International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 0748

PROFITABILITY OF VARIOUS ENERGY SUPPLY SYSTEMS WHEN RENOVATING A SINGLE-FAMILY HOUSES IN SWEDEN: CASE STUDY

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ABSTRACT

The majority of single-family houses in Sweden are affected by deteriorations in building envelopes as well as heating, ventilation and air conditioning systems, since they are about 30 years old. Theses house are therefore in need of extensive renovation, which provides an excellent opportunity to incorporate energy efficiency measures to reduce both the energy consumption and also operational. Although former studies analyzed the cost effectiveness of various renovation packages, they mainly excluded the evaluation of energy price implications on cost effectiveness of different renovation package in Sweden. Accordingly, this study considers three energy prices and quantifies the payback period (PBP) and internal rate of return (IRR) of the packages, when renovating a single-family house in Sweden. The renovation packages included three distinct energy supply systems, commonly installed when implementing energy renovations: ground source heat pump (GSHP), photovoltaic solar panels (PV), and an integrated GSHP and PV system. The analyses of results show that a the GSHP system provides higher IRR and the lowest PBP compared to the other two renovation packages, due to its high performance in reducing energy consumption and its relatively low investment cost. Furthermore, results show that raising the energy price can increase the IRR and reduce the PBP of the renovation packages and respectively. Moreover, increasing the interest rate adds on PBP of renovation packages, since it depreciates the cost for saved energy.

Keywords: single-family house, energy renovation, energy simulations, payback period, internal rate of return

1. INTRODUCTION

Single-family houses account for more than 50% of the total building stock in Sweden [1] and are responsible for 12% of the total final energy [2]. According to the Swedish Statistics Central Bureau (SCB), 86% of these houses are about 30 years old, from which 50% of them use electricity to support heating demands [3]. Moreover, technical installations of the single-family houses and insulation layers of their building envelopes are likely to be close to the end of their expected life cycle [4]. According, these houses are in need of considerable renovations, which provides an excellent opportunity to incorporate energy efficiency measures to both improve the energy performance of the single-family house and their operational costs.

Implementing energy renovation should be based on several considerations. The first consideration is related to the national goals for energy use in buildings in Sweden. The Swedish Government has set a target of a 50% reduction in total energy use per heated floor area by 2030, compared to the level in the reference year 1995[1] [5]. The total energy consumption refers to the energy need for supporting space heating, space cooling,

[1] In 1995, the energy need for space heating and domestic hot water was about 95 (kWh/m^2) [6], while the electricity demand for operating mechanical systems in single-family houses was 43 (kWh/m^2) respectively [7]. It was assumed that single-family houses in Sweden had no cooling demand in 1995.

domestic hot water and electricity need for operating mechanical systems. The abovementioned target has led to more demanding requirements in Swedish building regulations, both for new constructions and renovations of existing buildings [8]. The second consideration concentrates on the cost of such a renovation for the house owner. Energy renovations require high cost investments, setting a great challenge for house owners [9]. Financing such a renovation often involves taking out a loan, which will only be granted if the renovation increases the value of the property or reduces operational costs to offset the interest costs of the loan. The value of property in Sweden is highly dependent on the location of the property, and thus the loan solution it cannot be broadly applicable. In such a case, house owners need to prioritize the adoption of energy efficiency measures that will allow them to save a serious amount of energy and minimize the operational costs.

This study proposed three packages for the renovation of an existing single-family house in Växjö municipality in Sweden and quantifies the payback period (PBP) and internal rate of return (IRR) of the packages. The PBP corresponds to the time, in which-for a given discount rate- the investment cost will be repaid [10]. As house owners prefer investments with a low risk exposure [11], a short PBP is more preferable. On the other hand, IRR represents the interest rate, which- for a given time- can be acquired from the investment [12]. A high IRR signifies the profitability of an investment. The evaluation of the PBP and IRR assists for projecting energy efficiency policies, while helping house owners to be more aware of the outcomes of the investments they decide to make.

2. METHODS

The single-family house was built in 1979 and located in Växjö municipality in Sweden. It had a total heated area of 140 m^2 with ventilated volume of about 350 m^3. Table 1 presents the thermal specifications of the single-family house, furthermore it shows different characteristics of its heating, cooling and ventilation system. EnergyPlus simulation tool (8.5.0) was used to evaluate the energy performance of the house. The initial heating system was an electrical boiler, which was connected to water-based underfloor and radiator distribution systems.

Table 1. The characteristics of the detached house

U-value of external walls	0.25 (W/m². K)
U-value of attic roof	0.08 (W/m². K)
U-value of external floor	0.27 (W/m². K)
U-value of external windows	1 (W/m². K)
Airtightness at a pressure of ±50 Pa	1.6 (l/s.m²)
The temperature set point of the heat distribution system (water-based radiators)	60 ºC
The occupancy schedule	16h during working days and 24h during weekends
Operative temperature	18º -22º C
Air flow rate	±0.35 l/m²
The efficiency of the supply fan	70%
The efficiency of the heat recovery system	75%

The renovation packages included three distinct energy supply systems, commonly installed when implementing energy renovations. The first package considers installation of a ground source heat pump (GSHP) with a COP of 3 and total power of 4W. The second package includes installation of photovoltaic (PV) panels. In total 31 PV panels, with a total area of 43.7 m^2 were installed on the south-sloping roof with 45° tilt toward south. Each PV panel had a power output of 285 W [13]. The third renovation package comprises an integrated GSHP and PV system (GSHP-PV). Table 2 presents the renovation packages and their respective lifespan.

Table 2. Renovation packages

Packages	Description	Lifespan
1	Installing a ground source heat pump	20 Y
2	Installing photovoltaic (PV) panels	20 Y
3	Installing a ground source heat pump along with photovoltaic panels	15 Y

The IRR and PBP were quantified using equations 1, and 3. The IRR is the interest rate of "i", which for a given lifespan of "t", the preset value (PV) is zero. While PBP is the lifespan of "t", which for a given interest rate of "i", makes PV zero.

$$\mathrm{PV} = \sum_{t=0}^{n} (\mathrm{D'}_t) * \frac{1}{(1+\mathrm{r})^{\mathrm{t}}} - (\mathrm{I} + \mathrm{U}) \qquad \text{Eq. 1}$$

$$\mathrm{D'}_t = (\mathrm{E}_0 - \mathrm{E}_t) * \alpha(1+\beta)^{\mathrm{t}} \qquad \text{Eq. 2}$$

Where;
NPV is the net present value during lifespan of n year;
D'_t is annual energy saving cost;
E_0 is the initial total energy consumption before renovations;
E_t is the total energy consumption after renovations;
R is interest rate;

t is lifespan of n years;
α is energy price per kwh/m²;
β is inflation in energy price (%);
I_0 is the investment cost;
U is the maintenance cost;

The IRR was calculated for lifespans of 30 and 50 years. Furthermore, in quantifying PBP, interest rates of 1%, 3%, and 5% were considered. These decisions were made to analyze the implication of lifespan and interest rate on IRR and PBP respectively. In addition, three different energy prices were considered when calculating IRR and PBP (Table 3). The first and second scenarios represent the lowest and highest energy prices among European countries, while the third one is the energy price in Sweden.

Table 3. Energy price

Scenario	Energy price for electricity
1*[14]	1.05 (SEK/kWh)
2*[14]	2.9 (SEK/kWh)
3*[14]	1.54 (SEK/kWh)

*Including tax and levies

Table 4 presents the investment, maintenance, installation and labor cost of three renovation packages. In calculating IRR and PBP, the energy supply systems were replaced when they reached to the end of their lifespan.

Table 3. Investment and maintenance costs of renovation packages

Packages	Investment	Maintenance	Installation and labor
1[15]	6000 (SEK/kW)	150 (SEK/ kW.Y)	24000(SEK/kW)
2*[13]	19000 (SEK/kW)	342 (SEK/ kW.Y)	3800(SEK/kW)
3*[13,1 5]	25000(SEK/kW)	492 (SEK/ kW.Y)	27800(SEK/kW)

*Including 30% tax deduction

3. RESULTS

The total energy consumption of the single-family house in initial condition was about 109 kWh/m^2, from which space heating and cooling consumptions were responsible for about 58% and 8%, while the ventilation system and domestic hot water shared about 13% and 21% of the total energy consumption. The renovation packages allowed satisfying the national target in reducing the total energy consumption by 50%. The analyses of results show that the GSHP-PV system had the highest energy performance, as it reduced the total energy consumption by about 99.8%. While the GSHP and PV systems cut the total energy consumption by about 61.5% and 42%.

Figure 1 shows the IRR, obtained for three renovation packages with three different energy prices and lifespans of 30 and 50 years. The analyses of results show that increase in energy price augmented the IRR among renovation packages. With an energy price of 1.05 (SEK/ kWh) and lifespan was 30 years, none of renovation packages were profitable, accordingly these packages loss value at their respective IRR. Because when energy price is low, the investment cost of renovation packages outweighed the cost for saved energy. However, with a lifespan of 50 years GSHP yielded financial gain due to its performance in reducing total energy consumption and its relatively low investment cost. The investment cost of GSHP was about 70% and 41% of the investment cost required for installing PV and GSHP-PV systems respectively.

With an energy price of 1.54 (SEK/kWh) and lifespan of 30 years, only GSHP and GSHP-PV systems were profitable renovation packages, while with a lifespan of 50 years all renovation packages yielded financial gain. In can be included that GSHP was the most profitable renovation solution, since it provided value at highest IRR.

With an energy cost of 2.9 (SEK/ kWh) and lifespans of 30 and 50 years, all renovation packages yielded profits. However, GSHP was still most financial rewarding renovation package. Furthermore, the analyses of results show that increase in energy price can augment the profitability of the renovation packages. Because, a higher energy price adds on cost for saved energy and thereby eases the effect of investment cost on profitability of the renovation packages.

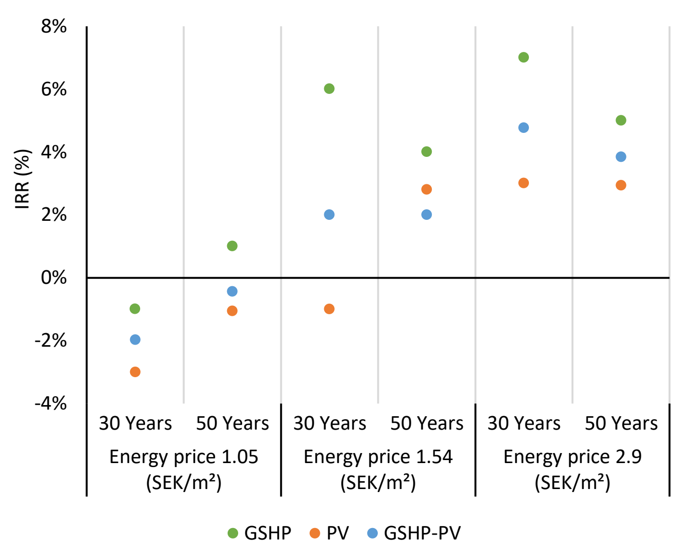

Fig 1. IRR among renovation packages

Figure 2 shows the PBP, calculated for three renovation packages with interest rates of 1%, 3%, and 6% along with three different energy prices. With an energy cost of 1.05 (SEK/ kWh) and interest rates of 1% and 3%, the investment cost for installing GSHP was repaid, while the investment costs for installing other renovation packages will never be returned. This occurs due to high investment costs of PV and GSHP-PV system, as they exceed the cost for saved energy. Accordingly, the PV and GSHP-PV system can be considered as unprofitable renovation packages in terms of economic benefits.

With an energy price of 1.54 (SEK/ kWh) and interest rates of 1%, 3%, and 5%, the investment cost for installing the GSHP was repaid, however its PBP was raised by increasing the interest rates. Because, a great interest rate depreciates the cost for saved energy over the lifespan, thereby it added on PBP. Furthermore, with an energy cost of 1.54 (SEK/ kWh) and interest rate of 1%, the investment cost of GSHP-PV system was repaid, while the investment cost of PV system will never be returned. Because, the high investment costs of GSHP-PV and PV systems outweighed the cost for saved energy.

With an energy cost of 2.9 (SEK/kWh), the investment costs of GSHP and GSHP-PV systems were repaid. But, when the interest rate is lowered from 5% to 1% and 5% to 3%, the PBP of GSHP is decreased by 29% and 18% respectively. Similarly, when the interest rate is declined from 5% to 1% and 5% to 3%, the PBP of GSHP-PV is lessened by 54% and 40%. Considering the PV system, its investment cost was returned only when interest rate is 1%.

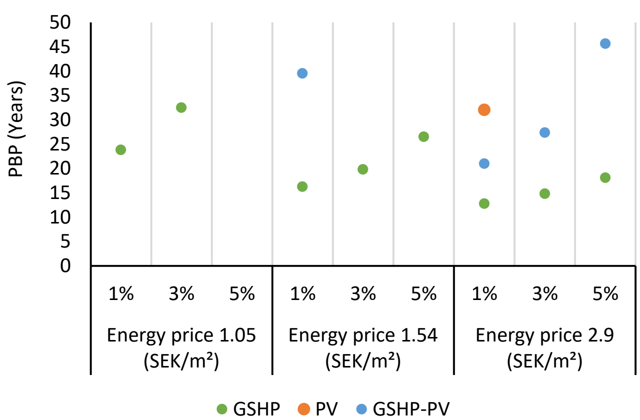

Fig 2. PBP among renovation packages

4. CONCLUSIONS

An ambitious target was set in Sweden, which binds the country to reduce the total energy consumption by 50% compared to 1995. At this point, one or two-family houses play a great role, since they are responsible for for 12% of the total final energy consumption in Sweden. Although, several attempts were made to improve the energy performance of these houses, the majority of them are in need for energy renovation. However, the high investment costs for implementing energy renovations can be considered as a great challenge for house owners. The latest statement shows the necessity of evaluating the cost effectiveness of various energy renovation packages, when renovating a single-family house. Accordingly, this study quantifies the internal rate of return (IRR) and the payback period (PBP) of three renovation packages, proposed for the renovation of an existing single-family house in Växjö municipality in Sweden. The first renovation package included the installation of a ground source heat pump (GSHP), while the second and third packages comprised the installation of photovoltaic panels (PV system) and mounting an integrated GSHP and PV system (GSHP-PV) respectively.

The IRR was calculated for lifespans of 30 and 50 years, while the PBP was obtained for a lifespan of 50 years and interest rates of 1%, 3% and 5%. Furthermore, three different energy prices were considered when quantifying IRR and PBP.

The analyses of results show that GSHP provides higher IRR, accordingly it yields highest value during the lifespan of the house, when compared to other renovation packages. This occurs due to high performance of GSHP in reducing total energy consumption and its relatively low investment cost. Furthermore, the results show that raising the energy cost can increase the IRR of the renovation packages, because it adds on cost for saved energy and thereby offset the investment costs.

Comparably, the GSHP provides the lowest PBP, when compared with PV and GSHP-PV systems. In addition, the results show that increasing interest rate adds on PBP of renovation packages, since it depreciates the cost for saved energy. In contrary, increasing the energy price can ease the investment cost of renovation package more effectively, thereby it reduces the PBP.

The results presented can use as an aid when adopting energy efficiency policies to advance the implementation of energy renovations. The future work quantifies the IRR and PBP by expanding the renovation packages and including the replacement of windows and insulation layers of building envelopes. Furthermore, the implications of different Swedish climate zones on IRR and PBP will be analyzed.

ACKNOWLEDGEMENT

This study is part of ProWOOD PhD program, financed by Knowledge Foundation. The authors appreciate their contributions.

REFERENCES

[1] Swedish Energy Agency, 2015b. Summary of energy statistics for dwellings and non-residential premises for 2014 (1654-7543). Retrieved from www.energimyndigheten.se

[2] Swedish Energy Agency, 2017. Energy Statistics for one- and two-dwelling buildings in 2016, ES 2001-2017:06

[3] Sköldberg, H. and Ryden, B., 2014. The heating market in Sweden-an overall view. Sverige Värmemarknad.

[4] Boverket, 2010. Teknisk status i den svenska bebyggelsen – resultat från projektet BETSI (The technical status of the existing building stock – results from the BETSI project)

[5] M.Sahlin, 2005. Nationellt program för energieffektivisering och energismart byggande [National Programme for Energy Efficiency and Energy-Smart Construction, in Swedish]. Government letter, 6, p. 145

[6] Janson, U., *Passive Houses in Sweden. From Design to Evaluation of Four Demonstration Projects*, R. EBD-T--10/12, Editor. 2010, Division of Energy and Building Design, Department of Architecture and Built Environment: Lund, Sweden. p. 390

[7] Swedish Energy Agancy, *Energy Situation [Title in Swedish: Energiläget]*. 2017: Bromma, Sweden. p. 1-86.

[8] Boverket, 2018. BBR 26 (Building regulation version 26), in: Boverket (Ed.), Boverket, www.boverket.se

[9] Bjørneboe, M.G., Svendsen, S. and Heller, A., 2018. Initiatives for the energy renovation of single-family houses in Denmark evaluated on the basis of barriers and motivators. Energy and Buildings, 167, pp.347-358.

[10] Amstalden, R.W., Kost, M., Nathani, C. and Imboden, D.M., 2007. Economic potential of energy-efficient retrofitting in the Swiss residential building sector: The effects of policy instruments and energy price expectations. Energy policy, 35(3), pp.1819-1829.

[11] Friedman, C., Becker, N. and Erell, E., 2018. Retrofitting residential building envelopes for energy efficiency: motivations of individual homeowners in Israel. Journal of environmental planning and management, 61(10), pp.1805-1827.

[12] Fowlie, M., Greenstone, M. and Wolfram, C., 2018. Do energy efficiency investments deliver? Evidence from the weatherization assistance program. The Quarterly Journal of Economics, 133(3), pp.1597-1644.

[13]Solhybrid. 2018 [cited Accessed agugust 2018; Available from: http://www.solhybrid.se/.

[14]Eurostat. 2019; Available from: http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do, [Accessed April 2019.[

[15] R. Fedrizzi, et al. *iNSPiRe – Retrofit Solutions Database –Target Building Simulations*. Available from: http://inspirefp7.eu/retrofit-solutions-database/target-building-simulations/.