# Renovation of Swedish single-family houses from the 1960s and 1970s to net-zero energy buildings – Case study

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**Abstract**

This paper evaluates whether a net-zero energy building (NZEB) can be attained by implementing on-site renewable electricity production when renovating to Passive House level. The assessment is based on the Swedish single-family housing stock constructed between 1961 and 1980, using two case study houses and three locations. Specific conditions of the houses, such as the type of heat generation and available roof area for installation of a photovoltaic system, determine whether a NZEB renovation is possible. Overall, the assessment showed that it is not cost-effective to aim for NZEB when implementing a PV system, based on the alternatives in this study.

*Keywords: energy renovation, NZEB, single-family houses, renewable energy*

## 1. Introduction

Single-family houses (SFHs) constructed between 1961 and 1980 account for approximately one-third of the total energy use, 31 TWh, for space heating and domestic hot water (DHW) in Swedish SFHs. These houses account for about 40 percent of the total energy use in buildings (Swedish Energy Agency, 2015b). There are roughly 715,000 houses from this period (Statistics Sweden, 2015) and they are largely homogeneous in technical terms, with low levels of thermal insulation, and ventilation with heat recovery is rare (Boverket, 2010a). The average energy use for houses from this period is about 40 percent higher than SFHs constructed between 2011 and 2013 (Swedish Energy Agency, 2015a). Many of these houses need to be renovated (Boverket, 2010b), providing an excellent opportunity to incorporate energy efficiency measures, to reduce both operational cost and greenhouse gas emissions related to energy use. A continuation of this is to also implement local renewable energy production to further reduce energy use.

National and international goals for a sustainable future are part of the overall objective to reduce greenhouse gas emissions and mitigate global warming and climate change (European Commission, 2011, SOU, 2016). The Swedish Government has set a target of a 50 percent reduction in total energy use per heated floor area by 2050, compared to the level in the reference year 1995 (Sahlin, 2006). Because of limitations in existing buildings, such as limited space, economic considerations, or preserving cultural heritage values, a 50 percent reduction of energy use is not possible in all buildings. To compensate for this, energy use must be reduced by more than 50 percent in some buildings to achieve an average of 50 percent energy use reduction. One way to achieve this is to renovate existing buildings to net-zero energy buildings (NZEB) whenever possible.

The purpose of this study was to determine whether a net-zero energy building (NZEB) could be attained for SFHs from 1960s and 1970s by implementing on-site renewable electricity production when implementing an extensive renovation package to Passive House level, based on the Swedish Passive House standard, FEBY 12 (Erlandsson et al., 2012).


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## 2. Method

A photovoltaics (PV) system for local renewable electricity production was installed on two reference houses to ascertain the viability of a NZEB renovation. The assessment involved comparing the electricity production from the PV system to the energy demand of the buildings after implementing extensive renovation packages to Passive House level. The reference houses were evaluated in three different locations in Sweden – from Malmö in the south (55.52 N, 13.37 E) to Kiruna in the north (67.82 N, 20.33 E).

When the Passive House standard is applied, thermal transmission and ventilation losses are reduced by about 70 percent (Ekström and Blomsterberg, 2016). The renovation measures used to achieve the Passive House level renovation are presented in Table 1. Based on the type of heat generation commonly used in Swedish SFHs from this period, the reference houses were evaluated with two alternatives: electric heating and a ground source heat pump. Non-electric heating such as pellets and district heating were excluded because of their reliance on other energy sources. Three locations were chosen to determine whether the difference in solar radiation and ambient conditions, such as temperature, impacted the possibility of achieving NZEB. These locations were Malmö in the south, Östersund located in central Sweden, and Kiruna in the north.

**Table 1. Description of the Passive House renovation level with renovation measures and the required performance level.**

| Renovation level | | Passive House |
|---|---|---|
| Building envelope | Facades | New |
| | External walls | 0.10 ±0.02 W/(m²·K) |
| | Roof | 0.10 ±0.02 W/(m²·K) |
| | Foundation | Improved, see Table 3 |
| | Cellar walls | +200 mm thermal insulation |
| | Windows | 0.80 W/(m²·K) |
| | Doors | 0.80 W/(m²·K) |
| | Thermal bridges | Calculated |
| | Airtightness, at ± 50 Pa | 0.3 l/(s·m²) |
| | Drainage | New |
| Installations | Ventilation system | Balanced, with heat recovery |
| | Ducts | New air ducts |
| | Heating system | New, depends on heat generation used |
| | Heat generation | New, depends on evaluated heat generation |
| DHW | Heater | New |
| | Pipes | New |
| | Fixtures | New |
| - | Household purpose electricity | Not included, new energy efficient appliances and lighting assumed |

Two case study buildings represented the SFH building stock from the period (Table 2). These houses were used in earlier studies of energy savings potential (Ekström and Blomsterberg, 2016) and cost-effectiveness (Ekström et al., 2017) of renovations aimed at reaching Passive House level. More detailed information about the renovation measures can be found in those papers. The impact of renovation measures on the building envelope of the reference houses is shown in Table 3.

**Table 2. Description and visualization for the two case study buildings before renovation.**

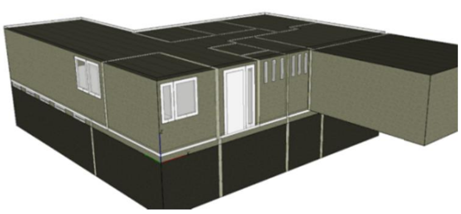
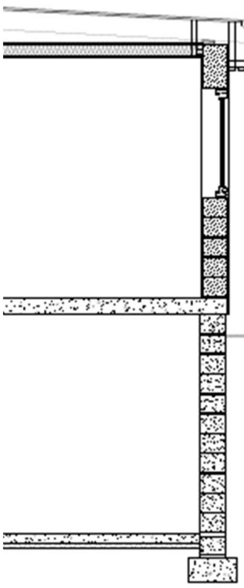
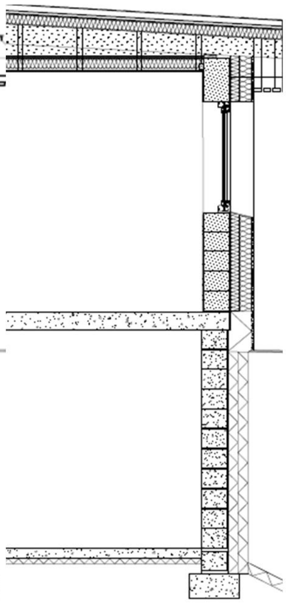
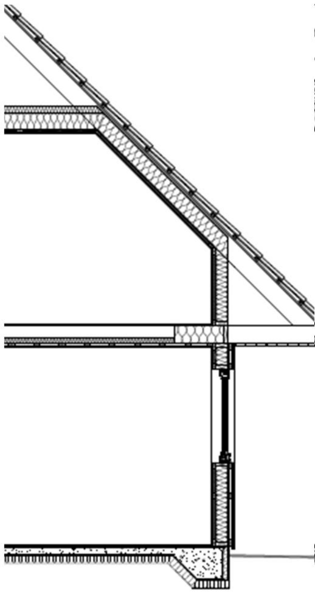
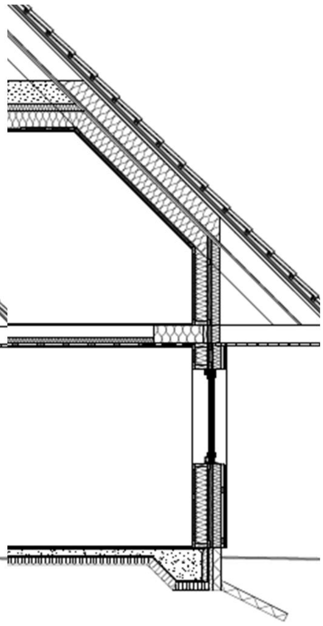
| | | |
|---|---|---|
| **Reference house 1** | |  |
| Year built: | 1965 | |
| Roof area: | 169 m², inclination < 5 ° | |
| $A_{temp}$: | 230 $m^2$ | |
| Ventilation: | Passive stack ventilation | |
| Description: One-storey house with a cellar and a pent roof, lightweight concrete walls and a concrete slab foundation. | | |
| **Reference house 2** | |  |
| Year built: | 1977 | |
| Roof area: | 80 m² + 80 m², inclination 45 ° | |
| $A_{temp}$: | 142 $m^2$ | |
| Ventilation: | Balanced ventilation, with heat recovery | |
| Description: One-and-a-half storey house with a ridged roof, 45°, wood frame structure walls insulated with mineral wool and a concrete slab foundation. | | |

**Table 3. Section drawings of the reference houses before and after implementing the passive house renovation packages.**

| Reference house 1 | | Reference house 2 | |
|---|---|---|---|
| **Before renovation** | **After renovation** | **Before renovation** | **After renovation** |
|  |  |  |  |

The building simulations include detailed models of the reference houses, with zones for each room. A specific building model was used for each alternative in the assessment. The input data regarding structures, thermal transmittance, airtightness, inhabitants, internal heat gains and shading was gathered from and prioritised as follows: 1) specific data for reference house; 2) Passive House requirements (Erlandsson et al., 2012); and 3) Sveby (Levin, 2012) was used for normalised user-related input data. The reference houses were assumed to be inhabited by two adults and two children. Weather data files included in the building energy simulation program (*IDA ICE 4.7*) from *SMHI (Swedish Meteorological and Hydrological Institute)*, with long-term measurements of climate and weather, were used for each location in the simulations. In Swedish conditions cooling is not commonly used in residential buildings, so is excluded from the analysis.

On-site production of renewable energy was evaluated by simulating the performance of the PV system, to ascertain whether it could cover the annual energy demand of the houses. A validated dynamic building energy simulation tool, *IDA ICE 4.7* (EQUA, 2016) was used to simulate energy demand, and the simulation program *SAM 2017.1.17* (NREL, 2017) was used to simulate the production from the PV system. The nominal efficiency of the PV panels was assumed to be 20.6 percent and an expected service life of 25 years (Lindahl, 2014), with a temperature coefficient of -0.3 percent per degree increase and an inverter with a maximum conversion efficiency of 96 percent. The PV panels were placed with the same tilt as the existing roof. The simulations used hourly values to compare self-consumption of the electricity from the PV system. The definition and equation for calculating the self-consumption, or solar fraction, used in this study is presented in equation (1):

$$\text{Solar fraction (\%)} = \frac{\text{energy from PV to load}}{\text{energy load}} \quad (1)$$

The total energy demand that production from the PV system needs to cover is the demand for household electricity, space heating, domestic hot water and facility electricity. The demand for household electricity is based on the annual average use in Swedish SFHs, 5900 kWh, and the domestic hot water demand is based on the normalised annual use in Swedish SFHs of 20 kWh per heated floor area, Sveby (Levin, 2012). The energy demand for space heating and facility electricity was simulated in *IDA ICE 4.7* for the specific case study buildings at the different locations and with the different types of heat generation. The assumed variation in the domestic hot water demand for the evaluation is presented in Figure 1 and Figure 2. Variation in household electricity demand was assumed as shown in Figure 3 and Figure 4.

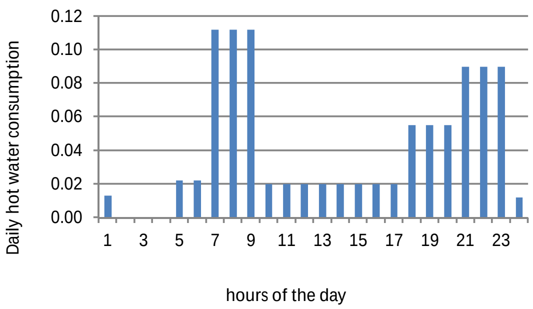



**Figure 1. Daily variation of DHW consumption based on a simplification (Bernardo et al., 2012).**

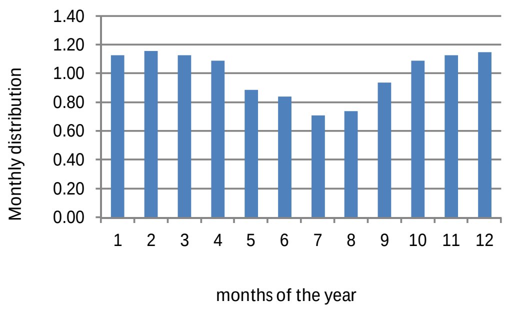



**Figure 2. Annual variation of DHW consumption based on FEBY12 (Erlandsson et al., 2012).**

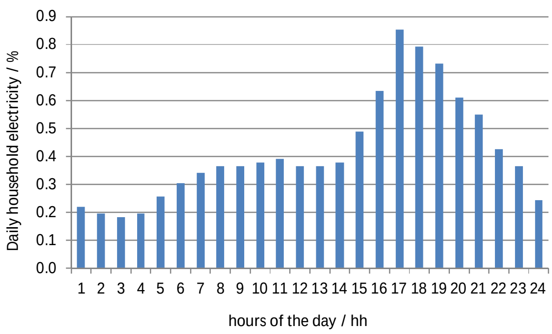



**Figure 3. Assumed daily profile for household electricity use based on measurements of Swedish passive houses. This is not included in specific energy use (Nilsson and Westberg, 2012).**

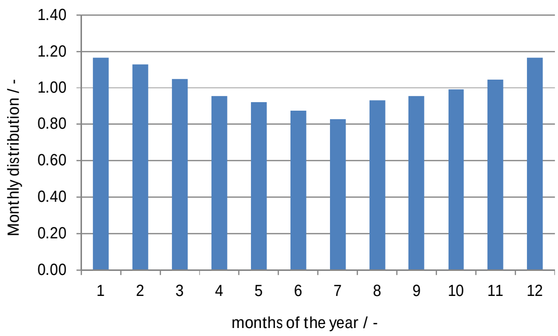



**Figure 4. Assumed yearly distribution of household electricity use based on measurements of Swedish passive houses (Nilsson and Westberg, 2012).**

The economic analysis, using the software *"Investment calculation for photovoltaics"* (Stridh, 2016), calculated the life cycle cost as net present value and internal rate of return. The investment cost of the system is based on the average prices, €1850 per installed kWp including VAT, presented in the software. A Government grant is available for installation of a PV system on a SFH, covering 20 percent of the investment costs (Svensk författningssamling 2016:900, 2009), which was included in the economic calculation. It was assumed that a loan was taken to cover the investment cost. The interest rate of the loan was assumed to be two percent higher than inflation, so the real interest rate used in the calculations of net present value was two percent.

The total price per kWh for bought electricity in Sweden is based on several parameters. In addition to the electricity price, there is also the grid service price, electricity certificate (Swedish Energy Agency, 2016), electricity tax (Swedish Tax Agency, 2017) plus VAT. The fixed fees were not included since they do not change with the energy demand, so they are not impacted by the reduced energy use from the renovation measures.

To determine the electricity price, information was gathered regarding average annual grid service price per kWh and monthly electricity prices per kWh for the variable price rate for SFHs (Statistics Sweden, 2017). The average electricity price depends on the electricity demand of the house – if the heat generation is based on electricity, electricity demand is higher and price per kWh lower, and if non-electric heat generation is used, electricity demand is lower and price per kWh higher. Only houses using electric heating were included in this study, so only electricity prices for such houses were included. Average electricity prices are about €0.13 per bought kWh for houses using electric heating (Figure 5). The price increase above inflation was assumed to zero.

The selling price for electricity sold to the grid, presented in Figure 6, was estimated based on the average price of €0.05 per kWh in *"Investment calculation for photovoltaics"*. Also included is the electricity certificate of €0.013, compensation for the grid owner of €0.005, certificate of origin of €0.0005, and a tax subsidy of €0.06 available for the first 15 years of production. All costs were estimated in Swedish Crowns (SEK) and converted to Euro (€) with a conversion rate of SEK 10 for €1.

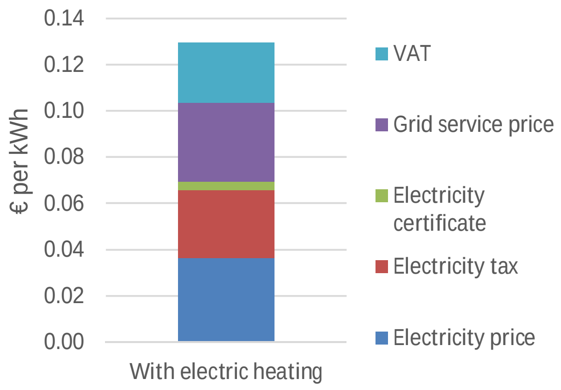



**Figure 5. Average annual price for electricity bought from the grid for houses using electricity for heat generation.**

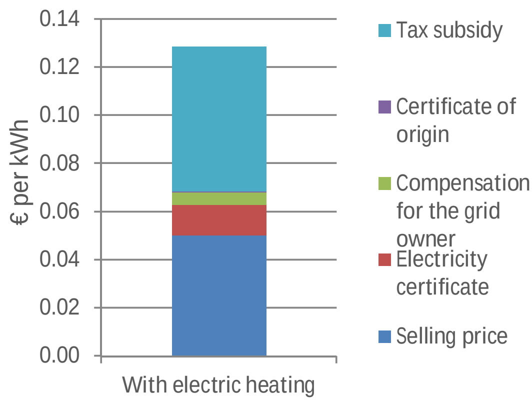



**Figure 6. Average annual price for electricity sold to the grid for houses using electricity for heat generation.**

## 3. Results and discussion

Results are presented, in Table 4 for Reference house 1 and in Table 5 for Reference house 2, as annual electricity demand (including space heating, domestic hot water, facility electricity and household electricity), annual electricity production from the PV system and self-consumption, based on the hourly demand and production. The aim was for the annual electricity production to equal that of the energy demand, to attain the NZEB level. The results are shown per location and type of heat generation. Also presented are the system size and the peak power of the evaluated systems. Alternatives presented in red do not attain the NZEB level.

**Table 4. Results from simulation of the PV system production for Reference house 1 with roof tilt of < 5 degrees. Alternatives presented in red do not attain the NZEB level.**

| Heat generation | Location | PV system size m² | Peak power kWp | Annual demand kWh | Annual production kWh | Self-consumption % |
|---|---|---|---|---|---|---|
| Electric heating | Malmö | 114* | 23.5 | 18 400 | 19 000 | 31.1 |
| | Östersund | 114* | 23.5 | 25 400 | 16 900 | 25.0 |
| | Kiruna | 114* | 23.5 | 30 600 | 14 200 | 21.3 |
| Ground source heat pump | Malmö | 65 | 13.4 | 10 200 | 10 900 | 34.6 |
| | Östersund | 90 | 18.4 | 12 600 | 13 200 | 30.1 |
| | Kiruna | 114* | 23.5 | 14 900 | 14 200 | 25.4 |

*Maximum available roof area.

**Table 5. Results from simulation of the PV system production for Reference house 2 with roof tilt of 45 degrees and east-west orientation. Alternatives presented in red do not attain the NZEB level.**

| Heat generation | Location | PV system size m² | Peak power kWp | Annual demand kWh | Annual production kWh | Self-consumption % |
|---|---|---|---|---|---|---|
| Electric heating | Malmö | 90 | 18.4 | 12 800 | 13 200 | 33.1 |
| | Östersund | 131 | 26.8 | 16 100 | 17 000 | 29.0 |
| | Kiruna | 163* | 33.5 | 18 700 | 18 000 | 26.3 |
| Ground source heat pump | Malmö | 57 | 11.7 | 8 600 | 8 700 | 35.9 |
| | Östersund | 82 | 16.8 | 9 800 | 10 700 | 32.8 |
| | Kiruna | 98 | 20.1 | 10 800 | 10 800 | 29.6 |

*Maximum available roof area.

The results show that fulfilling the aim of a NZEB building depends both on location and type of heat generation. In the case of Reference house 1, the PV system was limited by the size of the roof in three cases: for electric heating in Östersund and Kiruna, and for the ground source heat pump in Kiruna. For Reference house 2, this was only the case for electric heating in Kiruna. The results reflect both the increased demand for space heating in the colder climate and the reduced production from the PV system in the northern parts of Sweden.

The results from the life cycle cost calculations are presented, in Table 6 for Reference house 1 and in Table 7 for Reference house 2, with the investment cost for each system and as net present value and internal rate of return. The results are shown per type of heat generation and location. Alternatives presented in red are not profitable.

**Table 6. Profitability calculations for the implementation of PV systems on Reference house 1, presented with investment costs, net present value and internal rate of return. Alternatives presented in red are not profitable.**

| Heat generation | Location | Investment cost (€) | Net present value (€) | Internal rate of return (%) |
|---|---|---|---|---|
| Electric heating | Malmö | 35 250 | 680 | 2.2 |
| | Östersund | 35 250 | - 4 300 | 0.7 |
| | Kiruna | 35 250 | - 10 200 | - 2.4 |
| Ground source heat pump | Malmö | 20 100 | 710 | 2.4 |
| | Östersund | 27 600 | - 3 100 | 0.8 |
| | Kiruna | 35 250 | - 9 900 | - 1.2 |

**Table 7. Profitability calculations for the implementation of PV systems on Reference house 2, east-west orientation, presented with investment costs, net present value and internal rate of return. Alternatives presented in red are not profitable.**

| Heat generation | Location | Investment cost (€) | Net present value (€) | Internal rate of return (%) |
|---|---|---|---|---|
| Electric heating | Malmö | 27 600 | - 2 900 | 0.9 |
| | Östersund | 40 200 | - 9 300 | - 0.5 |
| | Kiruna | 50 300 | - 17 200 | - 1.9 |
| Ground source heat pump | Malmö | 17 600 | - 1 100 | 1.4 |
| | Östersund | 25 200 | - 5 500 | - 0.4 |
| | Kiruna | 23 000 | - 11 000 | - 2.2 |

The cost-effectiveness is also shown to be dependent on both the location and type of heat generation. It is only cost-effective to install a PV system with a size to attain NZEB for Reference house 1 in Malmö in the south of Sweden. This is the case with both types of heat generation, although the investment cost for the electric heated house is higher.

## 4. Conclusion

Overall, the assessment showed that it is not cost-effective to aim for NZEB when implementing a PV system, based on the alternatives in this study, assuming a lifetime of 25 years and no electricity price increase above inflation. In many cases, the NZEB level could be attained with the roofs available, but this depended on the location and type of heat generation of the houses.

In this study, the aim was to maximise annual PV production, therefore the PV panels were installed flat on the roof for Reference house 1. The tilt of the PV system could be optimized to increase production per panel and cost-effectiveness. However, by doing this, the total annual PV production is reduced because of the limited space, so the NZEB level would not be attained.

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