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Economic Analysis of an Installed Single Dwelling Seasonal Thermal Energy Store with Varying Demand

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Summary

The financial viability of a domestic sized solar Seasonal Thermal Energy Store (STES) installed in a low-energy house located in a Temperate Maritime Climate was investigated. Using the figures for the recorded performance in combination with the installation costs, a financial Life Cycle Analysis was undertaken to establish the cost effectiveness of this. Three Domestic Hot Water (DHW) usage scenarios were considered on the impact of DHW consumption on the solar energy available for space heating and the STES surplus (or deficit) heat.

A Life Cycle Cost (LCC) analysis identified the optimal cost-effective solution. As part of the life cycle cost analysis the effects of varying service life of the STES was considered. This shows that while a direct heating and hot water system incorporating STES can be economically viable in a temperate maritime climate in the long term, the financial viability of the solar/STES installation is seen to be heavily dependent on the profile of DHW consumption.

Key-words: Seasonal Thermal Energy Storage, Passive House, Solar Combi-systems

1. Introduction

Regulations, such as those mandated as a result of the EU's Energy Performance of Buildings Directive (EPBD) (Anon, 2010a), aim to significantly reduce the space heating demand of dwellings while increasing the use of renewables to meet the residual energy demand. The study of the performance of houses complying with the low energy Passivhaus standard (Feist & Adamson, 1989, Feist, 1993) provides an insight into the performance of low-energy buildings. When there is a low space heating demand in the dwelling (such as with the Passivhaus standard), the opportunity for meeting a significant portion of this with renewable resources such as solar become feasible.

The changes to the building regulations standards across Europe will see energy demand for DHW equal (if not exceed) energy demand for space heating for new build dwellings. The variability and relative dominance of DHW energy consumption is supported by a study undertaken by the UK's Energy Savings Trust (Anon, 2008) which estimated the average daily UK DHW consumption at 16.8MJ per dwelling (18.7 $kWh.m^{-2}a^{-1}$) based on an average usable floor area of $91m^2$ (Anon 2010b), which is in excess of the 15 $kWh.m^{-2}a^{-1}$ space heating demand required to comply with the Passive House standard.

While previous research has reported on large communal STES (for example Schmidt et al, 2003; Schmidt & Muller-Steinhagen, 2004) consideration also needs to be given to STES for single dwellings such as that carried out in this study. There are a number of countries in which the largest proportion of newly constructed houses

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are detached dwellings such as Ireland where 54.2% (2010), 62.3% (2011), 61% (2012) and 57% (2013) of new buildings are detached (Anon, 2014a). In addition, detached dwellings often afford the advantage of sufficient land area (value) for the installation of an STES.

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, (Badescu & Staicovici, 2006; Leckner & Zmeureanu, 2010; Hugo et al 2010), 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 STES installation which is the subject of this paper.

The house under consideration is a dwelling with a floor area of 215m2 constructed in 2006 to the Passivhaus standard and located in Galway, Ireland. It has a very low predicted space heating demand of 1832kWh, as determined by the Passive House Planning Package (PHPP), when it is used as a residence for a family. In June 2009, an underground aqueous Seasonal Thermal Energy Store was installed. The system is used to reduce the dwelling's installed electric space heating. An Evacuated Tube Solar collector array, of 10.6m2 aperture, collects solar energy and stores it indirectly in a 300 litre DHW (DHW) cylinder. Once the DHW tank reaches the required delivery temperature of 60°C, solar energy is diverted to meet the space heating demands via underfloor heating or the heat recovery and ventilation (HRV) system. Energy surplus to the DHW and space heating demands is diverted to a subterranean STES of capacity 22,730 litres. The energy stored in the STES is used to provide space heating via the underfloor heating and/or heat exchanger coil in the HRV system.

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.

Previous publications have provided details of the installation and reported on the operational performance of the installation (Colclough et al, 2010; Colclough, 2011; Colclough et al, 2012a; Colclough et al 2012b and the optimisation of the solar thermal installation used in the dwelling through numerical modeling reported by Clarke et al 2013.

This paper focuses on a financial analysis to determine the economic viability of the installed solar heating system based both on recorded performance. In addition the effects of two other DHW consumption scenarios (the average UK and the PHPP predicted DHW consumption) were estimated, given the atypically low DHW consumption recorded.

2. System Performance & Costs

2.1 Introduction

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 June 2010 to May 2011, which represents the most typical system usage pattern.

2.2 Space Heating

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. It is also noted 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 and temperatures across Ireland dropping to record lows in December 2010. Thereafter the internal temperatures always exceeded 17°C, even during periods when the house was unoccupied. In this paper, the space heating demand was assumed to be that predicted by the PHPP of 1,832 kWh, with the recorded solar fractions used to determine the direct space heating and STES provided space heating.

2.2 DHW Consumption

Three DHW consumption scenarios were assumed, and the effect of each on the distribution of energy between DHW, space heating, and the seasonal storage tank were estimated for the house in Moycullen in Galway, assuming maximum monthly solar contributions. The resulting distributions as presented previously (Colclough, 2011) were used as the basis for the financial analysis presented here using the financial metrics outlined below.

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 (rather than a domestic dwelling) during the period analysed and also its low occupancy level. The total solar contribution to DHW was 792kWh for the period reflecting the atypically high specific ratio of collector to storage DHW volume of 35.3m^2/m^3 (given the solar array of 10.6 m^2 feeding a DHW tank of 300 L). While the recorded DHW consumption is atypical, it does provide a real consumption, the effects of which on the distribution of energy on the three target systems are analysed under scenario A.

In addition to the recorded DHW consumption, the average UK DHW consumption as reported by the U.K.'s Department of Environment Food and Rural Affairs (Anon, 2008), was also used. This represents the medium DHW consumption considered in this analysis under scenario B.

The highest DHW consumption was that considered under the PHPP requirements (PHPP, 2007). Due to the floor area available within the house in Galway, the default assumption for the occupancy in the house was 6.2 people (based on the area available per person). This leads to a DHW requirement of 2968 kWh, almost twice that of the typical UK DHW consumption of 1703 kWh. This DHW consumption is considered under scenario C.

2.3 System Costs

Table 1 provides an itemised breakdown of all the DHW and space heating system generic costs for the installation in Galway, as recorded by the builder. It excludes the costs of the monitoring equipment, and costs associated with the site specific tasks such as felling of trees, the installation of a greenhouse over the STES etc. It also assumes that a heat transport mechanism is installed, this being a reasonable assumption for a house constructed to the passivhaus standard given that a HRV System is mandatory. Full details of the costs are available from Colclough (2011). The cost of the solar DHW installation (10.6m^2 solar array coupled with a 300 L tank) is considered the base system. The cost of the heat exchanger coil plus a three-way valve (plus labour costs) are itemised as the direct solar space heating system. The extra cost of the STES is detailed.

- In compiling Table 1, the following is noted:
- 15% of total manpower costs is attributable to the DHW installation
- 5% of total manpower costs is attributable to the HRV System
- 80% of total manpower costs is attributable to the STES installation and site works
- Site specific costs are excluded, e.g. greenhouse over seasonal store, tree felling etc.
- Installation costs of heating equipment in house not included
- Costs include VAT

Item	Solar DHW	Solar Space Htg	Seasonal Store
	Total cost €	Extra Cost €	Extra Cost €
Parts	5057.00	269.00	11822.30
Labour	1679.30	559.77	8956.27
Total	6736.30	828.77	20778.57

Table 1 Estimated Costs of Typical Solar DHW, Seasonal Store and Space Heating System

The costs were validated against the costs and sizing of European installed combisystems as undertaken by the International Energy Agency Solar Heating and Cooling programme (IEA-SHC) Task 32 study (Anon, 2003) and found to be within the normal range of combisystems costs.

3. Method

3.1 Life Cycle Cost and Savings Analysis

A life Cycle Cost (LCC) analysis using the time value of money as outlined by Kalogirou (2009) was carried out over a 40 year period. Life-cycle cost analysis is a tool to determine the most cost-effective option among different competing alternatives to do a project, when each is equally appropriate to be implemented on technical grounds. All the costs are usually discounted and totaled to a present day value known as net present value (NPV) using a discount factor d, which bring the individual future values of money to their present day value.

A 40 year period was chosen for the financial analysis given the significant capital investment costs required for the seasonal thermal energy store and the long service life of the STES. The investment in a STES is not expected to pay back in a short timeframe, but rather is assumed to be part of the energy infrastructure of the dwelling in the same way as appropriate orientation and insulation.

The analysis does not take into consideration the cost of financing the investment, tax incentives or annual corporate tax treatments. Emphasis is given in the life cycle analysis to the service life of the components.

It should be noted that tax incentives, such as the accelerated capital allowances currently available for investment in renewable energies in a number of countries such as the U.K.'s Renewable Heat Incentive (RHI) (DECC, 2013) would significantly increase the attractiveness of the installation.

Persson and Westmark (2013) noted the significant emotional, cognitive and social factors at play when consumers make investment decisions in STES systems, and have analysed the effects of behavioural economics in such systems. For the purposes of this study, behavioural economics are not analysed and the neoclassical economics approach has been adopted.

3.2 Expected Life of the Equipment

Given that solar thermal is a mature technology, the various components carry long warranties and it is anticipated that with minimal intervention, systems will continue to operate for 15 to 40 years (Anon, 2013).

In this analysis, the cost has been allocated for scheduled maintenance (mtce) of the system every six years, in line with the maintenance schedule carried out at the installation, and it is assumed that the solar thermal system will continue to operate for 20 years without further capital investment.

Unless otherwise stated, the analysis has assumed that the value of all equipment at the end of the 20 year period is zero. This leads to the "worst-case scenario" for the financial analysis, and the approach has been to adopt this conservative financial modelling throughout the remainder of the analysis.

However, while a 20 year service life is a reasonable assumption in the case of the DHW and space heating systems, considerable value can still be attributed to the STES at the end of the 20 year period. The question of how to value this resource can be approached in a number of ways. In this study the scenario of 40 years operation is considered, and it is assumed that in year 20, a system overhaul of the solar collector, DHW and direct space heating and seasonal energy storage heat exchanger coils will be required at a cost equivalent to the initial investment and adjusted for inflation and the discount rate. It is assumed that the STES tank itself and DHW tank will not require any extra investment.

3.3 Capital Costs

The capital costs in the life cycle analysis are those of the typical installation already outlined in Table 1.

In the analysis it is assumed that the capital costs of the space heating elements are negligible as an electrical space heating element is typically standard in HRV Systems. Thus they have been eliminated from both the solar and electric space heating analyses. In addition, it is assumed in the analysis that an existing HRV System is available as a heat delivery mechanism and an extra heat transport mechanism is thus not required. As previously outlined, this is a reasonable assumption given that the house under study is constructed to the Passivhaus standard. In the house under study, a wet underfloor heating system has been used occasionally in conjunction with the HRV System. However given that it is possible to heat the house using the heat exchanger coil in the HRV System exclusively, the costs of the underfloor heating installation are ignored.

One of the most significant variables in the analysis of the financial performance of the complete solar heating system is that of the value of the STES at the end of the 40 year planning horizon. Thus consideration is required of the NPV of the terminal value of the STES.

The value inherent in the installed STES is difficult to estimate. Given that it has an exceptionally long predicted service life and can be used over a longer planning horizon than the 40 years considered, a terminal value of €7,481 is assigned reflecting that 50% of the initial value of the STES will remain at year 40 assuming an 80 year economic life and adjusting for NPV.

3.4 Pump Operation and associated costs

In analysing the costs associated with the solar heating system, the annual running costs in addition to the capital costs (which have already been considered) must be included. It was estimated that the underfloor/HRV System heating pump consumed between 94kWh and 137kWh of electricity during the period of operation (depending on the scenario considered). This figure is used when calculating the amount of energy consumed by the pump in transferring heat from the STES.

For the solar circuit, it is calculated that the total consumption over a year is 118 kWh and 141kWh again depending on the scenario. In the analysis, this energy consumption is spread on a pro rata basis to each of the three target systems, based on the energy transferred to the target system.

A maintenance check is carried out and a glycol solution is added to the water in the solar circuit every six years. It is assumed that this costs €150 (at today's prices).

3.5 Treatment of the time value of money

A Life Cycle Cost and Savings analysis has been carried out with a number of different variables and results presented here using;

Annual Discount Rate d = 3%

This is based on the required IRR (Internal Rate of Return) within the company concerned at the time of the analysis.

Annual Rate of Inflation i = 2.2%,

This reflects the average of the Irish rates of inflation reported by Eurostat from 2001 to 2011 (Anon, 2012)

Annual Rate of Electricity Inflation i_e = 7.3%

This reflects the 11 year average rate of electricity inflation calculated using the eurocent Unit price of Domestic Electricity in Mar 2002 at 10.71c (source Electricity Supply Board - ESB bills) and in March 2014 at 19.28c (Anon 2014b). This represents an increase of 8.57c, or 80.01% in 11 years, equivalent to 7.27% on an annual basis). The rate of 19.28c excludes any Public Service Obligation (PSO) levy, (a government charge to cover the higher costs of peat and renewable energy in Ireland) as this cost is currently based on an annual charge rather than a charge per unit of electricity.

4. Results

4.1 Scenario A: Recorded DHW Consumption

Figure 1 shows a graphical representation of the NPV when the DHW consumption is assumed to be 852 kWh and the space heating consumption 1832 kWh.

The NPV for the base case (of electrical heating) is €53,184. This represents the most expensive option for heating the dwelling. The option of using the solar DHW and direct space heating system without the incorporation of a STES has an NPV of €41,497. Once the terminal NPV for the STES of €7,481 is considered, it is seen that the least expensive option for providing both DHW and space heating over the considered 40 year planning horizon is that of using the solar space heating and DHW heating incorporating the STES.

For the lowest DHW consumption scenario, it is seen that the breakeven point between the base case and the least cost option of using the solar space heating system with the STES occurs in year 32, after which time savings accrue.

It is seen that the first breakeven point for the DHW and direct solar space heating system occurs in year 19 with a second breakeven point in year 30.

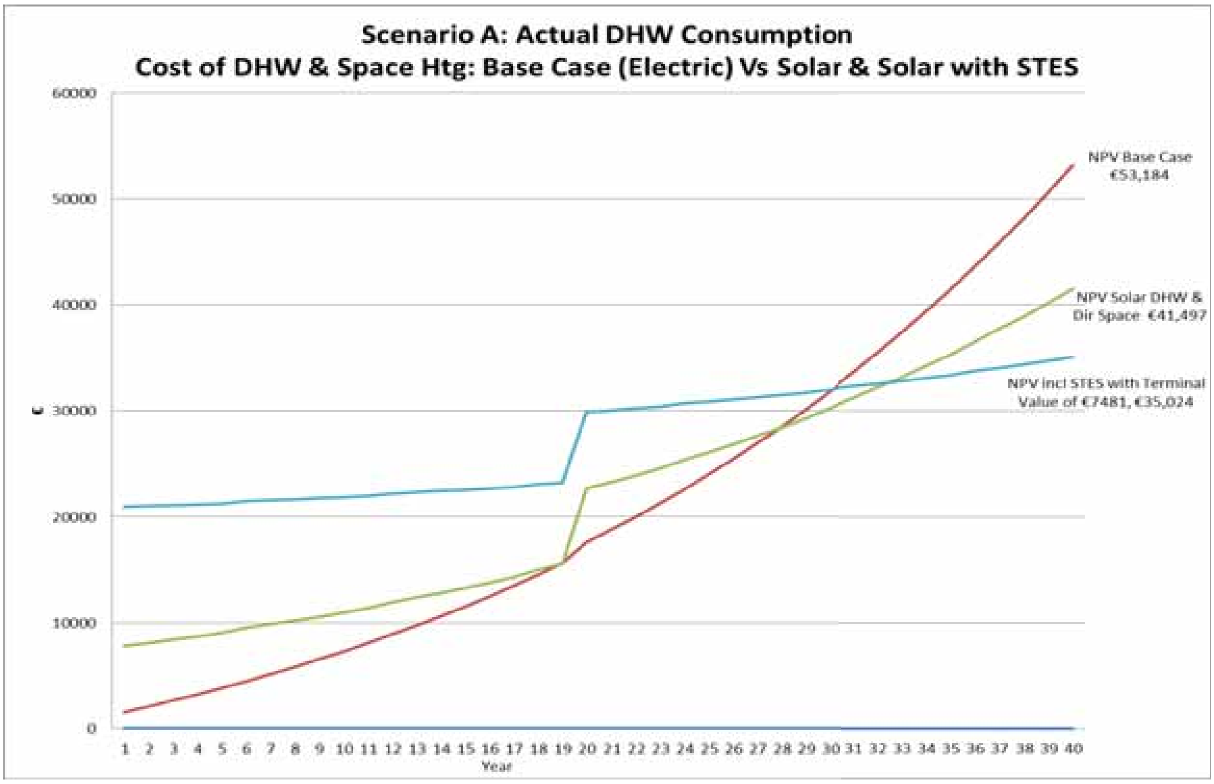

Fig 1. NPV for DHW consumption scenario A

4.2 Scenario B: Average UK DHW Consumption

Figure 2 shows the NPV for the "medium" DHW consumption scenario of 1703 kWh in combination with the space heating consumption of 1832 kWh.

The base case again is the most expensive option, with an NPV of €69,433, significantly higher than scenario A due to the higher DHW consumption. Significant savings are seen to occur once solar energy is used for the DHW and direct space heating, with an NPV of €46,232 without the use of the STES. Without considering the STES, breakeven for the solar system are seen to occur in year 14. However, the least cost option again is to use the solar space option incorporating the STES, with a total NPV of €38,203, and savings are seen to accrue from year 25.

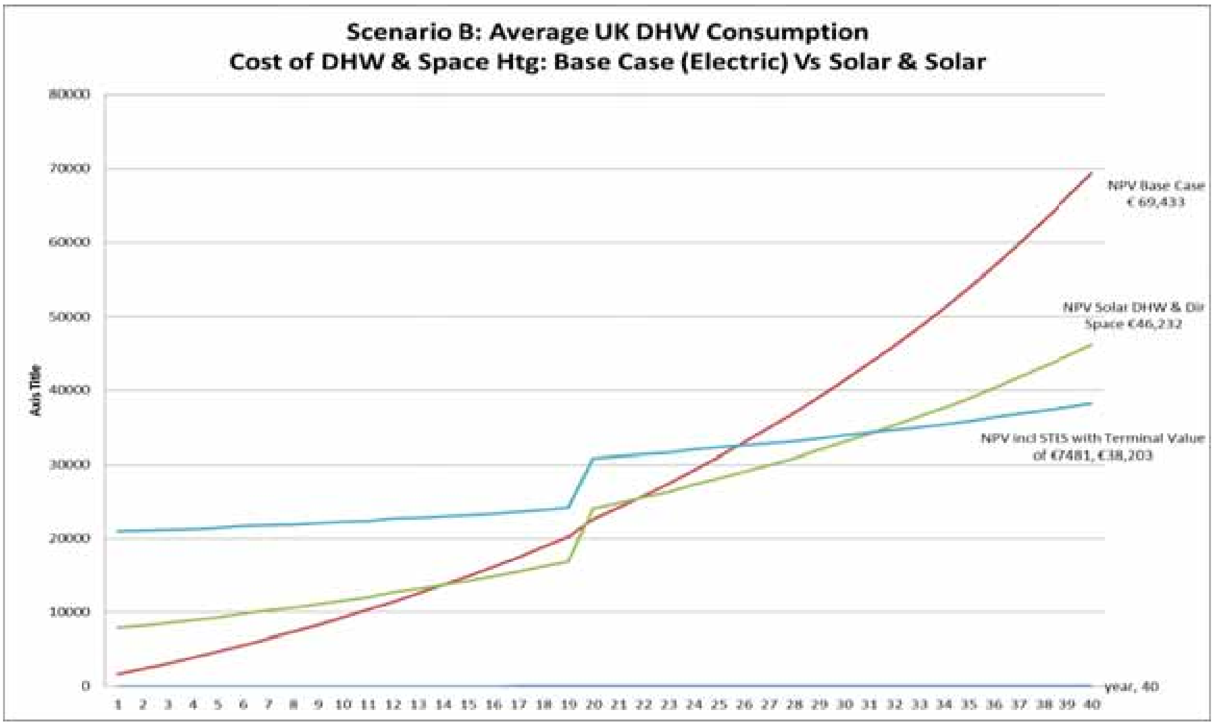

Fig 2. NPV for DHW consumption scenario B

4.3 Scenario C: PHPP predicted DHW Consumption

Figure 3 shows the NPV for the highest DHW consumption scenario of 2968 kWh in combination with the space heating consumption of 1832 kWh. While the PHPP predicted consumption is significantly higher than the average UK consumption, it is included here to reflect the upper end of DHW consumption given the significant variation in DHW consumption among dwellings.

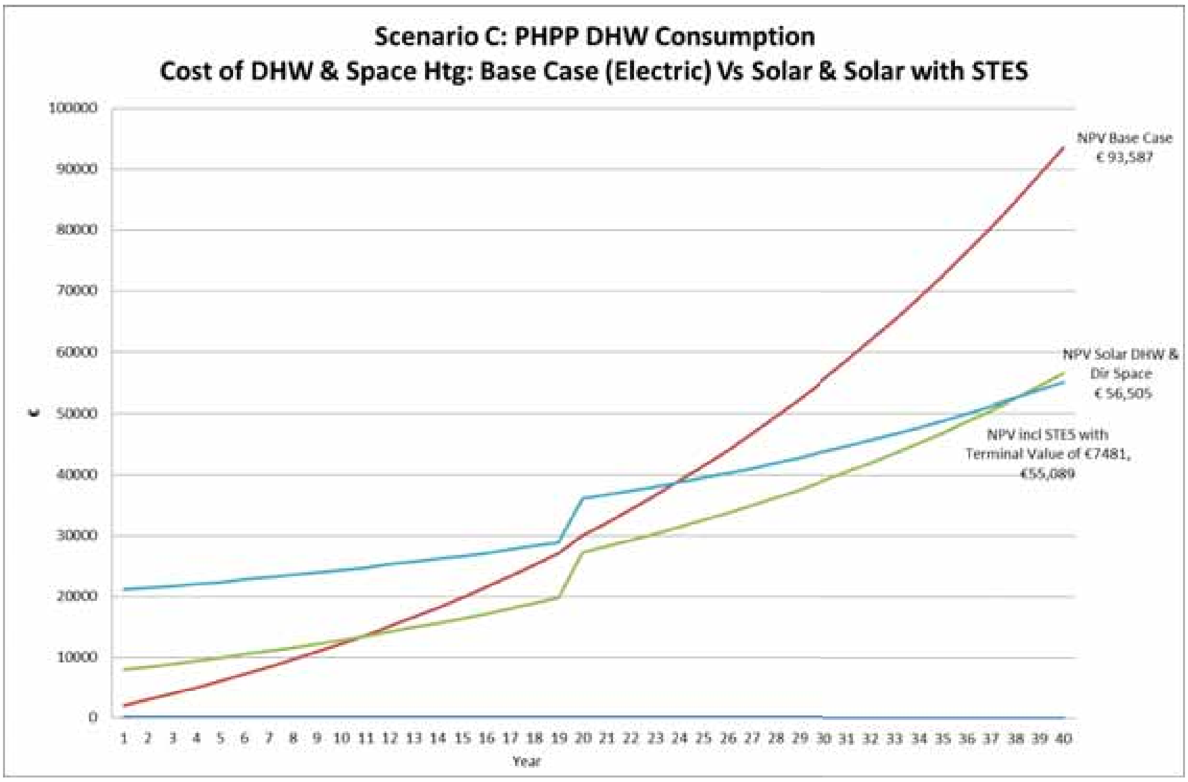

Fig 3. NPV for DHW consumption scenario C

The NPV for the base case is €93,587 reflecting the fact that the DHW consumption is more than 50% higher than the space heating consumption. For this scenario, the next most expensive option is still to use the solar solution excluding the STES, but it is seen that this is only aproximately €1,500 more expensive than the option of using the STES.

The breakeven point for the STES solution in scenario C occurs in year 23. However, given the marginal difference between the solar solutions (i.e. with and without the STES), consideration could also be given to the option of not including the STES. In this case, the breakeven point for the solar heating system is seen to occur in year 10, reflecting the significantly lower capital investment costs of the solar solution excluding the STES.

5. Discussion and conclusion

The LCA demonstrated an economically cost effective argument for solar DHW and direct solar space heating compared to the use of electricity. In addition, the net present value for solar DHW and space heating shows that the use of the STES reduces overall costs when one considers a planning horizon of 40 years.

The financial analysis undertaken using net present values demonstrated that there is a strong case for direct solar space heating compared with the use of electricity with payback for the solar space heating "upgrade" being achieved between year 10 (for high DHW consumption), and in year 19 (in the case of low DHW consumption). Payback periods for the system including the STES reduce from 30 years to 26 years to 23 years as the DHW consumption increases under the three scenarios.

It is important to consider the holistic nature of the solar solution. The high ratio of solar collectors to DHW storage ensures that the DHW solar fraction is exceptionally high, and that significant solar energy is available for use in space heating. However without the use of a STES, stagnation would occur in the solar collectors significantly impacting on the long-term reliability of the solution. Thus even without considering the fact that the long-term business case for the inclusion of the STES is positive, the inclusion of the STES is required for optimal operation.

The analysis has been carried out for a specific installation in Galway, Ireland for which the system costs were detailed and validated by benchmarking against the costs of similar combisystems as reported by the IEA. Further, the financial variables were chosen for the specific company, the country, and the time of the study. All of the above variables are subject to change with a corresponding impact on the financial viability of the specific installation considered. It is noted that while a discount rate of 3% was used, this has been influenced by the low level of building activity and the consequent strategy of generating returns marginally above the rate of inflation. Further work is required to analyse the use of STES with low energy housing for other markets and financial variables.

It is noted that the analysis is based on recorded performance figures from the installed system. Previous publications (Colclough, 2011, Clarke et al, 2013) highlight that the installation carried out by the builder was not optimally designed. The store design eliminated stratification and the pipeline length to and from the thermal store was excessive (18m each way), both of which worked to reduce the efficiency of the STES. In the case of the transfer of heat from the STES to the space heating system, the resultant heat transfer loss of 17.6% has been recorded (Colclough, 2011). In addition, using a Trnsys model of the installation, a further 30% reduction in the fossil fuel derived energy demand could have been achieved by increasing the solar array from 10.6 m² to 20 m² (Clarke et al, 2013). The extra costs associated with doubling the solar array is approximately €3,000 (see table 1). Thus by improved design, the system performance could potentially be increased by approximately 50% for marginal extra financial outlay. It is anticipated that with an increased system performance of 50%, there would be a significantly greater advantage to incorporating a STES than is currently evident from the analysis. In addition, the space heating system utilises direct space heating, (i.e. without the benefit of a diurnal store). It is anticipated that further increases in efficiency could be obtained simply by using a combined DHW and space heating buffer tank. Further work is required to determine the impact of a diurnal store on the performance and financial viability of the installation.

At a policy level, consideration should be given to how best to facilitate citizens in benefitting from the long term benefits of STES in meeting the EU Near Zero Energy Targets. In the same way that Feed in Tariff's have facilitated the PV industry in a number of European countries, governments should consider incentivising STES. This could perhaps be achieved through the use of the Renewable Heat Incentives initiative seen in the UK (anon 2013b). The analysis should be carried out for the UK market, considering the recent introduction of the renewable heat incentive, where the economic argument for the solar DHW and space heating system may be significantly enhanced by the inclusion of the STES.

In conclusion, the analysis shows that, for the specific house under study, the use of a Solar Energy system incorporating an STES for DHW and Space Heating shows financial savings compared with the use of electric heating given the timeframes consistent with the service life of the STES.

6. Acknowledgements

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