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Life-Cycle Cost Analysis of an Installed Multiunit Seasonal Thermal Energy Store

Shane Colclough, Neil J. Hewitt and Philip Griffiths
Centre for Sustainable Technologies, 26 B 16, Ulster University, Newtownabbey, BT37 0QB, Northern Ireland, UK

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Abstract: The financial viability of a solar STES (seasonal thermal energy store) installed in a mixed commercial and residential multiunit development of low-energy buildings located in Lysekil, Sweden, a maritime Scandinavian Climate has been investigated. Using recorded figures for the installation costs and performance, a financial life cycle analysis has been undertaken to determine the cost effectiveness of the system. The time value of money is considered and an LCC (life cycle cost) analysis undertaken to identify the cost-effectiveness of the solution. It shows that while a direct heating and hot water system incorporating STES can be economically viable in a Swedish maritime climate in the long term, assistance such as that provided by government incentives is required to assist with the high capital cost of the initial investment.

Key words: STES, passive house, financial analysis, nZEB, passivhaus, seasonal thermal energy storage, storage, LCC analysis.

1. Introduction and Description of Installation

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. The study of the performance of houses [2] complying with the low energy Passivhaus standard [3] provides an insight into the performance of the now mandated low-energy buildings of the future. A number of studies have documented the performance of the Passivhaus dwelling in various climates [4-7].

The falling prices of solar collectors, allows for additional solar collectors to be added at minimal extra cost thereby significantly increasing the DHW (domestic hot water) and space heating SF (solar fraction) of low-energy buildings, reducing significantly the carbon derived energy demand. Surplus heat generated in summer can be fed to an STES (seasonal thermal energy store) potentially allowing surplus summer heat to be used in the winter [8]. However, while much has been written on large communal STES (e.g. Ref. [9]) and to a lesser extent single dwelling STES, (e.g. Ref. [10]) consideration also needs to be given to STES for small multiuse schemes.

In addition, while papers have focused on the analysis of STES systems in combination with low energy houses through the use of dynamic building simulation software [11-14], a number of which also undertook financial analysis, few examples exist of a financial analysis based on recorded costs and monitored performance of an installation. The approach in Ref. [15] is used in this paper to carry out such an analysis of the financial viability of a space heating and DHW solar thermal installation utilising STES for a multiuse development complying with the Passivhaus standard in a Swedish maritime climate based on the recorded data.

An existing 381 m^2 building "Building 1" comprising four shop units and two bedroom apartments has been renovated to standards approaching the Passive House Enerphit standard. In

Corresponding author: Shane Colclough, Ph.D., research fields: energy storage, passive house and near zero energy buildings.

addition, a new built two-storey 390 m^2 building "Building 2" has been built to the Passive House standard and a 23 m^3 STES installed in its basement.

Space and DHW heating is provided by means of a DH (district heating) system in combination with a solar system. See Fig. 1 for a schematic of the wet heating system.

The 50 m^2 solar array comprises 10 panels of 1.8 m^2 aperture (totalling 18 m^2) of evacuated tube collectors and 16 panels of 2 m^2 aperture (totalling 32 m^2) of flat plate collectors. A 3,300 L buffer tank located in building one is logically divided into two based on thermal stratification considerations. The solar collectors supply heat to the heat exchanger coil in the middle of the buffer tank ("tank 1") or heat exchanger coil at the bottom of the buffertank ("tank 2"). Heat excess to the requirements of the buffer tank is fed to the STES (tank 3) located in the existing basement of building 2.

The location of the STES in the unused and unheated basement of building two reduces the costs typically associated with STES such as excavation costs and the costs associated with protecting the STES from water ingress from the surrounding soil. Further, the space used in the basement is the result of constructing the dwelling on a sloping site. The basement has a varying height from 2.1 m (where the STES is located) to less than 30 cm, in order to provide a level platform for the three-storey building above. Thus there are no additional costs associated with the sitting of the STES. Finally, costs are further reduced by purchasing a previously used tank, leading to a highly cost-effective STES installation.

2. Theory and Approach

2.1 Overview—Life Cycle Cost and Savings Analysis

Life-cycle cost analysis is a tool used to determine the most cost-effective option among different competing alternatives for a project, when each is equally

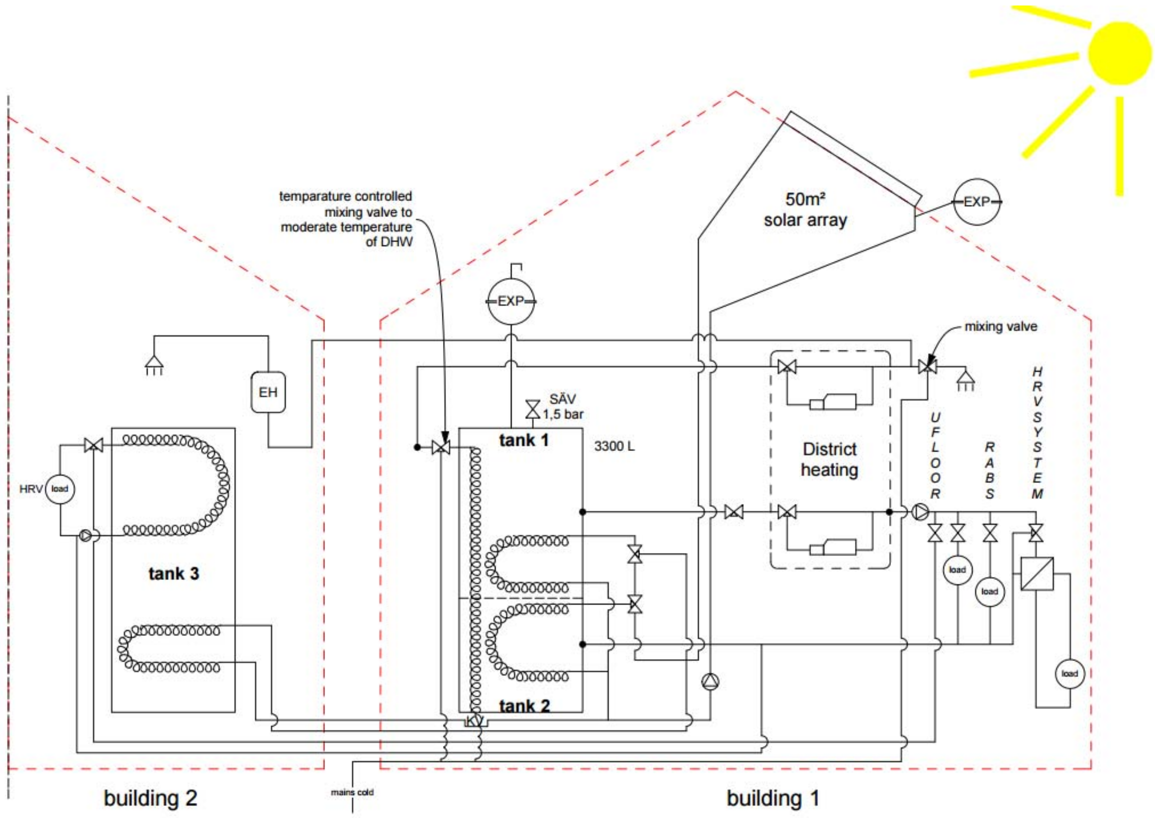

Fig. 1 Schematic of wet heating system.

appropriate to be implemented on technical grounds. All costs are usually discounted and totalled to a present day value known as the NPV (net present value) using a discount factor d, bringing costs to their present day value.

A 40 year period has been chosen for this analysis given the significant capital investment costs required for the STES and the long service life of the STES. The STES is considered to be part of the energy infrastructure of the dwelling in the same way as appropriate orientation, insulation and airtightness. The analysis does not consider the cost of financing the investment, tax incentives or annual corporate tax treatments.

2.2 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. Cost has been allocated for scheduled maintenance 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 with no further investment and that the value of all equipment at the end of the 20 years period is zero. In the case for the installation in Lysekil, the STES tank was purchased second-hand, at a considerable discount compared with the purchase of a similar tank new.

For this reason, it is assumed that the STES tank will also require replacement at the same time as the complete system was overhauled at a cost the same as was initially incurred. In addition, in order to reduce complications in the analysis it is assumed that the combi system will also be required to be replaced within the 20 years period. The approach of replacing all equipment 20 years period is considered a prudent but conservative financial approach.

2.3 Capital Costs

The capital costs are outlined in Table 1. It is assumed that the capital cost of the DH system is zero as a DH space heating system is necessary in order to provide backup for the solar installation in respect of both space heating and DHW. Thus, the capital costs of the installed DH system are eliminated from the solar and DH cost analyses. In addition, it is assumed in the analysis that an existing HRV system and underfloor heating system is available as a heat delivery mechanism and therefore an extra heat transport mechanism is not required.

2.4 Operational Costs

It is assumed that 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 cost is €150 (at today's prices).

In order to estimate the costs involved in an overhaul of the system, a cost equivalent to the full system cost of the DHW and HRV system, including replacement of the solar panels, combisystem tank and STES tank is allocated to year 20, and multiplied by the appropriate inflation conversion and NPV factors, resulting in a cost allocation of €37,652 in year 20. Thereafter, the six yearly maintenance interval continues to be scheduled, with the first scheduled maintenance intervention occurring six years after system overhaul.

The annual running costs in addition to the capital costs are also included. From measurements conducted at the site, it is known that the underfloor/HRV system heating pumps in building 1 consumes 155 kWh of electricity annually and 78 kWh in building 2 in distributing heat from the DH/solar system, and 17 kWh when distributing heat from the STES. The combined 250 kWh is negligible when compared with the 60,839 kWh of energy consumed in heating building 1 and 2 over the period. In addition, the 5,050 kWh electricity used for space heating and DHW heating is also relatively minor. Nonetheless, the energy costs of electricity are considered separate from the energy costs of the DH, and are included in the overall financial analysis.

Table 1 Capital costs for STES installation.

Costs solar seasonal store Kungsgatan Lysekil						(€/Kr rate 9.1 at 15/09/15)
Item	Descr.	Suppl	Price €	No.	Price ea Kr	Tot Kr
Collector vacuum U-tube 1.8 m^2 × 10 = 18 m^2	TZ47/1500-20U011-7S162_R 2,5 liter liquid	Sunking Sept 2011	5,275	10	4,800	48,000
Collector flat plate 2 m^2 × 16 = 32 m^2		Sunking Sept 2011	7,033	16	4,000	64,000
Controller	Steca TR 0603mc	Steca	136	1	1,242	1,242
Pumpstation:	Steca Solar DN25 TPA-25 +TPAF-25+WILO ST25/7	Steca	270	1	2,454	2,454
Flow meter	Steca TA VM1 Flow Meter DS	Steca	229	4	522	2,087
Sensor:	PT 1000		1,099	10	1,000	10,000
VEAB ductheater 0.29 lit in pipe	CWW 160-2-2,5	VEAB	1,582	12	1,200	14,400
Thermostatic regulating valve	Duco mixautomat	EO	44	1	400	400
3-way motorized valve Wege-Motor-Umschaltventil		EO	396	3	1,200	3,600
Expansionvessel solar max 10 bar	80 lit	Sol & energiteknik	151	2	686	1,372
Automatic aeriator valve for top position	LK aut airvent 740	EO	11	1	100	100
Propylenglukol konc.	25 lit	Sol & energiteknik	182	2	828	1,656
Internal tank (tank 1)	3,300 lit w 13 coils × 15 m finned cu-pipes 22 mm Cuporo	Husqvarna tanksvets	7,651	1	69,625	69,625
Labour to install tank 1, culvert, pipes, install solar panels, all inside and out + misc local materials		F&G, EO	12,914	1	117,520	117,520
Labour to install floorheat under old house + 20 mm PEX 60 m		F&G, EO	679	1	6,180	6,180
Cost of seasonal thermal energy store						
Solar flexrohr twin ss insulated pipes	DN20 13 mm insul 2 × 75 mm 25 m + EPDM insul	Foamteam	1,181	50	215	10,750
Labour to install Solar flexrohr twin ss		Åke Häggman, Niklasson	1,152	1	10,480	10,480
Tank 2: Steel tank in basement	23.6 m^3	Emils skrot Norköping April 2013	2,198	1	20,000	20,000
Finned cupper pipes & fittings tank 2		Rinkaby rör	1,138	1	10,358	10,358
Foam insulation of tank 2	150 mm	Ecofoam AB	2,754	1	25,063	25,063
Cupper pipes	from store	Sch Ltd	1,099	1	10,000	10,000
Connection to existing district heating		EO	2,198	1	20,000	20,000
New expasion vessels in attic	2 × 80 lit expansion vessels in attic	EO May 2013	1,538	1	14,000	14,000
Repairs of leaks and new liquid	2013	EO	1,648	1	15,000	15,000
Upgrade to larger circulationpump EC type	Wilo Stratos 25/1-10 Can PN10	LP July 2014	440	1	4,000	4,000
Repairs leaks roof new with new teflon tape	changed part liquid	EO July 2015	879	1	8,000	8,000
Sum:			**€53,878**			**SEK 490,287**

2.5 Treatment of the Time Value of Money

The LCC (life cycle cost) and savings analysis has been carried out with the following financial variables.

Annual discount rate d = 3% (based on the required IRR (internal rate of return) within the company concerned at the time of the analysis).

Annual rate of inflation i = 3%, reflecting the low average rates of inflation experience in Europe [16].

Annual rate of electricity inflation i_e = 7.3% based on the average rate of electricity inflation over the period 1980 to 2016 [17].

3. Results of Financial Analysis

3.1 Building 1

Fig. 2 gives a graphical representation of the NPV of the cost of the DHW and space heating for building 1 over the 40 years period, allowing the break point to be readily obtained.

The overall NPV of the heating cost for building 1 using the DH system option is €389,678 with the cost using the solar installation (in combination with the DH) at €306,520. The base case (i.e. using only DH) clearly is least expensive initially, as no extra expenditure is required. However over the 40 years period, the NPV of the base case is €83,158 (27.1%) higher compared with using the solar installation reflecting the higher DH annual running costs.

Breakeven occurs in year 16, after which the solar heating has a lower net present value than the base case. However, in year 20 the solar equipment has to be replaced. With the extra capital investment (reflecting a replacement of all equipment), breakeven does not occur again until year 26. From year 26, the solar installation has a lower NPV compared with the base case.

It is noted that in this building 1 financial analysis, the extra cost associated with the STES is ignored given that no financial benefit will accrue in respect of heating building 1. It is assumed that while the solar panels and combi system have been designed to provide heat to building 1 and 2, in building 1 analysis, the extra solar heat provided to building 2 has not been considered a benefit. Thus while the costs are reduced

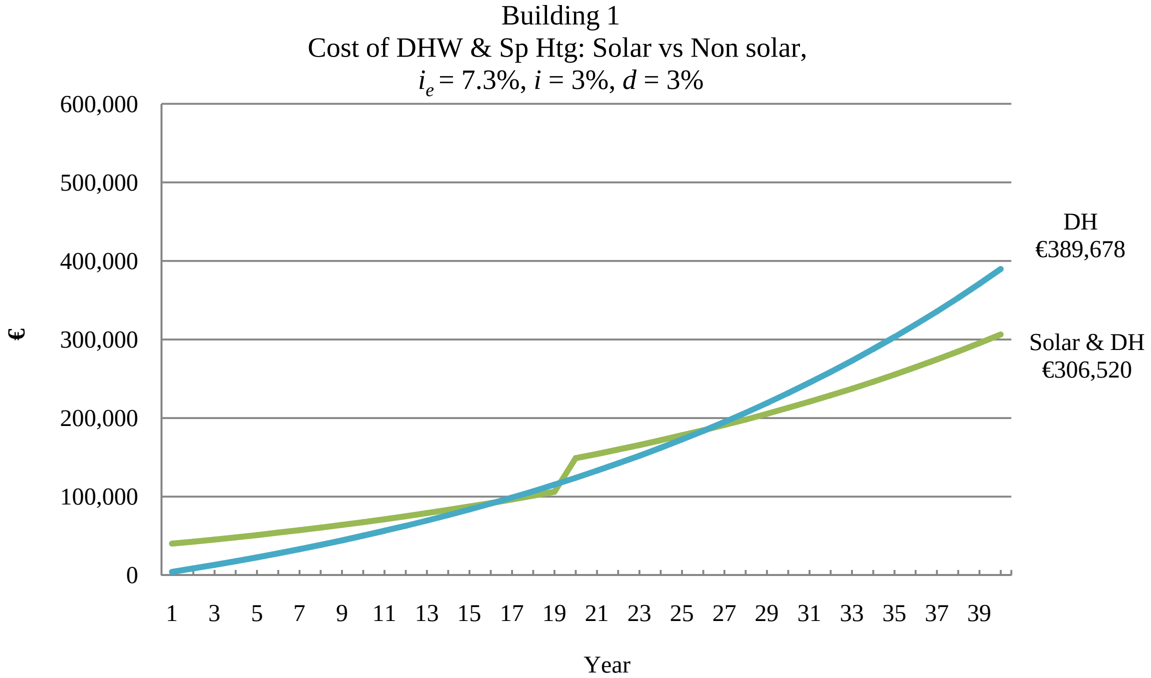

Fig. 2 NPV costs for heating building 1, comparing DH with solar.

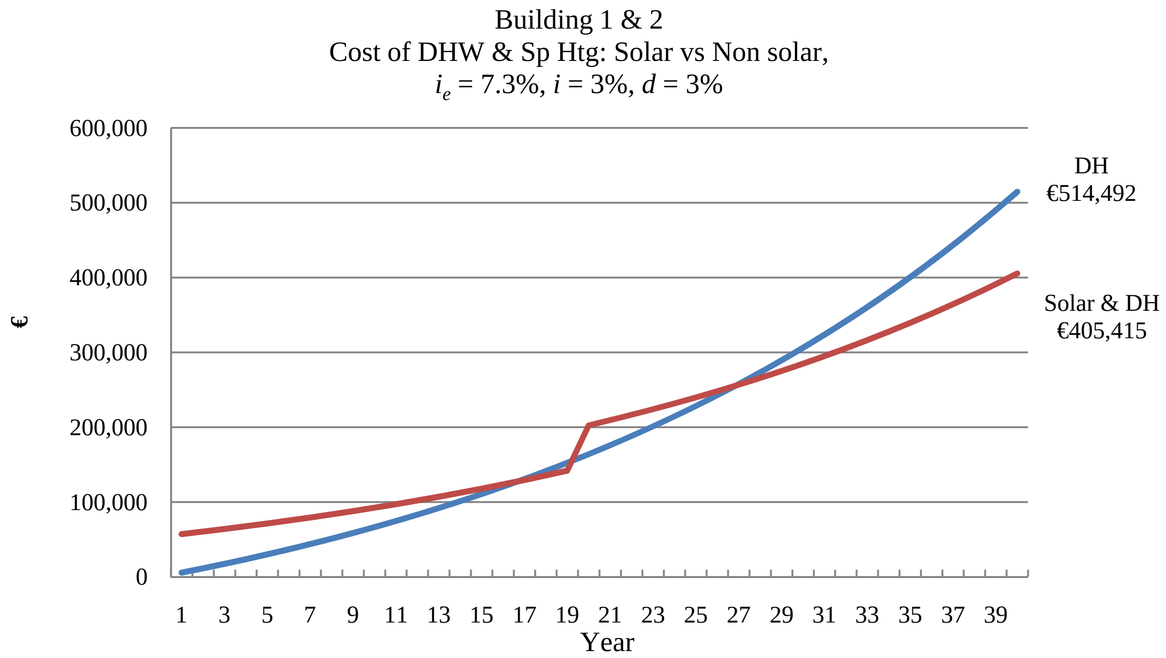

Fig. 3 NPV costs for heating building 1 and 2, comparing DH with solar.

(due to the exclusion of the STES), similarly the benefits of the large solar array are also reduced. This is a necessary shortcoming of this financial analysis in respect of building 1.

3.2 Building 2

Fig. 3 gives the net present value for space heating and DHW for the combined load of building 1 and building 2, incorporating the cost and also the benefit of the STES. It shows that the overall NPV of the cost of heating building 1 and 2 using the DH system option (in combination with electric space heating) is €514,492, while the cost of using solar in combination with DH is €405,415. It is noted that the extra cost of heating building 1 and 2 compared with just heating building 1 with the solar option is only €98,895 (32%), compared with €124,814 (again 32%) in the case of the DH option. While the DH base case is least expensive initially, the NPV of the base case is €109,077 (27%) higher than the NPV for using the solar installation, with breakeven occurring in year 17. This reflects the extra cost associated with the STES after which the solar installation has a lower NPV. Given the extra capital investment in year 20 (reflecting a replacement of all equipment), breakeven occurs again in year 27 after which the solar installation has a lower NPV.

Coincidentally the solar option provides a 27% saving for building 1 (ignoring the STES) and a 27% saving for building 1 and 2 (incorporating the STES).

4. Discussion and Conclusions

The costs of providing the required DHW and space heating for a multiunit development in Lysekil, Sweden are summarised. It is demonstrated that it is possible to provide significant solar space heating cost effectively by integrating an STES and that there is an economic argument for the inclusion of an STES in the long term.

There are both advantages and disadvantages associated with using actual system costs and recorded performance figures for the installation in the analysis of the financial viability of an STES. The approach of grounding the analysis in a real installation provides the benefit of providing real figures in the analysis, rather than figures based on theoretical system modelling. However, the actual installation could be optimized further which would result in a more favorable financial viability. Also, it is noted is that while Fig. 2 gives the costs associated with heating building 1 only, and excludes the STES, the STES is required from a technical perspective to avoid thermal stratification by providing a heat load for the 50 m^2 of solar panels. Because the excess heat can be accommodated by the STES, the SF achieved in building 1 is increased beyond what would be possible without the STES.

In addition, the financial variables used are specific to the peculiarities of the site. A number of specifics are of note. The use of a second-hand STES tank significantly increases the financial viability of the installation. In addition, the relatively high long-term Swedish electricity inflation rate of over 7% also contributes to the viability of the STES, although it should be noted that in recent years the wholesale electricity rate in Sweden has declined. Also of note is the fact that the DH available at the site provides a low-cost means of heating and thus would mitigate against installing anything other than a basic system.

Overall, the specific STES is seen to be financially viable. Further scenarios should be considered as part of a separate paper to examine the impact of the variables for other multiunit STES implementations.

Acknowledgements

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