Linnæus University
Sweden

Degree project

Investigation of impact of detached house buildings orientation on energy saving result of renovation scenarios and energy generation of installed PV panels in Växjö

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Abstract

Most of the detached houses in Sweden were built more than 30 years ago, and most of them are old and need a deep renovation. The renovation is an excellent opportunity to apply the energy measure with a combination of renewable energy such as PV solar, which could be a great option to reduce energy consumption and contribute to reducing greenhouse emissions. For this reason, selecting effective renovation scenarios for buildings could be important and challenging. One of these challenges is applying typical scenarios for one archetype's buildings. A building could be in the same archetypes with similar geometry and properties but in different directions. In this study, the researcher aims to investigate the yearly heat demand energy saving of buildings from one archetype, the same renovation scenario, and the same area but in four different directions, 0-30-60-90 degrees from the south (case studies). This project's additional aim is to examine the electricity generation from PV when installed on one and both sides for four houses in the same area in four different directions, 0-30-60-90 degrees from the south.

Design Builder software was used as a graphical user interface through the Energy Plus engine. In this way, the heat demand of case studies was simulated for different scenarios (Standard renovation and advanced renovation) in the Växjö region. The results from the simulation of the houses with different directions showed that the heat demand energy decreased by, on average, 20% for standard and 28% for advanced renovation. The comparison of the case studies with the same renovation scenario concludes that they are no differences in the heat energy savings, which means the direction of the building has no big impact on the energy saving of the renovation scenario in the Växjö region. The installation side of the PV has no impact on the annual electricity generation from PV for the house with a direction of 0 degrees from the south. For the other houses, the yearly electricity generation from the PV increased by 36.8% with one side on the roof (South direction). House number 4 is the best direction to install PV with one side on the roof (south direction), and house 3 is the next best direction to install PV on one side.

When installed on both sides of the roof, the annual electricity generation from the PV decreased by 5,3% with four houses in different directions. The changes are not so high may be due to the weather of the Växjö, which is 65 % cloudy according to the weather data file from TMY. Another reason is that the PV was installed on both sides of the pitched roof. When the houses have different directions, 0 to 90 degrees from the south, that may be increased the electricity generation from the PV on one side and reduce it on the other.

Keyword

Detached, single-family house, energy measure, simulation, heat demand energy, archetype, renovation, PV electricity generation.

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Best regards

Hassan Ali

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1. Introduction

Worldwide energy increased by 49% globally from 1990 to 2020 [1]. The total energy used in 2020 was 100 000 TWh and reduced by 5% compared to 2019. Worldwide energy consumption is divided into three main sectors, which are transportation, industrial, residential, and commercial. Each sector has unique energy needs and opportunities for reducing energy consumption and transitioning to renewable energy sources.

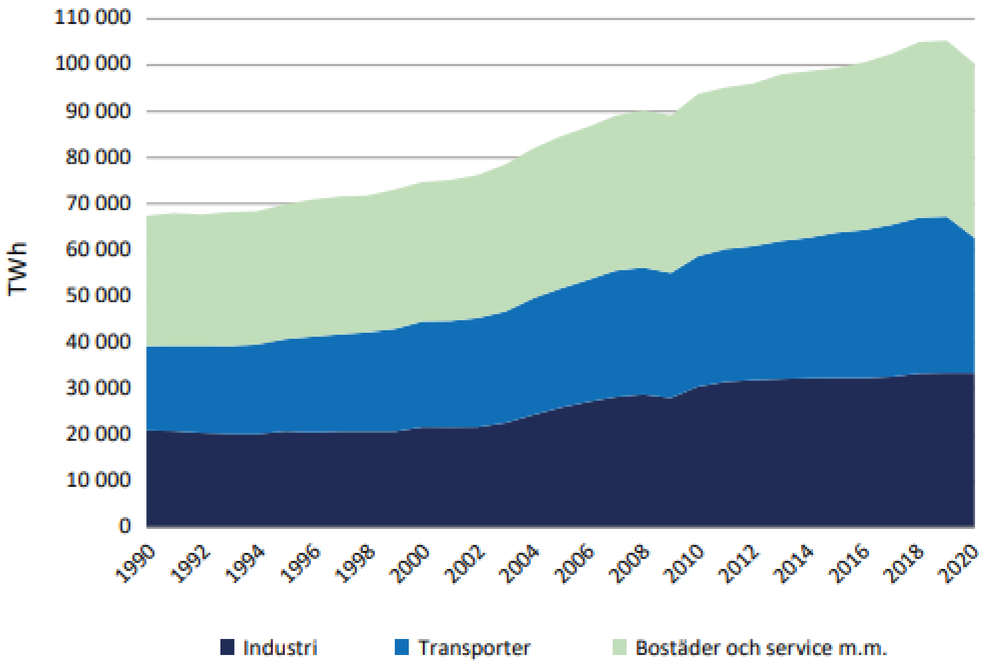


Figure 1: Global energy consumption by sectors from 1990-2021(Source from Swedish Energy Agency)

The residential and commercial sectors include homes, apartments, and commercial buildings, accounting for 38% of the global energy used by 2020, and the industrial and transport sectors accounted for 33 and 29 percent, respectively [1]. According to Figure 1, the transportation sector accounts for a significant share, increasing 60% of global energy consumption from 1990 to 2021. Implementing energy-efficient design and using innovative home technologies, deep renovation of the old house, and switching to renewable energy sources like solar panels can reduce energy consumption in the building sector.

The building sector significantly contributes to global energy consumption and greenhouse gas emissions, accounting for approximately 51% of electricity consumption, 51% of district heat energy use, and 19% of energy linked to greenhouse gas (GHG) emissions [1].

Reducing greenhouse gas emissions in most countries takes different stakes, such as the Paris Agreement, a legally binding international climate change treaty adopted in December 2015. The goal of the Paris Agreement is to limit global warming to 2 degrees Celsius and mind efforts to limit the temperature increase to 1,5 degrees Celsius. [2]

European Union (EU) has set ambitious climate goals to tackle climate change and reduce greenhouse emissions. The main goals are to reduce greenhouse emissions by 80% by 2050, increase the share of renewable energy, and invest in clean technology. The building sector at the European Union level is

40% of total energy consumption and 36 % of carbon dioxide emissions [3]. Because of that, The Energy Performance Buildings Directive (EPBD) requires all new houses to be near zero-building energy by the end of 2020 [4].

About 1.6 million detached houses in Sweden were built more than 30 years ago and need deep renovation [5]. Those detached houses account for more than 50% of the total building stock in Sweden and are accountable for 12% of the total energy consumption [6]. The indicated renovation process is an excellent opportunity to apply energy measures to decrease energy demand and install renewable energy-utilizing equipment to increase the energy supply. Renovating buildings and combining renewable energy can play a significant role in balancing the energy trade. It could help achieve SDGs like Goal 7-Affordable, Clean Energy, and Goal 13-Climate Action.

1.1 Background

During 60 s and the first half of the 70s, needed a high quantity of new houses in Sweden, and to achieve this goal, one million new houses were built, including multi- and single-family houses, in a short period. According to the time short was built, those houses lead that they were built in a typical way, which needs to be improved for energy-efficient building. Those houses used oil for space heating, and the oil crisis from 1973 increased the cost of oil, which resulted in a new way of reducing the energy use of those houses. In this period, between 1961-1980, there were almost 714 000 single-family houses, and they used a high amount of energy. The result is that the buildings were built in a standard way, making them an excellent candidate for standard renovation. [7]

Most of those detached houses in Sweden are affected by a degradation in the building envelope, which leads to high heat flux through the different components of the building. Those detached houses need a deep renovation which can provide an excellent opportunity to install renewable energy because this could be an essential option to reduce the total energy consumption of those detached houses. [8]

1.2 Aim and goal

The presented thesis aims to investigate energy saving for houses in Växjö in the same area, with the same archetype and renovation scenario, but different orientation (direction).

Furthermore, the thesis aims to investigate the change in the photovoltaic (PV) panel electricity generation for houses in the same area but in different directions. Two scenarios are investigated, i.e, where the PV panels are installed on one side of the roof and when installed on both sides, to determine the scenario that generates more electricity.

1.3 Limitations of the Study

In this research, the simulation only covers insulation (improving the insulation of the walls, roof, floor, and windows). The work is only based on a simulation of the climate of the Växjö weather file and one archetype of the house (the 70s). No physical visits have been made to the current detached house, and no physical measurements have been carried out during the calculation. The other limitation is the economy; payback is not included in this work.

2. Theory

2.1 Renovation

Generally, renovation of the house is defined as upgrading the building's components, which results in a better indoor climate and better comfort for tenancy [9]. Renovation could be changing the walls, roof, and floor structure by adding insulation, and this will reduce the heat flux through those components. The windows will be replaced with more glazes, resulting in higher efficiency. Renovation of the building envelope consists of adding insulation through the house's different components, which results in lower thermal transmittance (U-values) of those components. Through the renovation, there is a great potential to save primary energy on detached houses built between 60 to 70s; because of this period, there was no tightening of the insulation standards, and many of those detached houses generally account in Nordic countries. Approximately 2% of those detached houses installed energy-efficiency windows, improved wall insulation, and installed new types of heating systems. Using new types of heat systems, such as heat pumps and renovation measurements, can reduce the primary energy used by more than 80% for space and hot water. [10].

The renovation market is dominated by a craftsman, based totally on individual solutions to emerging the one-stop-shop business model for energy renovation of single-family houses; one renovation company can provide full service, including consulting to the detached houses owners, can achieve the goal of energy efficiency improvement. [10]

2.1.1 Thermal transmittance (U-Value)

The thermal envelope is like the skin of the building, which protects the thermal and acoustic of the interior. Each component consists of a building envelope with a specific thermal transmittance, which describes the amount of heat loss through a square meter of that material for every degree(K) difference in temperature inside and outside. Lower thermal transmittance participates to the energy efficiency of the building. To achieve the lower values required, use a higher thermal resistance insulator for the different envelope components. Each insulator material has a specific thermal conductivity (lambda), measuring watts per meter kelvin. [11]

Thermal resistance (R-Values) of every layer used to insulate the wall, roof, and floor have different abilities to resist heat transfer at a certain thickness [12]. Higher thermal resistance could be a great option when looking for material insulation. Equation (1) could be used to calculate the thermal resistance of the material:

$\theta = thickness\ of\ material\ and\ measure\ (m)$

$\lambda = \ the\ thermal\ conductivity\ of\ the\ material, and\ it\ is\ measured \frac{W}{(m * K)}$

$$R = \frac{\theta(\ Thicknes\ of\ material)}{\lambda(lambda{:}thermal\ conductivity\ of\ material)}\ (1)$$

Thermal transmittance (U-values) evaluates the rate of heat gain or loss through the thickness of combined elements of material, and it can calculate by equation 2:

$$U = \frac{1}{R} = \frac{1}{Rse} + \frac{1}{Rsi} \sum_i^n \frac{1}{Ri} \quad (2)$$

$$U = Heat\ transfer\ coefficient\ (thermal\ transmittance) in \frac{W}{K * m^2}$$

$$R = Thermal\ resistance\ of\ the\ material\ in\ \frac{K * m^2}{W}$$

$$Rse = It\ is\ fixed\ external\ resistance(\ According\ to\ the\ norm\ climat)$$

$$Rsi = it\ is\ fixed\ internal\ resistance(\ According\ to\ the\ norm\ climat)$$

$$Ri = sum\ of\ the\ total\ resistivity\ of\ all\ elements\ to\ n\ \ quantity.$$

Renovation of the building envelope reduces heat transfer through to the components of the building and gives better thermal transmittance(U-values). This results in an even reduction in energy demand for heating. According to a case house study in Denmark, compared before and after the renovation, it results in lower thermal transmittance, gives the house better indoor climate standards, and reduces energy consumption by 23%. [13]

2.1.2 Windows

Most detached houses in Sweden were built before the 70s, which needs to be adequately required a current energy efficiency standard. Windows in many of those houses are old and have lower energy efficiency. There is an excellent potential to use energy-efficiency windows in existing detached houses. About 15TWh of heat losses account for annually through the windows of Swedish residential buildings. U- values of windows range from 1.1 to 1.8 W/m^2K. Lower U- values of Windows resulted in lower heat losses. [14].

A study av L. Gustavsson and U. Tettey from 2020 showed that annual final energy demand for space heating decreased from 101 kWh/m^2 to 79.0 kWh/m^2 when U-values for windows decreased from 2.9W/m^2K to 1.2W/m^2K. This study showed that implemented energy-efficiency measures for windows represent 21.8% of heatings energy saving [15].

2.2 Heating options

The energy cost for space and domestic heat water represents 80% of the total energy in detached houses in Sweden. Depending on the kind of heat sources used, there is an excellent opportunity to reduce the energy demand for space and tap water. Swedish detached houses have heat pumps and district heating, depending on the house's location. Combining other renewable energy such as solar panels and solar heat collectors, can minimize the heat demand, which is a good option for energy efficiency in the building sector. [16]

2.2.1 Heat pump

Heat pumps extract heat from sources such as the ground, the water in a lake, geothermal, or air outside. An optimized heat pump can reduce the heat demand for space and hot water by approximately 80%nd 90% [17]. The heat pump is named depending on the heat sources used. The principle working of the heat pumps is similar. The heat from the heat pump is distributed inside the detached house by water-based and space-heating systems. [17]

All kinds of heat pumps operate using electricity, but the advantage is linked to high efficiency when the heat pump converts to heat. According to the term efficiency heat pump, there is a coefficient of performance of heat pump (COP) and seasonal performance factor (SPF). COP is a measure of efficiency, defined as the ratio of the work done by a device to the amount of work given to the device. In the case of the heat pump, efficiency is the ratio of valuable heat energy produced from electrical consumption. COP of the heat pump 2.5 means the heat pump supplier 2.5 times as much heat energy to the system compared to the electricity consumed. The SPF is the ratio of annual heat generated to the yearly electricity consumed for the heat pump operation. [18]

2.2.1.1 Air source heat pump

According to the air source heat pump, there are two kinds of heat pumps:

- Air to the water system, which the heat from heat pumps is used to heat water which is then circulated the house via radiators or an underfloor heating system. This system can also be used to domestic heat water.
- Air-to-air systems have fans to circulate warm air around the house, and this does not have the opportunity to heat the water.

An air source heat pump uses the same technology as a fridge but works reversely. The heat is extracted from the air outside the house, even on a cold day, and transferred to warm by a special liquid called refrigerant. When it becomes warm, the refrigerant liquid turns into compressed gas, making it even hotter. The heat is transferred to the water-basing heating system of the house. The gas condenses back into a liquid, and the process begins again. [19]

2.2.1.2 Ground source heat pump

Ground source heat pumps provide around 50-70% energy savings, similar to groundwater and lake water heat. According to the ground source, there are ground source heat pumps with boreholes (figure 2a) and ground loops (figure 2 b).

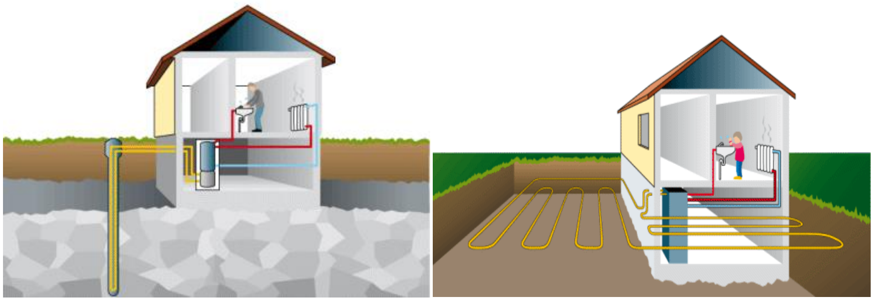


Figure 2:Illustration of two sorts of ground source heat pump (2a left one) boreholes and (2b right) loops (Source from Swedish Energy Agency)

The ground source heat pump with ground loops; the heat obtains from the coil of pipes buried in the ground. It comprised a hose buried in the ground with a liquid circulating and a loop with a depth of 0,9-1,5 meters and a distance between them not exceeding 1,5 meters.

The ground source heat pump with a borehole extracts heat from a borehole in the ground with a depth of often less than 200 meters, and the distance between two boreholes should be at most at least 20 meters. Keeping this distance prevents the two boreholes from affecting and cooling one another. Using the ground source heat pump could also reduce 90% of the energy demand of the house, and the heat pump would cover this. [20] [21]

2.3 Solar Energy

The capacity of the solar energy output is approximately 1000 kWh per square meter in Sweden. This solar energy could reduce heat demand for a detached house using heat collectors and electricity production with solar panels. [22]

2.3.1 Solar panels

Solar panels comprise the much smaller unit, which is called photovoltaic cells. These photovoltaic cells convert sunlight into electricity. The photon or the particles of the sunlight knock the free electron from an atom and generate a flow of electricity. This process is called solar photovoltaic technology and is a clean way of generating electricity from solar radiation. [23]

Depending on the material consisting of the solar panels, there are monocrystalline photovoltaic and polycrystalline cells. According to the monocrystalline photovoltaic cells consist of a single silicon crystal, which has higher performance, around 23% energy efficiency, and higher prices than the polycrystal. Polycrystalline photovoltaics consists of various fine silicon crystals, and the combination of the various layer make electron movement more difficult and energy efficiency around 16,79%. [24]

The best direction for solar panels determines by location. According to Sweden, the best way to install solar panels is in the south direction with an angle of 30-50 degrees, which can give optimal energy production. [25]

2.3.2 Solar heat collector

Solar heat systems can reduce the energy demand for heat by 2000-6000 kWh/year in an ordinary single-family house, depending on the system and the size of the solar collector. With the solar heat in southern

Sweden, there is an opportunity for detached houses to use heat collected from the sun for a period between 4-6 months, representing a warm period where heat from the sun can use to domestic heat water. This heating system depends on water-based heating in a storage water tank connected to the heat collector (Figure 3). This system can reduce around half the annual hot water demand for an ordinary detached house. [26]

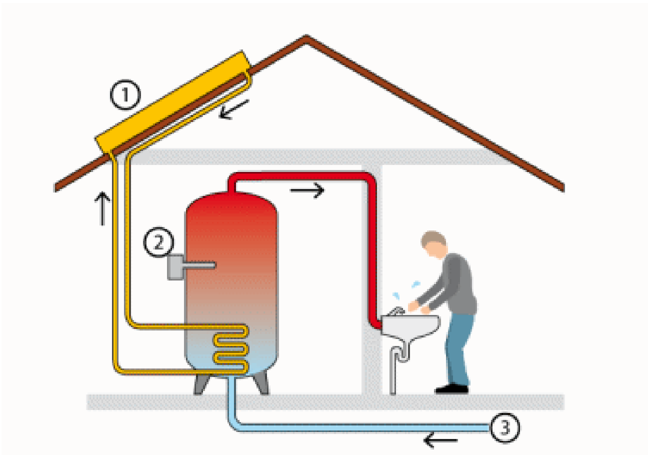


Figure 3: Illustration of solar heat collector that supplies warm water (Source from Swedish Energy Agency)

2.4 Ventilation

The ventilation aims to bring fresh air into the house, which is good for the health and the standard of dwellings. There are three primary ventilation systems used for the building. Those ventilation systems are natural and mechanical, with neither heat nor heat recovery. Regarding the energy efficiency of the detached house, mechanical ventilation with heat recovery is the best option to reduce the house's energy consumption. [27]

2.4.1 Natural Ventilation

Natural ventilation performance depends on how the house is used and the occupants' activity. A house with a natural ventilation system does not contain a fan, fresh air is drawn through the gaps, and air pollution from the rooms and the exhaust air from the kitchen and bathrooms is released through the ventilation chimneys (Figure 4). There is no opportunity to restore the exhaust air by using natural ventilation.

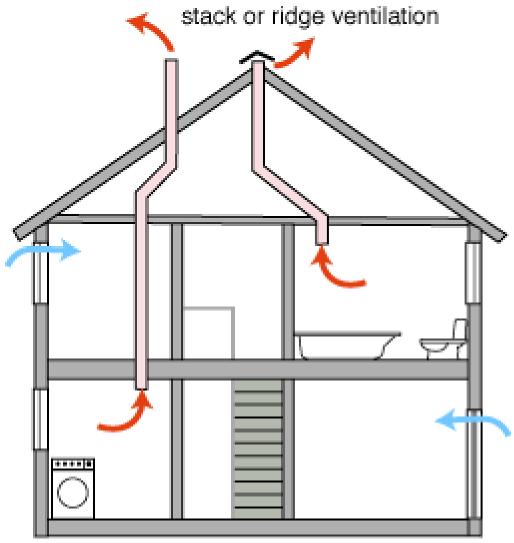


Figure 4: Illustration of a house with natural ventilation [28]

The detached house built 70s are often not tight, and natural ventilation is used, which result in the air flowing through gaps in the structure. The air circulation is poor, particularly during the summer, and there is no temperature difference between the outdoors and indoors, resulting in high energy loss. [27] [29]

2.4.2 Mechanical Ventilation (not heat recovery)

According to the exhaust air ventilation system, the polluted room air and the exhaust air from the kitchen and bedrooms are extracted continuously by a fan. The fresh air is supplied through the registers attached to the windows frames or walls (Figure 5). This kind of ventilation has a self-regulating outdoor air register which limits airflow when outdoor air is at a lower temperature [30].

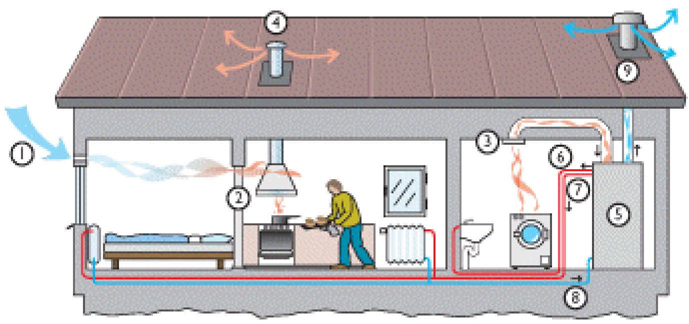


Figure 5: Illustration of mechanical ventilation with no heat recovery (Source from Swedish Energy Agency)

Some maintenance is required to have a good ventilation system performance, such as checking the fans periodically and ensuring clean registers; otherwise, air circulation needs to be improved, and the fan could be less effective. In this type of ventilation, it is possible to connect a heat pump to the exhaust air fan to recover heat from the ventilation air. [30]

2.4.3 Mechanical Ventilation with heat recovery

This type of ventilation exhausts and supplies air with heat recovery, also called the FTX system. There is a possibility to supply large quantities of ventilation air, and the system performs great without consideration for the weather. This kind of ventilation has two fans; one supplies air while the other exhausts air through two duct systems. Exhaust air is drawn from the kitchen, bedrooms, and unoccupied places, and the supply air flows through to the living rooms. The heat is transferred from exhaust air to cold outdoor air in the heat exchanger (Figure 6). This ventilation system has between 50 and 60% energy saving compared to the system without recovered heat. [31]

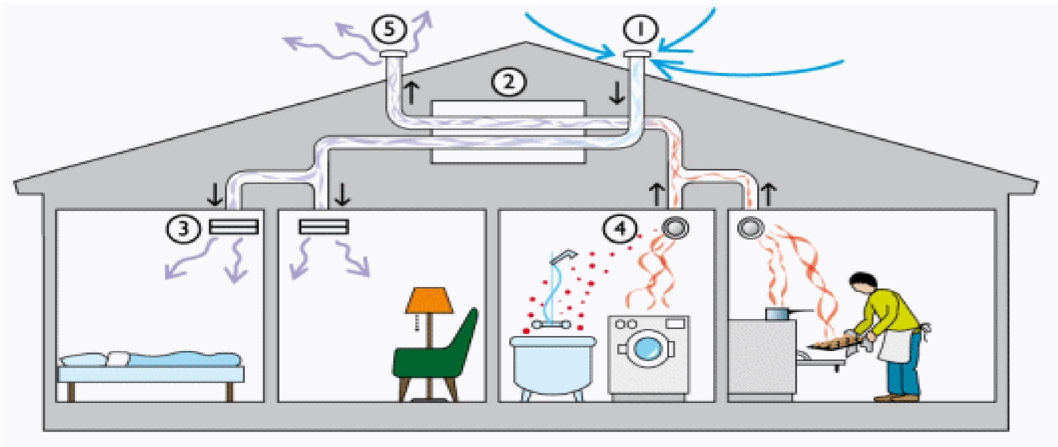


Figure 6: Illustration of mechanical ventilation with heat recovery (Source from Swedish Energy Agency)

The study carried out in Sweden that compared the energy efficiency when the ventilation switched to mechanical ventilation with heat recovered in a detached house showed that the energy efficiency is around 50% compared to ventilation with no heat recovery. [32]

2.5 Energy Balance in Building

According to Figure 7, the Energy gains are the arrows indicating the inside of the building, and the energy losses are the arrows pointing out the building.

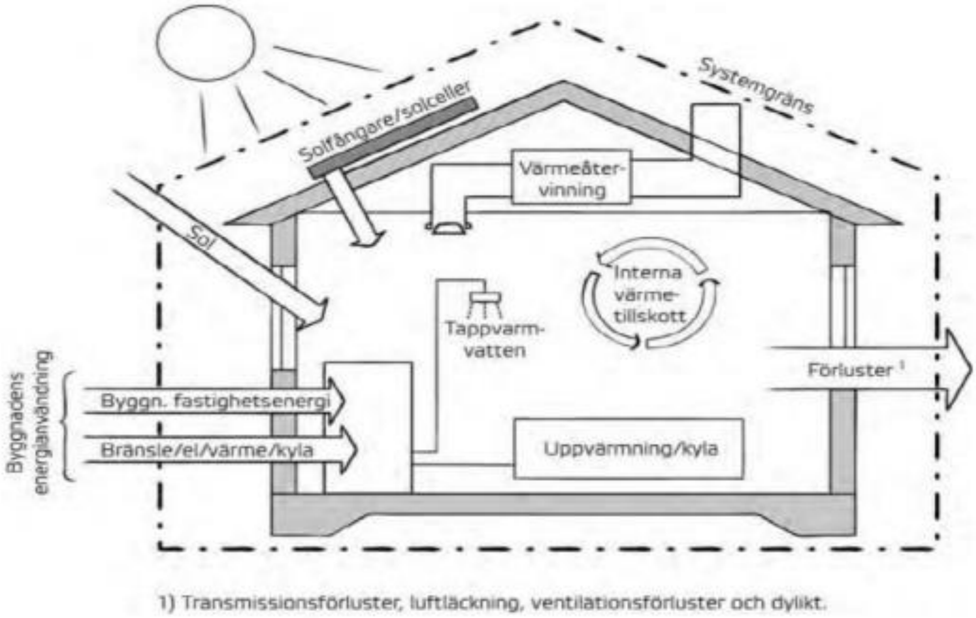


Figure 7: Illustration of the building as a system (Source from Boverket 2012)

The primary heat flux affecting the energy balance of the building is the heat losses through to the building envelopes, which are also called transmission losses, and through the junction of the windows and wall or wall and doors (leakage), and ventilation losses. The Heat gain is heating from solar radiation, occupancy, equipment, and domestic heat water. Having efficient energy building requires increasing the heat gain and decreasing the heat losses. With energy balance, heat demand energy is calculated from the following equation, the heat energy loss subtracted from the heat energy gains. [33]

$$Heat\ deamnd = Q_{Trans} + Q_{vent} + Q_{sewage} - (Q_{sun} + Q_{hot\ water} + Q_{pers,apps})$$

Energy balance can be calculated by hand, and many parameters are to be considered, such as solar radiation and outdoor temperature for one year, which could be helpful with computer simulation software such as Energy Plus through the Design-builder interface.

3. Methodology

The study was conducted to calculate the annual heat demand energy for four houses in the same area in four different directions in three renovation scenarios.

The last part of a report was conducted to calculate the yearly electricity generation from PV for four houses in the same area, and the PV covered 25% of the roof area in four different directions. This section consists of two central parts: qualitative and quantitative methods.

3.1 Qualitative methods

This section of the thesis consists of a literature study through the previous study regarding the renovations of detached houses from the 70s. It is based on the review's articles from the Web of Science using advanced research and using through this statement logic "and," "or," and "not" between the word, and this is one of the examples, search TI= (renovation and detached and houses) which is meant the reviews articles contain only title for above keywords. There is a possibility to select the recent publication years.

Other search engines are used, such as science direct. As a result, the search engines concluded to get review articles describing the renovation measures of the detached houses from the 60 and 70s, which was helpful in the theory and background of this thesis.

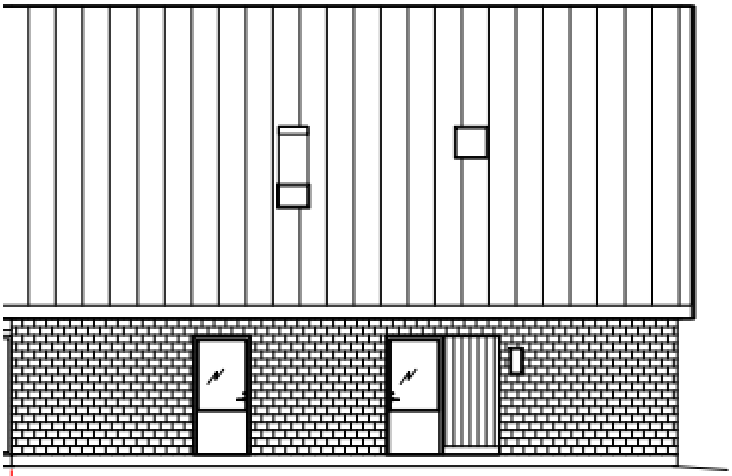
Various helpful sources from the Swedish Energy Authority were even used in this thesis. As a result, this concludes enough knowledge about the work.

According to the data collected from the current detached houses from the 70s, the direction plan and the U- values of the material from the database of the Tabula web of tool to create the reference houses model.

3.2 Quantitative methods

3.2.1 Reference house

The reference house is a single-family house located in Teleborg in Växjö, and it is a part of the building stock built-in 1973. Regarding Figure 8, there is additional information about the detached house design and the house orientation from different directions. The other valuable information for simulation is the dimensions of doors and windows and their orientation.



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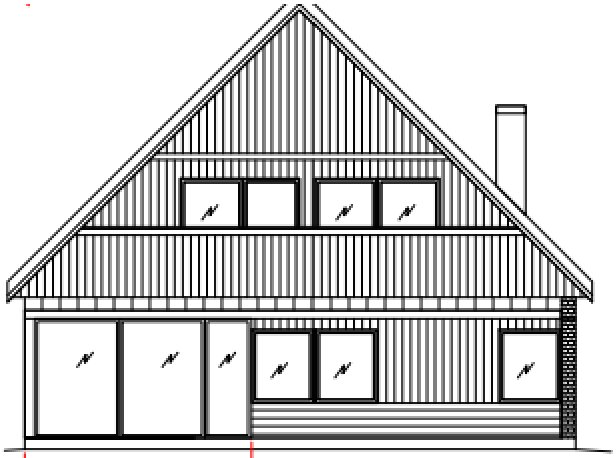

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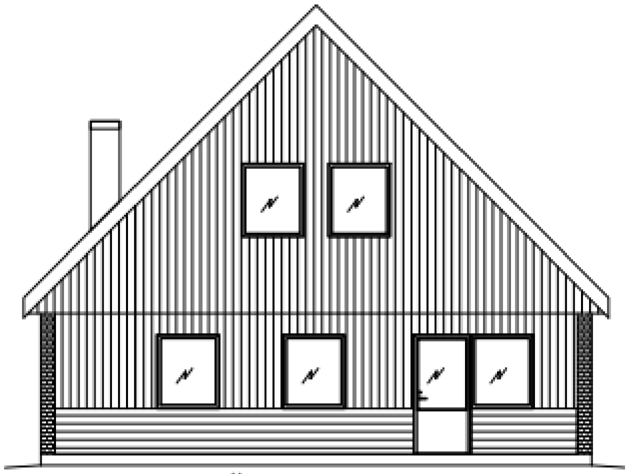


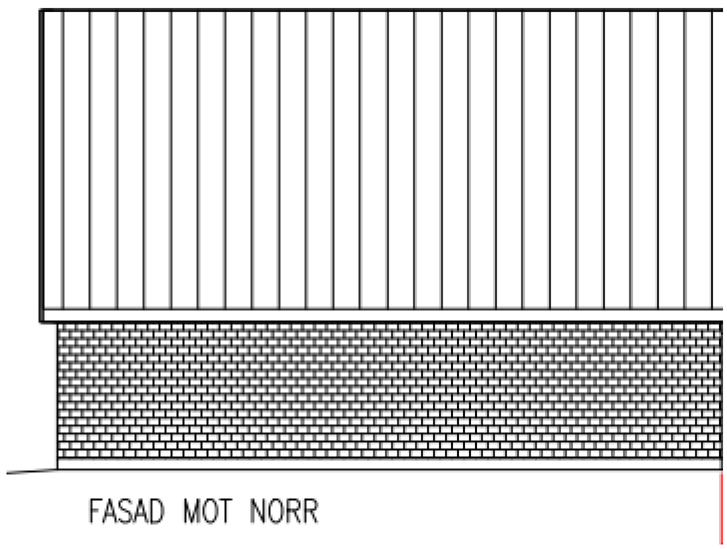


Figure 8: Illustration of the plan of the detached house

The current detached house floor area is roughly 152,3m^2 and consists of a two-plan house with a pitched roof at an angle of 45º. The reference houses have natural ventilation, and the actual ventilation airflow in the case of the house used as default, which is assumed that the airflow is roughly 0,5 ac per hour, means the air will be changed once per two hours. The schedule is set ON for all days on the software.

3.2.3 Design-Builder Software

Design Builder is whole building Performance Analysis Software that is a graphical user interface to utilize the Energy Plus simulation engine. It is a complete 3-D visual design modeling and energy use simulation program that provides information on building energy consumption, CO2 emissions, occupant comfort, and daylighting effects. [34]

The design-builder submitted an international validation standard according to the ANSI/ASHRAE Standard 140-2014, a global building regulatory energy code provided by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers. ASHRAE standard 140-2014 is a specific test procedure that can be applied to evaluate the range of applicability and capability of software designed to calculate the thermal performance of a building. [35]

The weather data file type is TMY which is meteorological data with data values every hour in a year [36], and the software took care of the temperature, vent, and solar radiation for one year. The software had default input according to the activity, which also needed to be updated according to the case house. In this section, the software calculates the heat gain from the occupant and saves it in a file. [37]

Design builder software gives the possibility to choose the simulation by using the energy plus by days or hours for one year. The software had default input according to the construction part of the building. The construction material of the houses needed to be updated in this section, and the software calculated the thermal transmittance of each building component. The software also had HVAC system files that needed to input the case of the actual house, and there are possibilities in this software to choose the solar panels. [37]

3.2.4 Simulation

The simulation was performed with the help of Energy Plus version 9.4 through the graphical interface Design-Builder version 7.2 in three renovation scenarios:

- Model of the detached house without renovation
- Model of the detached houses with standard renovation
- Model of the detached houses with advanced renovation

Four houses in the same area with similar geometry and properties but in four different directions are considered, and the abovementioned renovation scenarios are applied for these buildings and simulated energy consumption. The directions of the houses are considered as case studies, which the house with 0 degrees direction (orientation) from the south is case study 1, the house with 30 degrees direction from the south is case study 2, the house with 60 degrees direction from the south is case study 3, and the house with 90 degrees direction from the south is case studies 4.

Standard renovations mean the U-Values of the roof were added 200 mm insulation of loose wool, the wall was added 445 mm of insulation wood panel, the floor was added 40 mm insulation of wood panel(assumed), and the window was a new triple glazed window. Advanced renovation means the roof added 500 mm of insulation of loose wool, the wall was added 70 mm of insulation of wood panel, the floor was added 445 mm of insulation, which assumed a wood panel, and the window replaced by a 2+2 window glazed.

The database of the Tabula web tool is used to get more information about the U-values for the single-family detached houses in Sweden, which were built between 1961-1975, and the current reference house is one of the building stocks regarding this period. [38]

The database from the Tabula web tool collected the different U-values for building envelopes in three different cases from cases 1-3 in the followings tables:

Table 1: U-Values of the building surface of the reference house (Source from Tabula Web tool)

Building Surface	U-values(W/m^{2}K)
Roof	0,21
Wall	0,31
Floor	0,32
Windows	2,30

The standard renovation consists of some improvements to the U-values of the building envelope (Table 2):

Table 2: U-Values of the building surface with the standard renovation (Source from Tabula Web tool)

Building Surface	U-values(W/m^{2}K)
Roof	0,10
Wall	0,22
Floor	0,24
Windows	0,90

The advanced renovation means the building envelope is more improved the U-values according to the source from Tabula Web tool (Table 3):

Table 3: U-Values of the building surface with the advanced renovation (Source from Tabula Web tool)

Building Surface	U-values(W/m^{2}K)
Roof	0,05
Wall	0,19
Floor	0,23
Windows	0,76

The simulation of the model houses consists of several steps. The first step is to choose the location of the detached house and the climate date, and then create the house's geometry in the Design-Builder software according to the house's floor plan, which is from the information of the direction plan of the house. Then after several steps, go through to complete the activity of the house according to the occupancy and their schedules, material construction of the house according to the different insulation materials used on the different components of the house, the material used for windows and doors (Show table 1-3) and which HVAC system used in the houses will be defined. The last step consists of the simulation in Energy Plus, and the simulation period was made for one year.

3.2.4.1 Simulation of the reference house

According to the data collected from the detached house from the 70s, it created the geometry of the house in the design-builder. (Figure 9)

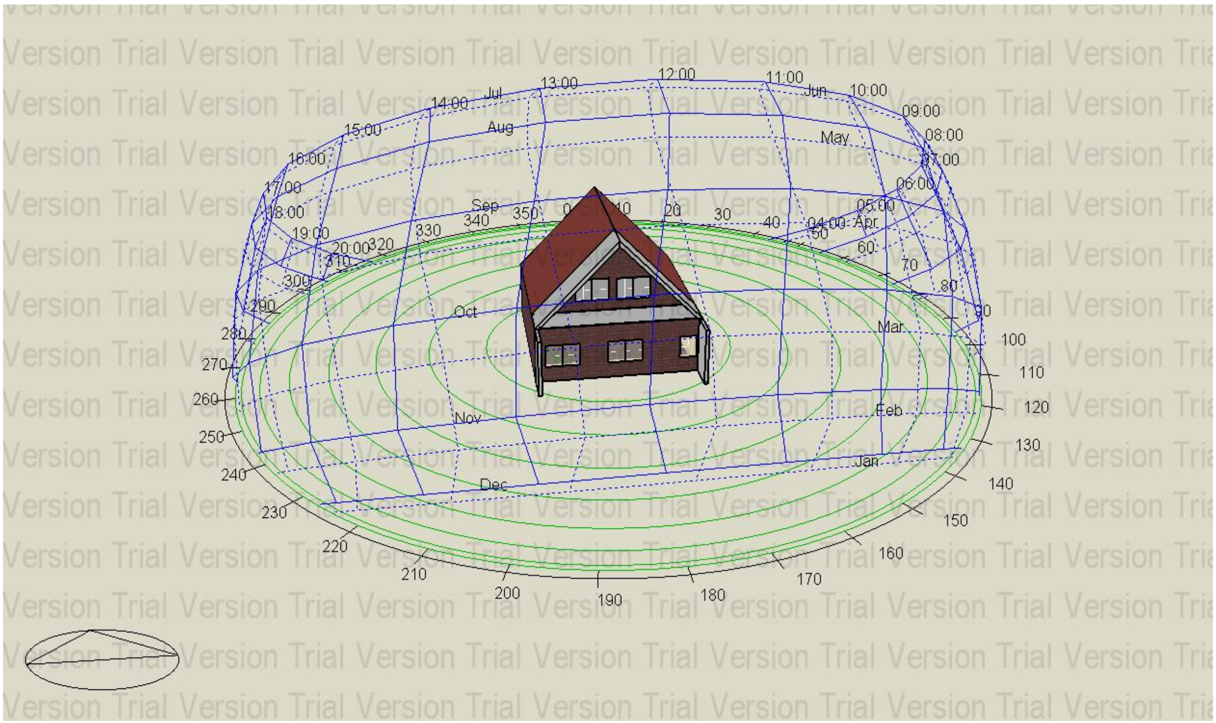
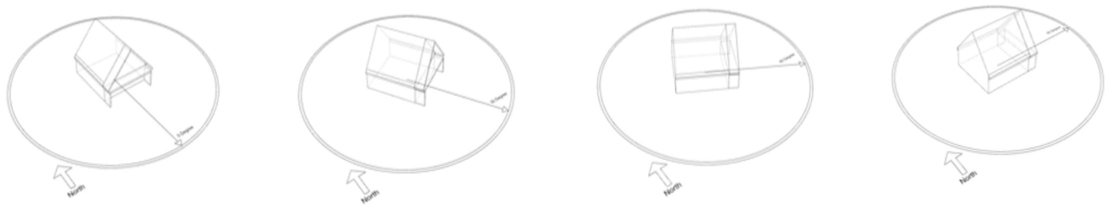


Figure 9: Illustration of the reference house with simulation solar radiation (Source from Design Builder)

This resulted in completing the activity of the occupancy that is related to the number of people per unit floor area, and this concludes there are four people in the house and its occupancy is 0,0260 people/m^2 and assumed that the occupancy was present in the house all days. The lighting types of equipment are used as a default in this case, which releases heat of approximately 1,5 W/m^2, but the domestic heat and water were calculated manually based on the Swedish energy code [39] (shown in Appendix A), and this result is 0,95 l/m^2 per day.

The heating set point values were assumed to be 21°C in this detached house, and the heating setback was neglected. The clothing's thermal insulation followed ISO7730-Standard [40], set to 1 for clothes in winter and 0.5 for summer.

The different U-values of the building envelope were added to the models (According to Table 1). The four model houses without renovation, with similar properties and geometry but in four different directions, 0-30-60-90 degrees from the south (case studies), to get additional knowledge on whether the heat demand will decrease or increase by variation of the directions of the houses. According to Figure 10.



Case study 1 *0 degree* | Case study 2 *30 degree* | Case study 3 *60 degree* | Case study 4 *90 degree*

Figure 10: Illustration of the four houses with different directions (cases 1-4)

3.2.4.2 Simulation of the standard renovation house

The four model houses simulation was made the same way as the reference house that the four cases were simulated in the design-builder software. According to the reference house, some of the building's envelope insulations were changed to the lower material, which had lower thermal transmittance (U-values) regarding Table 2, and the simulation of the four cases was illustrated the same as in Figure 10.

3.2.4.3 Simulation of the advanced renovation house

The four houses model simulation was made the same way as the standard renovation in the design-builder software, and some of the building's envelope layers were adjusted to lower thermal transmittance (U-values), according to Table 3 from the database of the Tabula Web of the tool. Regarding simulation, the model house simulated the same as the previous modeling in four case studies, illustrated in Figure 10.

3.2.4.4 Simulation of the standard renovation model with solar panels

This part of the simulation consists of the previous houses after the standard renovation, with solar panels covering 25% of the roof area. The total roof area was 140 m^2, and the whole area that solar panels will cover is 35 m^2; on each side of the roof, solar panels were installed for an area of 17.5 m^2. And another scenario is that the PV was installed only on one side of the roof (south direction). According to the design-builder, the solar panel's energy will be converted by a simple inverter from DC to AC, and the inverter's efficiency was assumed to be 96%.

As in previous cases, those four model houses with PV were installed on both sides of the roof, and another scenario that PV was installed on one side of the roof was simulated through the design-builder as shown in previous Figure 10.

4. Results

This part consists of the results from the simulation for four model houses with similar properties and geometry but in four different directions and results from the simulation of the model houses with PV installed on one side and both sides on the roof.

4.1 Renovation scenario with four cases

This section shows the results of the models and simulations of the houses without renovation, standard, and advanced renovation regarding the four cases (cases 1-4).

4.1.1 Case 1

For case 1, where the house is oriented at 0 degrees from the south, the annual heat demand from the simulation result for the no renovation scenario is 11926 kWh. For the standard renovation scenario, the annual heat demand from the simulation result is 9491 kWh, and 8566 kWh for the advanced renovation scenario (see appendix B). An illustration of the results from the renovation scenario in case 1, presented in Figure 11, shows how the heat demand decreased from the different scenarios.

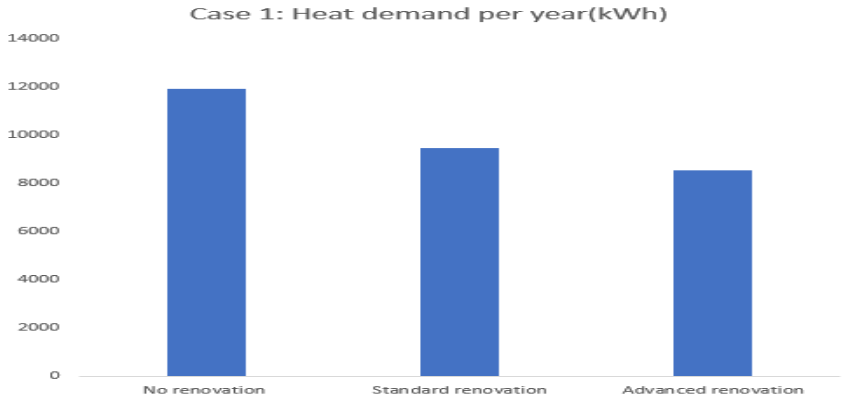


Figure 11: The yearly heat demand for the house with renovation scenario in case study 1

The scenario without renovation was chosen as a baseline to calculate the percentage of the heat demand decreased from no renovation, standard, and advanced, which is finalized in Table 4.

Table 4: Percentage of annual heat demand energy savings from different renovations scenarios case 1

Scenarios	Heat demand kWh/year	% heat demand energy decreased per year
No renovation	11926	
Standard renovation	9491	-20,4
Advanced renovation	8566	-28,2

4.1.2 Case 2

The model house with 30 degrees orientation from the south was also simulated with three renovation scenarios, i.e, no renovation (reference house), standard and advanced renovation. The result from the simulation software, which was analyzed through Excel, concludes that the total energy for heat demand of the model house for the no renovation scenario is 12084 kWh per year, 9652 kWh per year for the standard model house scenario, and 8717 kWh per year for the advanced renovated model scenario (see appendix C). Previous results presented in Figure 12 illustrate how the heat demand decreased from the different renovation scenarios.

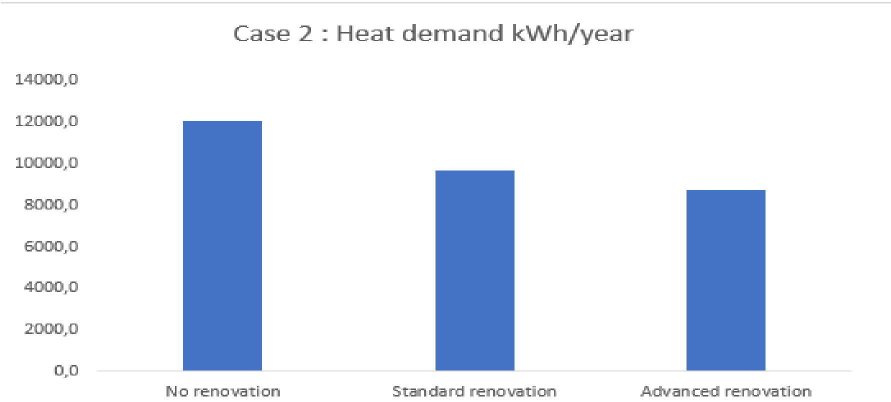


Figure 12: Illustration of the annual heat demand from the different renovation scenarios in case study 2

To get more details about the percentage of heat demand that decreased from the different scenarios, consider the no renovation scenarios (Reference house) as a baseline to calculate the percentage of heat saved from baseline to other renovation scenarios and the results represented in Table 5.

Table 5: Percentage of annual heat demand energy saving from different scenarios in case 2

Renovation scenarios	Heat demand (kWh/year)	% heat demand energy decreased per year
No renovation	12084	
Standard renovation	9652	-20,1
Advanced renovation	8717	-27,9

4.1.3 Case 3

For case 3, the three renovation scenarios for the model houses, i.e, no renovation, standard, and advanced renovation, were simulated with the house direction at 60 degrees from the south. The simulation results of the total heat demand per year for the no renovation scenario was 12250 kWh, 9818 kWh for the standard renovation, and 8875 kWh for the advanced renovations (see appendix D). Through Excel, these results are presented in Figure 13.

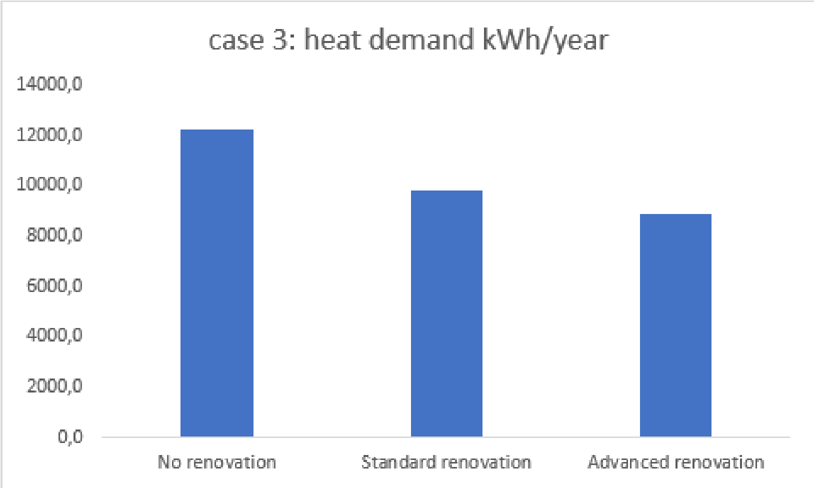


Figure 13: Annual heat demand of the house by the different renovation scenarios case study 3

Regarding the results from the simulation software and the utilization of the Excel program, the reference house is a baseline to compare the percentage of the heat demand energy that decreased in the other scenarios. The results are presented in Table 6.

Table 6: Percentage of annual heat demand energy saving from different scenarios in case 3

Renovation scenarios	Heat demand (kWh/year	% heat demand energy decreased per year
No renovation	12250	
Standard renovation	9818	-19,9
Advanced renovation	8875	-27,6

4.1.4 Case 4

For case 4, three renovation scenarios for the model house, i.e, no renovation, standard and advanced renovations, were simulated for the house at 90 degrees orientation from the south. The simulation results of the annual heat demand energy was 12311 kWh, 9879 kWh for the standard renovation, and 8939 kWh for the advanced renovation scenario (Appendix E). For visualization, the Excel program illustrates the results in Figure 14.

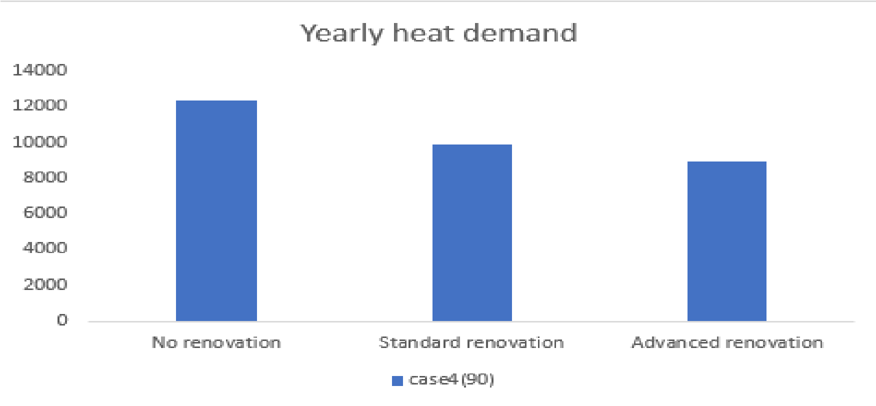


Figure 14: Annual heat demand of the house with different renovation scenarios case study 4

According to the results from different scenarios, the reference house was used as a baseline to evaluate the decreasing percentage of the heat demand for the different scenarios. Results are presented in Table 7.

Table 7: Percentage of the annual heat demand energy saving from the different renovation scenarios in case 4

Renovations scenarios	Heat demand (kWh/year)	% heat demand per year
No renovation	12311	
Standard renovation	9879	-19,8
Advanced renovation	8939	-27,4

4.2 Standard renovation model and PV on both sides

The four standard model houses added 25 % of the roof area with PV panels and then simulated through different directions; which house 1 is a 0 degrees orientation from the south as in case study 1, house 2 is a 30 degrees case study 2, house 3 is 60 degrees case study 3, and the house 4 is 90 degrees.

The total generation of electricity per year was 5556 kWh for house 1, 5513 kWh for house 2, 5349 kWh for House 3, and 5266 kWh for house 4 (Appendix F). The results from the simulation program were collected in the Excel files and then illustrated as a diagram shown in Figure 15.

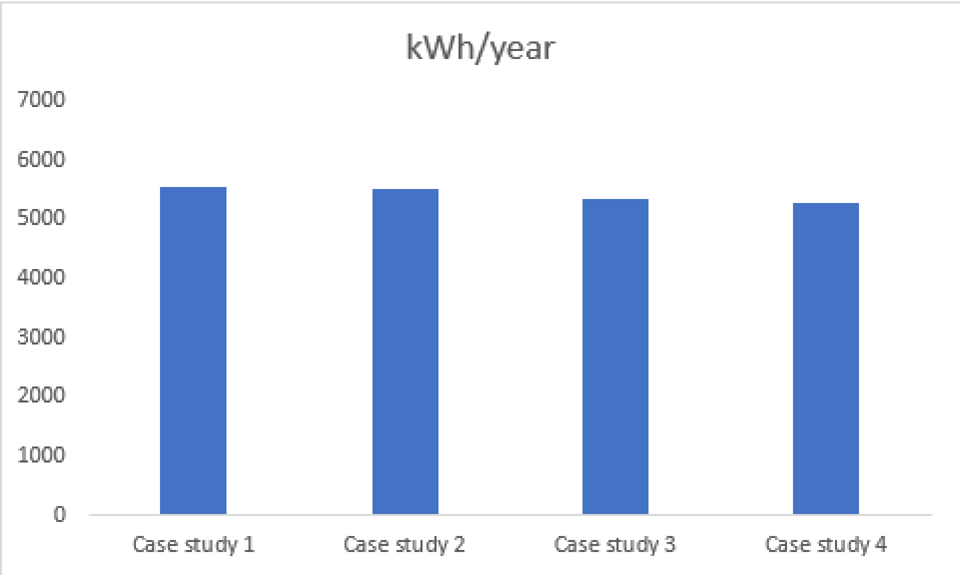


Figure 15: Annual generation of electricity from PV installed on both sides of the roof.

Regarding the yearly electricity generation from PV for the four houses with different directions(orientations), it's an excellent opportunity to evaluate the percentage of the electricity generation variation of the different houses. According to these results, house 1 is the baseline to compare other houses and then calculate the decreasing percentage of yearly electricity generation, and this concludes in Table 8.

Table 8: The percentage of electricity generation from PV installed on both sides of the roof

	Direction from south	Generation electricity (kWh/year)	% decreased
House 1	0 degrees	5556	
House 2	30 degrees	5513	0,78
House 3	60 degrees	5349	3,73
House 4	90 degrees	5266	5,22

4.3 Standard renovation model and PV on one side of the roof

Four houses in the same area with four different directions installed PV on one side of the roof. The result from the simulation concludes that the yearly electricity generation from the PV for house 1(case study 1) was 5564 kWh, house 2(case study 2) was 6642 kWh, house 3 (case study 3) was 7364 kWh, and house 4(case study 4) was 7612 kWh (Appendix G). Shown in Figure 16:

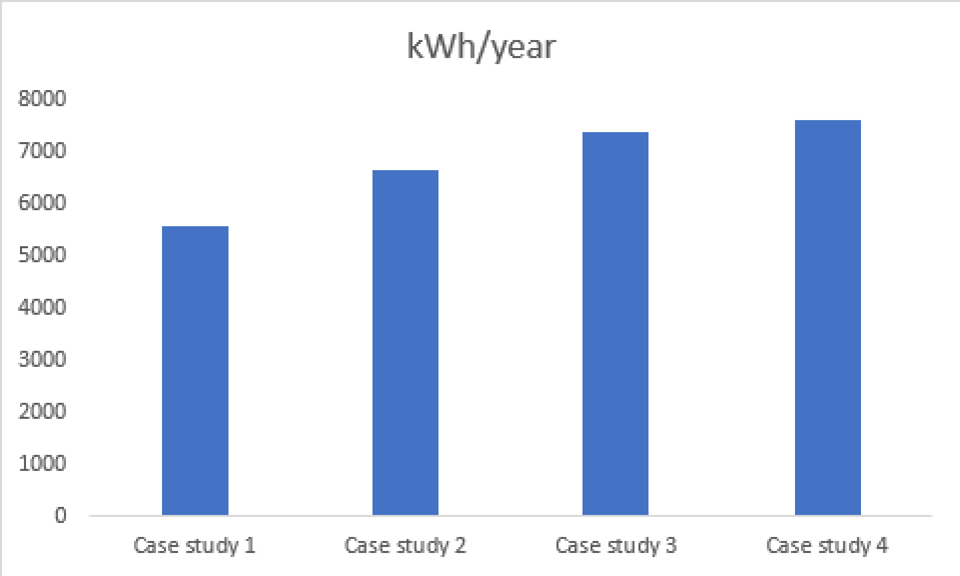


Figure 16: Annual electricity generation from PV installed on one side of the roof

House number 1 is considered as a baseline to calculate the percentage of the PV electricity increased for the other houses, and this result is presented in following Table 8:

Table 9:Percentage electricity generation for the houses with PV installation on one side of the roof

	Direction from south	PV electricity Generation (Kwh/year)	% increased
House 1	0 degrees	5564	
House 2	30 degrees	6642	19,37
House 3	60 degrees	7364	32,35
House 4	90 degrees	7612	36,81

5. Discussion

The houses with the same archetype in Växjö case studies were simulated in three renovation scenarios. For case 1 and using the no renovation scenario as the baseline, the yearly heat demand for the standard renovation decreased by roughly 20,4% and 28,2% for the advanced renovation.

The results from case 2 show that the yearly heat demand decreased by 20,1% for standard renovation and 27,9 % for advanced renovation, and the case 3, annual heat demand decreased by 19,9% for standard renovation and 27,6% for advanced renovation. In case 4, the yearly heat demand decreased by 19,8% for standard renovation and 27,4% for advanced renovation.

According to these results presented for cases (1-4), the yearly heat demand for the different renovation scenarios decreased by an average of 20% for standard renovation and 28% for advanced renovation. For the case studies with the standard renovation scenario results in case 1, the yearly heat energy decreases by 20,4%, case 2 is 20,1%, case 3 is 19,9%, and case 4 is 19,8%.

For the advanced renovation scenario with different directions(orientation), results in case 1 heat demand energy decreased by 28,2%, case 2 is 27,9%, case 3 is 27,6%, and case 4 is 27,4%. These results from the same renovation with different orientations (cases) conclude that there are no differences in houses' yearly heat demand savings in Växjö. (See Table 10 for summary results for the case studies and the renovations scenarios)

Table 10: Simulation results from the different renovations scenarios with case studies

	heat demand (kWh/ year)				% yearly heat energy saving			
	case 1 (0 degrees)	Case2 (30)	case3(60)	case4(90)	case 1	case 2	case 3	case 4
No renovation	11926	12084	12250	12311				
Standard renovation	9491	9652	9818	9879	-20,4%	-20,1%	-19,9%	-19,8%
Advanced renovation	8566	8717	8875	8939	-28,2%	-27,9%	-27,6%	-27,4%

One of the main parts of the results section is analyzing the PV annual electricity generation. When the houses installed PV on one side of the roof, this concludes that the yearly electricity generation from the PV was increased by 36,81% from house 1 to house 4.

The electricity generated from the PV installed on both sides of the roof decreased by 5,3% from house 1 to house 4. This result was unexpected, and it could be caused by two reasons: the impact of the Energy Plus Weather (EPW) from the data file TMY or the impact of installing PV on both sides.

The data file from the TMY Växjö region showed that the weather is 65% cloudy (Shown in Figure 17).

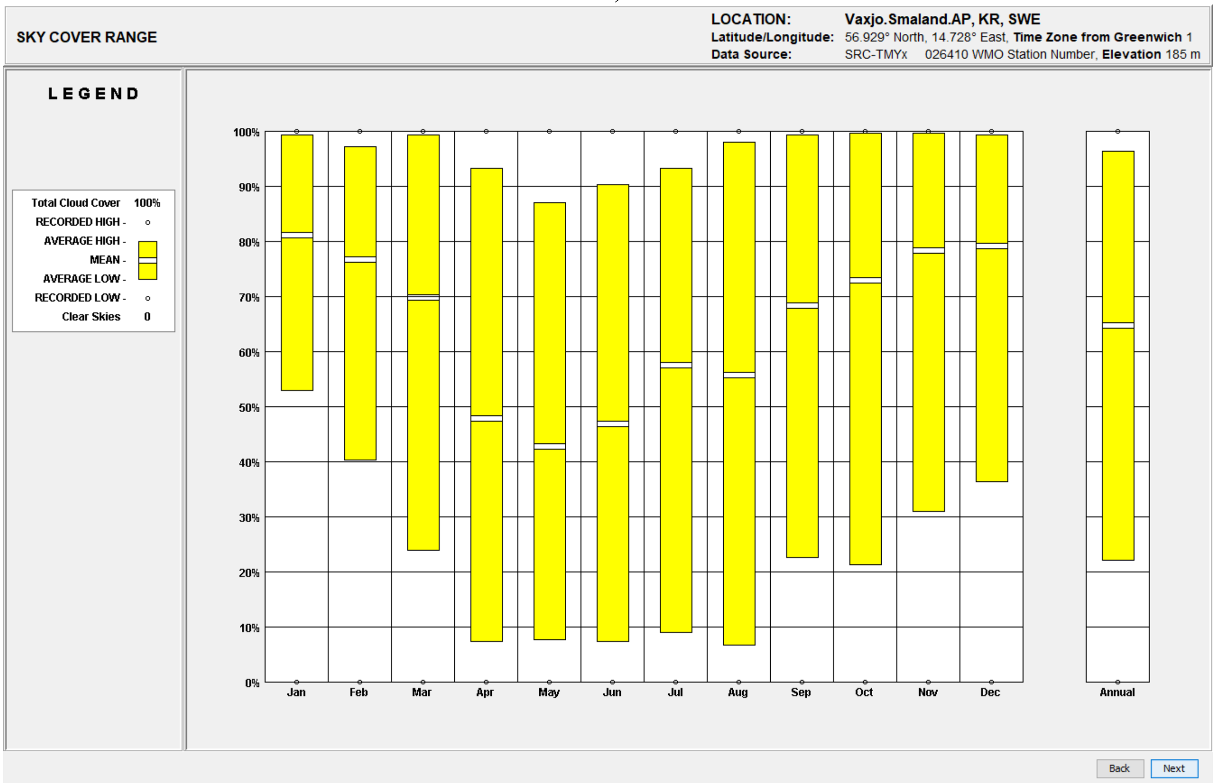


Figure 17: Växjö weather data (Source from TMY weather data file)

Maybe this could be a reason that the electricity generation from PV decreased. Another reason is the PV installation regarding the design of the house. It is a pitched roof, and the PV was installed on both sides, as shown in Figure 18.

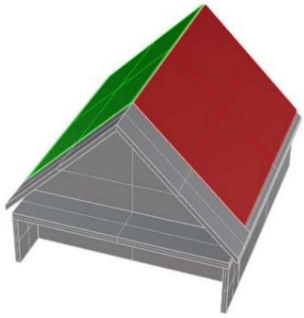


Figure 18: Illustration of the PV panels installed on both sides of the roof.

For the houses in the same area, the PV installation on both sides when the house's orientation changed could result in one side increasing while the other decreasing, which can be another reason the electricity generation decreased. These results from the PV generation open the door for further analysis by other researchers.

6. Conclusion

Advanced renovation is the best option for renovation scenarios for energy saving, and the direction of the house has no impact on the heat demand energy of the houses with the same renovation scenario.

The installation side of the PV has no impact on house 1, with the direction 0 degrees from the south, and this means that the house owner for this house could install PV on one side or both sides.

House number 4 is the best direction to install PV with one side on the roof (south direction) and, the house could generate 36,8% more than house 1; and house 3 is the next best direction to install PV on one side of the roof for the houses in Växjö. Therefore, orientation of PV is important when it is going to be installed just on one side.

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Appendix A

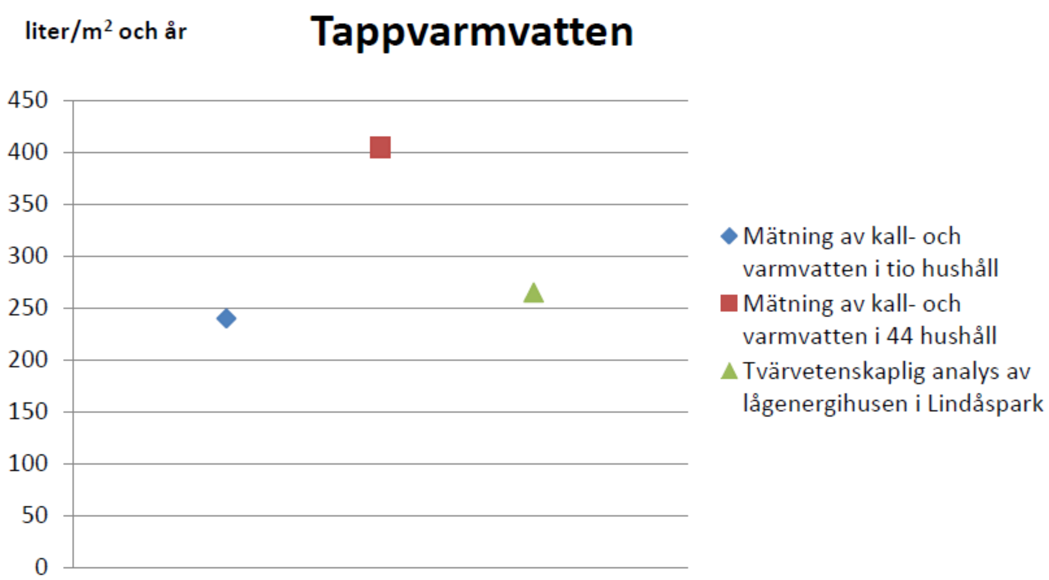
4.3.2 Småhus

Schabloner

Schabloner som uttrycks i liter/m2 och år saknas i det genomgångna underlaget.

Mätningar

I Figur 7 redovisas resultat från tre olika mätprojekt. Det viktade medelvärdet för mätningarna är 350 liter/m^2 och år.



Figur 7. Mätningar av tappvarmvatten i småhus [liter/m^2 och år]

[13] Dvs. det viktade medelvärdet exklusive Svenska Bostäders mätdata.

Regarding the data collected from Swedish single-house domestic heat water use, their average is 380 l/m^2 per year. Convert this value per day instead of the year.

$$Domestic\ heat\ water\ = 350 \frac{liter}{m^2\ year} * \frac{1}{360} = 0{,}95 \text{ liter per day}$$

Appendix B

Case 1

with no renovation

Month	Zone Sensible Heating kWh
Jan	2441
Feb	1840
Mar	1634
Apr	982
May	2
Jun	0
Jul	0
Aug	0
Sep	0
Oct	1155
Nov	1652
Dec	2220
Total (1 year)	11926

Standard renovation

Month	Zone Sensible Heating kWh
Jan	1944
Feb	1470
Mar	1311
Apr	763
May	0
Jun	0
Jul	0
Aug	0
Sep	0
Oct	905
Nov	1325
Dec	1774
total 1 year	9491

Advanced renovation

Month	Zone Sensible Heating kWh
Jan	1755
Feb	1330
Mar	1183
Apr	680
May	0
Jun	0
Jul	0
Aug	0
Sep	0
Oct	814
Nov	1201
Dec	1603
Total (1 year)	8566

Appendix C

Case 2

No renovation

Month	Zone Sensible Heating kWh
Jan	2476
Feb	1879
Mar	1661
Apr	960
May	0,4
Jun	0
Jul	0
Aug	0
Sep	0
Oct	1190
Nov	1674
Dec	2244
Total (1 year)	12084

Standard renovation

Month	Zone Sensible Heating kWh
Jan	1978
Feb	1507
Mar	1338
Apr	741
May	0
Jun	0
Jul	0
Aug	0
Sep	0
Oct	945
Nov	1346
Dec	1797
Total (1 year)	9652

Advanced renovation

Month	Zone Sensible Heating kWh
Jan	1787
Feb	1364
Mar	1207
Apr	660
May	0
Jun	0
Jul	0
Aug	0
Sep	0
Oct	851
Nov	1221
Dec	1626
Total (1 year)	8717

Appendix D:

Case 3

No renovation

Month	Zone Sensible Heating kWh
Jan	2514
Feb	1921
Mar	1690
Apr	938
May	0
Jun	0
Jul	0
Aug	0
Sep	0
Oct	1213
Nov	1705
Dec	2269
Total (1 year)	12250

Standard renovation

Month	Zone Sensible Heating kWh
Jan	2013
Feb	1548
Mar	1368
Apr	720
May	0
Jun	0
Jul	0
Aug	0
Sep	0
Oct	970
Nov	1379
Dec	1821
Total (1 year)	9818

Advanced renovation

Month	Zone Sensible Heating kWh
Jan	1822
Feb	1406
Mar	1235
Apr	631
May	0
Jun	0
Jul	0
Aug	0
Sep	0
Oct	878
Nov	1254
Dec	1649
Total (1 year)	8875

Appendix E

Case 4

No renovation

Month	Zone Sensible Heating kWh
Jan	2517
Feb	1938
Mar	1705
Apr	950
May	0
Jun	0
Jul	0
Aug	0
Sep	0
Oct	1210
Nov	1720
Dec	2271
Total (1 year)	12311

Standard renovation

Month	Zone Sensible Heating kWh
Jan	2017
Feb	1564
Mar	1384
Apr	731
May	0
Jun	0
Jul	0
Aug	0
Sep	0
Oct	968
Nov	1394
Dec	1823
Total (1 year)	9879

Advanced renovation

Month	Zone Sensible Heating kWh
Jan	1826
Feb	1422
Mar	1254
Apr	640
May	0
Jun	0
Jul	0
Aug	0
Sep	0
Oct	877
Nov	1269
Dec	1651
Total (1 year)	8939

Appendix F: PV on both sides of the roof

PV electricity generation monthly(kWh)

House 1 (0 degrees)

Month	Generation (Electricity) kWh
Jan	75
Feb	190
Mar	416
Apr	738
May	942
Jun	921
Jul	823
Aug	689
Sep	404
Oct	217
Nov	90
Dec	52
total 1 year	5556

House 2 (30 degrees)

Month	Generation (Electricity) kWh
Jan	87
Feb	197
Mar	416
Apr	725
May	915
Jun	904
Jul	806
Aug	675
Sep	403,7
Oct	228,2
Nov	93,6
Dec	62
Total (1 year)	5513

House 3 (60 degrees)

Month	Generation (Electricity) kWh
Jan	106
Feb	219
Mar	418
Apr	687
May	852
Jun	851
Jul	758
Aug	634
Sep	394
Oct	240
Nov	113
Dec	76
Total (1 year)	5349

House 4 (90 degrees)

Month	Generation (Electricity) kWh
Jan	112
Feb	236
Mar	423
Apr	648
May	839
Jun	830
Jul	739
Aug	610
Sep	381
Oct	240
Nov	126
Dec	80
Total (1 year)	5266

Appendix G: PV on one side of the roof

House 1 (0 degrees from the south)

Month	Generation (Electricity) kWh
Jan	81
Feb	186
Mar	407
Apr	701
May	973
Jun	868
Jul	791
Aug	746
Sep	427
Oct	247
Nov	80
Dec	57
Total (1 year)	5564

House 2 (30 degrees from the south)

Month	Generation (Electricity) kWh
Jan	132
Feb	277
Mar	536
Apr	861
May	1083
Jun	955
Jul	878
Aug	841
Sep	528
Oct	327
Nov	130
Dec	94
Total (1 year)	6642

House 3 (60 degrees from the south)

Month	Generation (Electricity) kWh
Jan	172
Feb	357
Mar	639
Apr	976
May	1132
Jun	1001
Jul	925
Aug	882
Sep	594
Oct	380
Nov	181
Dec	124
Total (1 year)	7364

House 4 (90 degrees from the south)

Month	Generation (Electricity) kWh
Jan	184
Feb	393
Mar	688
Apr	1033
May	1139
Jun	1026
Jul	946
Aug	871
Sep	610
Oct	384
Nov	207
Dec	132
Total (1 year)	7612

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