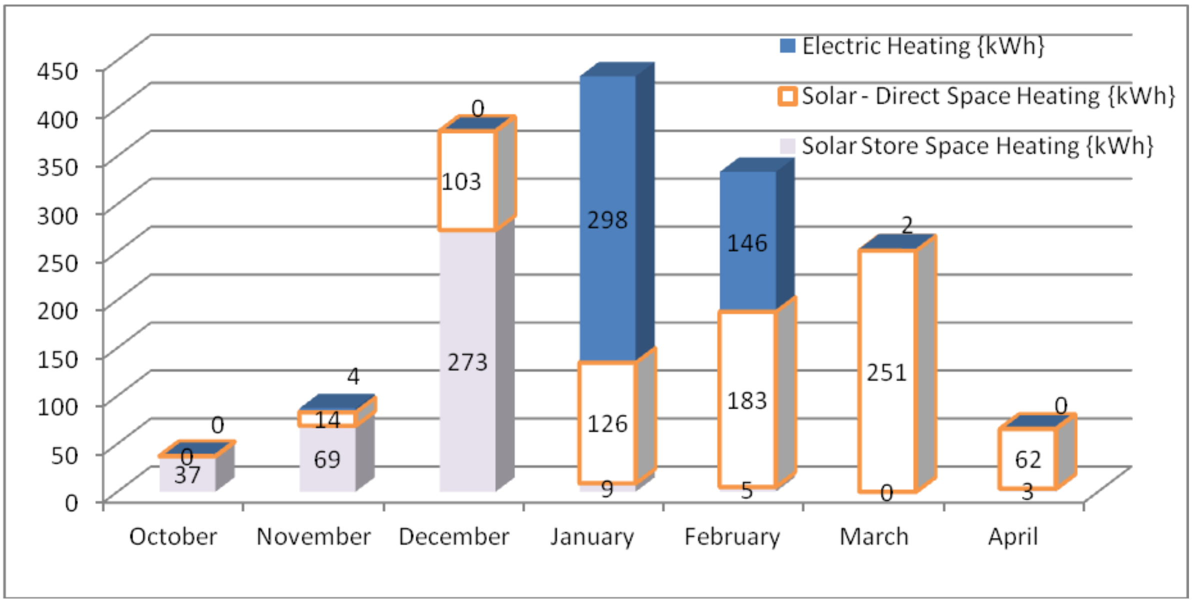

Fig 3 Electric, Direct Solar, and Stored Solar Space Heating, Oct 2010 to Apr 2011

It can be seen that the ISES made a significant contribution in October, November and December, but was depleted by January 2011. It should be noted that on 26 November 2010 the fluid to air heat exchanger was connected to the existing HRV system in the house. This enabled solar heat collected by the 10.6 m² solar array to be input directly to the house space heating system rather than via the intermediary of the ISES.

Fig 4 is the result of TRNSYS modelling of the installation in Galway. It shows that irrespective of the solar array and ISES size, the maximum combined solar fraction achievable for the house under study asymptotically approaches 0.77 for a space heating requirement of 1181kWh and a DHW consumption of 859kWh (i.e. the loads experienced for the year 2010). This defines the maximum benefit of solar heating possible for the house under study in its location and it is noted that the space SF of 0.72 represents close to the upper limit obtained from the modelling.

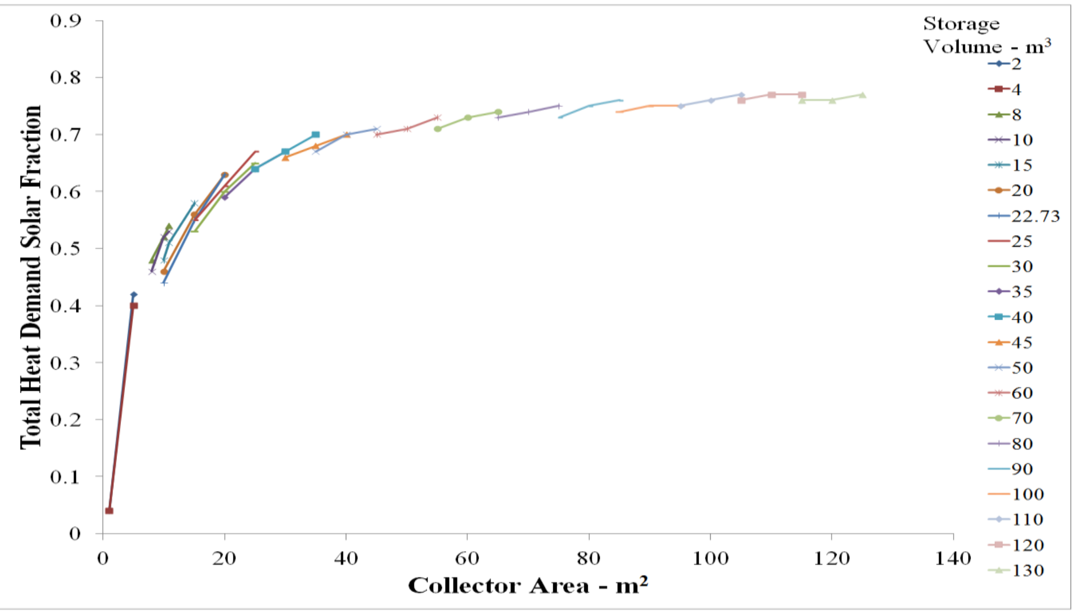

Fig 4 Modelled Solar Fraction vs. Collector Area (increasing Storage Volume)

4 Net Present Value Financial Analysis of Heating Costs

An NPV financial cost analysis was undertaken for the installation. In the analysis a Consumer Price Index inflation rate of 2%, an electricity inflation rate of 3%, and a discount rate of 5% were used. The costs also include scheduled system maintenance and operating costs. Figure 5 shows that while the initial system costs are high, the total cost of providing domestic hot water and space heating is significantly lower using the solar system with integrated ISES in the long-term. The case for the ISES is all the stronger when one considers that in this analysis no terminal value was assigned to the concrete ISES.

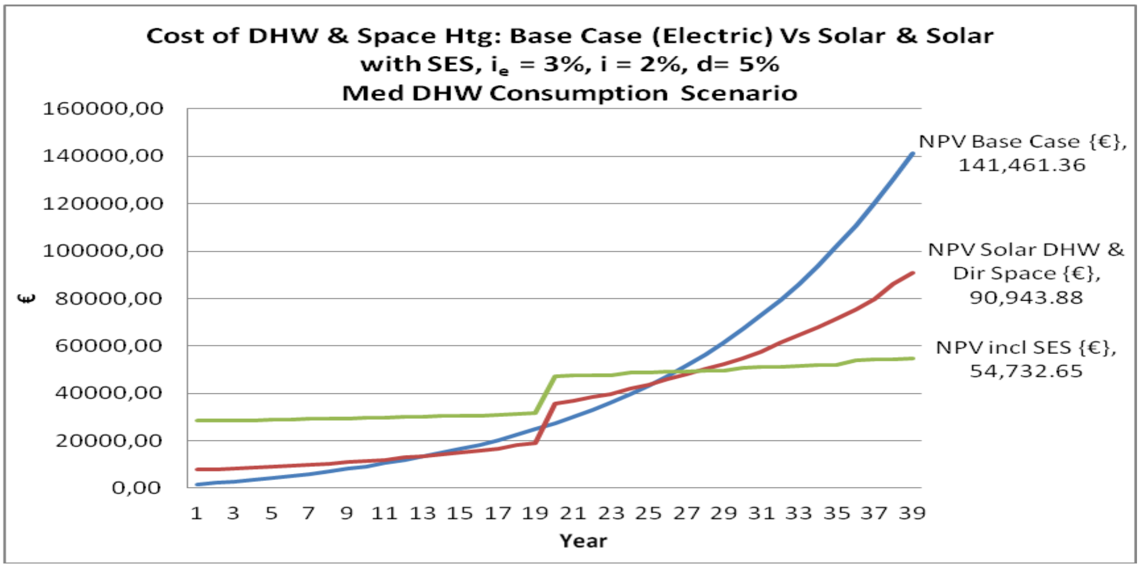

Fig 5 Net Present Value system and operation cost comparisons

5 Carbon Analysis

Zero Carbon Definition and Databases used

A number of definitions exist in relation to zero carbon. The house under study is subject to the building regulations pertaining in the Republic of Ireland. While there is a stated aim to achieve a carbon neutral standard via the 2013 building regulations in the Republic of Ireland, the definition of carbon neutral homes is not available at the time of writing.

The definition used for this paper is that required by the UK government under the 2016 Code for Sustainable Homes Regulations and therefore only the emissions covered by Building Regulations (heating, fixed lighting, hot water and building services) are considered. Emissions from cooking and 'plug-in' appliances such as computers and televisions were not included.

Using this definition in relation to the Passivhaus in Galway, accurate figures are available for hot water and space heating and building services (solar/underfloor pump operation). No figures are available for the (low energy) lighting used.

In relation to the Annualised Embodied Energy (AEE) analysis below, a "best estimate" analysis is carried out for the embodied energy for the Solar & ISES installation using the UK's ICE database. At the time of writing the official Embodied Energy database was still in compilation for the Republic of Ireland.

Operational Carbon Emissions savings for 2010/2011 Heating Season

The total solar space heating contribution was 1142 kWh. During the same period, solar contributed 629kWh of the DHW load, giving a total solar contribution of 1771kWh. Operation of the solar pump consumed 35.1kWh and operation of the underfloor/HRV HX pump consumed 43.8kWh over the heating period, giving a total of 78.9kWh. Subtracting the consumed 78.9 kWh from the 1771 kWh electricity saved, gives a balance of 1685 kWh.

Thus there is a carbon emissions saving of 874 kg of CO_2 pa using the figure of 519 g per kWh.***i***. Had the total DHW and space heating load of 2298kWh been met by electricity, the emissions would have been 1192kg. Thus a reduction of 75.3% was achieved.

Embodied Energy Analysis

The weight of prefabricated concrete for the 23m^3 tank is 17000kg. Assuming an embodied energy figure of 2.0 MJ per kilogram of prefabricated concrete***ii***, the embodied energy in the concrete ISES tank is equivalent to 34,000 MJ or 9444kWhr at a conversion factor of 3.6. Assuming a service life of 50 years, the Annualised Embodied Energy (AEE) is 189 kWh/a.

Using a similar methiod the AEE of the installation was calculated (Fig 6).

Component	Weight {kg}	Specific Embodied Energy {MJ/kg} (ICE)	Embodied Energy {kWhr}	Service Life {yrs}	AEE {kWh/a}
ISES	17000	2.0	9444	50	189
EPS Insulation	630	88.0	15400	50	308
$10m^2$ Solar system			10000***iii***	20	500
Total					997

Fig 6. Annualised Embodied Energy Analysis

The annualised embodied energy of pipework, the HRV Heat Exchanger coil and additional small components were not included on the list, as they are estimated to represent less than 5% of the total. At the conversion rate of 2.7 used by the PHPP, avoiding the production of 1685kWh of electricity is equivalent to avoiding 4550kWh of primary energy required for electricity production.

The analysis shows that an annualised embodied energy of 997 kWh is expended in order to avoid the 4550kWh of primary energy required for the production of the amount of electricity production for the period under study. Thus

Net Energy Ratio = (-ΔAEU/AEE) = 4550/997 = 4.56

Conclusion

The paper demonstrates the viability and potential of solar domestic hot water and space heating coupled with Inter Seasonal Energy Storage when applied to the low-energy house under study in the Irish climate. An exceptionally high space heating solar fraction of 72% was achieved for the house under study, reducing the heating season to 4 months by virtue of direct solar space heating. A further reduction of two months in the heating season was achieved through the addition of the ISES.

It was found that the least cost option in the long-term for providing domestic hot water and space heating was through the use of a solar heating system comprising Solar panels, DHW installation, direct solar space heating and an Inter Seasonal Energy Store. It was shown that the maximum theoretical solar fraction possible was 77%. The carbon analysis showed an annual operational avoidance of 874 kg of CO_2, while the life cycle energy analysis demonstrated an annual operational benefit of greater than 4.5 times the annualised embodied energy of the solar heating system.

i http://www.esb.ie/esbcustomersupply/residential/manage-your-account/fuel-mix.jsp
ii ICE database, University of Bath, 2009, http://www.bath.ac.uk/mech-eng/sert/embodied/
iii Hernandez, P, Kenny, P, Development of a methodology for life cycle building energy ratings, Energy Policy 39 (2011) p 3779 – 3788