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Energy audit of a single-family house in a city in the middle of Sweden

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Abstract

The world is currently submerged in two big problems: supply energy crisis and climate change. It is clear that society has to do its best to overcome these challenges, and one effective way to mitigate their effects is by conducting an energy audit, which helps to identify the weaknesses and strengths of the buildings, enabling improvements in their thermal efficiency.

The main goal of this study was to carry out an energy audit on a century-old single-family house located in a city in the middle of Sweden. To achieve this, relevant data of the building was gathered such as the bills and some temperature and dimension measurements. Subsequently, the calculations of the energy losses and gains were done manually. From this step it was observed that almost 70 % of the thermal losses occurred due to transmission through the walls, windows and roof. To reduce these losses, potential energy-saving measures were studied, such as replacing the 2-panel windows with 3-panel windows and adding 200 mm of mineral wool to the roof. Both improvements reduced transmission losses around 700 kWh/year and diminished CO2 emissions around 20 kg/year, which implied a decrease of 1262 and 1277 SEK per year for each measure respectively. However, the profitability of these measures was difficult to attain because the required initial capitals are probably higher than the investments allowed, which are around 17371 and 17579 SEK for each measure respectively.

Moreover, a study about installing photovoltaic solar cells was conducted and it resulted in a significant positive impact in the energy usage of the house. In particular, this improvement lead to a reduction of 2471 kWh per year, which equaled to an annual decrease of 6036 SEK. These annual savings implied an investment allowed of 58620 SEK. Furthermore, a decrease of 99 kg of CO2 emissions per year was obtained. In conclusion, this measure yielded substantial profitability, making it the most recommended option for future energy-saving improvements.

Finally, changing in the occupant's behavior by reducing the indoor temperature had a positive impact on the house without the need for an initial investment. Specifically, it decreased around 105 kWh per year.

Keywords: 'energy audit', 'building energy efficiency', 'renewable sources', 'building envelope', 'windows efficiency' and 'isolation of houses in Sweden'.

Preface

For many years, I have aspired to become an industrial engineer specialized in the energy systems area because I wanted to contribute to society's efforts in overcoming the climate change crisis the world is currently submerged in. This project represents the culmination of my master's studies and it has provided me an opportunity to consolidate my knowledge in the field of energy engineering, a subject that I am passionate about. In order to reach this point, I have invested a lot of effort, but I am aware that many people have assisted me throughout this journey. Therefore, the first thing I would like to do before proceeding with this thesis is expressing my gratitude to them.

This project would not have been possible without the assistance of my supervisor, Nawzad Mardan, who has encouraged to give the best of myself. And of course, thanks to my assistant supervisor, Roland Forsberg, who has provided me with all I needed to undertake this study. I am grateful for having both of them as supervisors because they are really passionate about the field of energy.

Moreover, I would like to extend my gratitude to the owners of the house of study for opening their doors and allowing me to carry out an energy audit of their property.

Finally, I would like to express my gratitude to my beloved ones for their support throughout these months.

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1 Introduction

First of all, a description of the project and its background is made. Also the main aim and objectives are stated in this section.

1.1 Description of the project

This project carries out a complete energy audit of a residence in Skutskär, a city in the middle of Sweden. This method is now widely prevalent worldwide and it consists in studying a building from an energy perspective in order to identify its weaknesses and strengths so proper optimizations can be proposed. In other words, the main goal of an energy audit is to increase the energy efficiency of the system under study so the energy use can be decreased.

Nowadays, addressing global warming has become an ethical imperative due to its undeniable consequences, such as rising temperatures. The energy audit can also play a crucial role in improving the environmental impact of buildings and advancing towards sustainable energy systems.

Furthermore, the geopolitical tensions between Russia and Ukraine have caused a global impact on the supply chain of energy sources, leading to a mismatch between energy supply and demand. Consequently, the energy prices have significantly risen, impacting drastically in every country's economy. This situation has further emphasized the importance of implementing energy improvements, making the energy audit to play a key role in addressing this economic crisis.

As mentioned earlier, the residential single-family house under study is located in Skutskär, a city in the middle of Sweden. This building was constructed in 1908, which indicates many possibilities for improvement, since the technologies implemented to convert energy have been significantly optimized over the last century. This project was very interesting for the author for the possibility to improve the house energetically in the greenest possible way. Moreover, if the results of this study were implemented, the families living in this house or in similar houses could reduce their energy costs, which might assist them in mitigating the impact of the future energy crises.

1.2 Background

This project was proposed as part of the thesis work list at the University of Gävle and it is supervised by Roland Forsberg and Nawzad Mardan. The idea of conducting an energy audit myself was really attractive, as it can increase my knowledge as an industrial engineer. Additionally, there is a high likelihood that I will need to analyze energy systems in order to improve its efficiency throughout my career. Furthermore, since the energetical crisis and global warming are some of the main concerns of today's society, I would like to make a positive contribution towards addressing these challenges.

Energy audits can be very different from one country to another due to variations in regulations. For example, not all countries have the same strict regulations regarding the carbon footprint of buildings. Moreover, the project can vary depending on the construction methods and location of the house. Important factors to consider for conducting a proper analysis of the building are the local weather, materials used, characteristics of the location, availability energy sources near the house, and sustainability regulations of the country of study.

Given that the house of study is located in a city in the middle of Sweden, it is important to understand the context of the energy audits in this northern country. Swedish Energy Performance Certificates assess the energy performance of buildings based on energy bills.

1.3 Literature review

In order to carry out the energy audit, several scientific journals and papers were reviewed, and the most relevant ones will be studied in this section. Tools such as Google Scholar, Diva-portal and Science Direct were used to search all literature related to this project. The key words used to find the following literature have been 'energy audit', 'energy saving measures', 'windows efficiency' and 'solar panels in Sweden'.

First and foremost, when conducting an energy audit, it is important to analyze the main sources of energy loss in the house in order to reduce them. Dodoo et al. (2017) employed a simulation tool to analyze different variable parameters and combinations in a 3-storey concrete frame multi-storey residential building constructed in the 1970s in Sweden. The selected parameters encompassed outdoor microclimate, building thermal envelope, and household electrical equipment, including technical installations. In this study, they determined that the most important factor in reducing energy usage in a residential building was the building envelope, which includes the walls, the windows, the roof and the door. The house being audited already has insulated walls, but it would be interesting to study reinforcing the insulation by adding a new material that could improve the thermal behavior.

Regarding the windows, they should also be studied since they probably suffer from transmission losses as well. In order to analyze them, there are different relevant aspects such as the shape of the window, its area and the orientation. Regarding these last two factors, traditionally in Sweden, the windows facing the south are larger than those facing the north. A study conducted by Person et al. (2006) used the simulation tool DEROB-LTH to investigate whether there were significant changes in thermal behavior by reducing the area of windows facing the south and increasing the area of the windows facing the north. The results showed that the size of the energy efficient windows did not have a major influence on the heating demand in the winter, but was relevant for the cooling need in the summer. Moreover, this study also stated that the optimal window size facing south was smaller than the original size of the examined buildings.

Furthermore, several studies concluded that the thermal and optical properties of the glass are the most influential factors in determining the thermal losses and optimizing windows. The study carried by Gasparella et al. (2011) used TRNSYS software to analyze the building performance and determined that the thermal transmittance is relevant in both winter and summer conditions, affecting both energy usage and peak loads. Another study conducted by Gao et al. (2014) carried out a laboratory experiment to study whether improving the glazing properties helped enhance thermal and optical performance. The results showed that after adding aerogel glazing units, which improved the glass properties, there was a 58% reduction in heat losses and 38% reduction in light transmittance. From these papers, it is clear that a beneficial energy-saving measure would likely be replacing the 2-panels-windows in the house with more energy-efficient windows. This improvement is expected to decrease the energy thermal losses while taking advantage of the natural lighting provided by the windows.

Once the possible energy-saving measures for the building envelope have been searched, the implementation of electricity production sources should be studied as well. The supervisor of this thesis recommended considering the implementation of solar panels, as photovoltaic energy is one of the most promising sources of electricity production. According to Mohammedi et al. (2014), this energy source consists in taking profit of the irradiance of the sun by converting it into direct current through solar panels. Solar energy has the principal benefit of sustainability since it does not produce carbon emissions. Furthermore, it is an inexhaustible energy source since the sun will always be present, unlike fossil fuels that have a limited lifespan. Considering these benefits, it can be said that the implementation of solar energy can play a key role in making the house as environmentally friendly as possible and ensuring the longevity of this measure to compensate the initial investment.

However, solar energy not only has benefits but can also be affected by several factors that reduce the amount of energy converted, which is clearly a disadvantage. The same study mentioned earlier tested, through an experiment, how the efficiency can vary depending on the impact of the shadows (Mohammedi et al. 2014). To conduct the test, they analyzed different combinations of shadows on 18 modules of solar cells. The results showed that shadows negatively affected the efficiency, and in general terms, it was better to have a completely shaded string than several partially shaded ones. In the case of the house studied in this project, there is not a high risk of shadows since there are no tall buildings or trees near the building. Therefore, the efficiency of the installed solar cells should not decrease due to this factor.

Another factor that affects the solar energy conversion is the environmental conditions since they can influence the system's efficiency. These conditions can vary significantly depending on the location of the panel installation. The study carried by Dahlin & Reifeldt (2015) studied different European countries by comparing the installed capacity of solar power, the amount of solar power converted, geographic positioning, and financial incentives for each country, with the aim of finding solutions for Sweden in the future. The results showed that the number of solar panels can significantly influence the profitability of this energy source. A larger amount of panels could compensate for the lack of sunlight hours during cold months in a country like Sweden.

Moreover, according to an experimental study conducted by Yahyaoui & Segatto (2016) the power of the installation can also be influenced by the voltage and the current. This research paper tested these two factors by empirical evidence using a Control and Data Acquisition System, which proved the effectiveness of varying the current and voltage indicators.

Regarding the profitability of solar energy as an energy-saving measure, northern countries such as Sweden are known for having fewer sunlight hours during a significant part of the year. Therefore, the economic feasibility should be carefully analyzed since the house of study is located in a city in Mid-Sweden. According to Sommerfelt et al. (2016), the positioning of the solar panels influenced the profitability of solar energy. The study stated that installing panels facing south was the best option. Furthermore, the same study analyzed the feasibility of installing solar photovoltaic cells in Sweden using a Monte Carlo simulation. The profitability of solar panels implementation in Sweden was significantly high (97%) when owners could take advantage of a subsidy. However, the study also stated that without any economic aid, the payback period for a photovoltaic panel installation ranged from 9 to 25 years. The study also concluded that for the sustained near-term growth of the market, direct support policies from the government were necessary (Sommerfelt et al. 2016).

The good news is that according to a study made by Yang et al. (2020), the Swedish government is actively promoting the installation of solar cells by offering several subsidies. This paper stated that since 2009, Sweden offered a direct capital subsidy for the installation of grid-connected photovoltaic systems, which covered 60% of the installation cost in 2009 and 20% in 2020. Furthermore, a tax deduction of 0.6 SEK/kWh for sold electricity was introduced in 2015, applicable to up to 30,000 kWh or the amount of electricity purchased per year. The study also indicated that the Swedish government will continue to encourage the expansion of solar energy as part of its efforts to mitigate the effects of the current climate crisis. Therefore, it is highly likely that this measure could be a profitable option for reducing the energy use of the house under study.

Lastly, when carrying out an energy audit, it is important to note that not only changes to the building envelope and the implementation of renewable sources might help reduce the energy usage. Mata et al. (2013) calculated the energy demand of individual buildings taking into account their physical and thermal properties, the characteristics of the existing heating and ventilation systems and the climate conditions. To achieve this, the study used a Simulink model, which solved the energy balance for buildings, and a provisional user interface written in MATLAB, which handled the input and output data from the Simulink model. This study concluded that measures leading to a reduction in indoor air temperature resulted in one of the greatest energy savings, estimated at around 14 %. In this regard, altering the occupants' behavior regarding the energy usage can also make a difference. Adopting habits such as lowering the indoor temperature in winter and raising it in summer can significantly impact the energy costs.

In summary, based on this literature review, it is clear that analyzing potential energy-saving measures aimed at reducing transmission losses would be a crucial point in this energy audit. These improvements should focus on enhancing wall insulation and improving the glass properties of the windows. Furthermore, in order to make a profitable solar panel installation, this project has to consider the financial assistance, panel positioning, the number of panels, voltage, and current. And the last but not least measure should focus on studying how changing the behavior of the occupants can help reduce energy usage.

1.4 Aim and objectives

The main aim of this research project is to conduct an energy audit of a single-family house located in Skutskär. The goal is to propose and analyze improvements that can decrease the energy usage and increase the sustainability of the building.

Therefore, the primary objective is to perform accurate energy measurements and carry out several calculations to gather information about the strengths and weaknesses of the house. Another important objective is to examine at least two energy-saving measures that might be feasibly implemented in the house, analyzing them from a realistic economic perspective. These measures include the implementation of solar panel cells and also the optimization of the building envelope and windows.

1.5 Approach

To carry out this project, a literature review has been conducted, and relevant data has been gathered. Following this first step, calculations of the current energy behavior of the house, as well as calculations of possible energy-saving measures, have been performed manually. The software used for the project is WINSUN, which has helped with the calculations of the photovoltaic solar cells.

2 Theory

In anticipation of the energy audit, firstly a variety of terms and concepts must be defined before getting to the point. In this chapter, several files provided by Roland Forsberg have been utilized.

2.1 Energy audit

First of all, the definition of what an energy audit is must be stated. It is a survey of a building, which generally is a residence house but it can also be about an industrial factory or a mall. The purpose of this survey is to improve the energy efficiency of the system, reduce the energy usage, and decrease the building's carbon footprint.

When conducting an energy audit, the initial step is to study the energy distribution within the house to determine the main thermal losses and devise solutions. After this step, it is important to gather information from literature review to select appropriate solutions for the house of study and analyze them. To assess the impact of these improvements, the analysis will consider not only the decrease in energy usage but also the payback period and greenhouse emissions for each of them will be calculated.

Finally, a discussion is held to determine the most effective improvements and make a decision.

2.2 Energy balance equation

The main goal of an energy audit is to reduce purchased energy and reduce energy costs. Thus, it is essential to minimize thermal losses to maintain energy balance. The energy balance equation states that the energy entering a system, such as the house under study, must be equal to energy leaving it. The Equation 1 below shows the balance between the energy entering (E_{in}) and the energy leaving the system (E_{out}).

$$E_{in}\,[Wh] = E_{out}\,[Wh] \quad (1)$$

It should be noted that E_{in} is a sum of the energy coming from different sources, as shown in Equation 2. First, there is $E_{heating}$, which refers to the energy heating supplied by external sources. Next, there is $E_{house\ holding}$, which accounts for the energy provided by occupants, equipment, and lightning within the house. Additionally, there is E_{solar}, which is the energy obtained from solar radiation. Furthermore, there are $E_{domestic}$ and E_{wood}, which correspond to the domestic electricity use and the wood usage, respectively.

$$E_{in}\,[Wh] = E_{heating} + E_{house\ holding} + E_{solar} + E_{domestic} + E_{wood} \quad (2)$$

E_{out} is also a sum of energies leaving the system due to different factors, as shown in Equation 3. Firstly, there is $E_{transmission}$, which represents transmission losses. Secondly, there are also losses from ventilation, represented by $E_{ventilation}$ and $E_{unc.ventilation}$. Moreover, there are thermal losses caused by the hot tap water, represented as $E_{hot\ tap\ water}$. Finally, there is E_{heater}, representing the energy usage of the workshop heater in the house.

$$E_{out}\,[Wh] = E_{transmission} + E_{ventilation} + E_{unc.ventilation} + E_{hot\ tap\ water} + E_{heater} \quad (3)$$

Once all the energies are stated, their definitions and the way to calculate them are determined below.

2.3 Energy supplied by external sources

In this sub-chapter, the different energies supplied by external sources will be defined.

2.3.1 Energy supplied for heating

The energy represented as $E_{heating}$ is used for heating the house and comes from external suppliers, which is purchased by the occupants of the residence. In this project, it includes the heat pump, electric radiator, and the workshop heater in the house. When carrying out an energy audit, one of the main objectives is to reduce this type of energy aiming towards a reduction of the house bills.

To estimate the total amount of this energy used and its cost, the energy bills provided by the owners are used.

2.3.2 Energy supplied for domestic electricity usage

The energy represented as $E_{domestic}$ involves the energy used for the electricity of the house as the television, fridge, and other machines. Its value can be found in the invoices.

2.3.3 Energy supplied by wood usage

The value of this energy, represented as E_{wood}, is provided by the owners and represents the annual amount of wood.

2.4 Energy gains

In this sub-chapter, the different gains will be defined.

2.4.1 Energy gains from house holding

House holding energy, represented as $E_{house\ holding}$, refers to the heat emitted by the elements of the house, even if it is in a slightly amount. The main sources of energy are the people living in the house, the lights of the building, and equipment such as computers, fridges and other electronic devices.

Furthermore, areas of the house that receive direct sunlight and are at a higher temperature can contribute to house holding energy. This includes windows, walls, and the roof.

2.4.2 Energy gains from solar radiation

The energy represented as E_{solar} comes from solar radiation, which enters to the house through windows as sunlight and warms up the single-family house. This fact helps in cold months, which goes from the middle of September to the middle of May. It should be noted that even though there are fewer hours of sunlight in winter, they are still useful enough to increase the temperature of the house. During the warmer months, from the middle of May to the middle of September, the sun radiation does not contribute significantly as the building is already warm due to the high outdoor temperature.

The equation to calculate the energy gains from solar radiation is the following:

$$E_{solar}\,[W \cdot h] = A \cdot\ q \cdot r \cdot c \cdot\ \ d \quad (4)$$

The factors of the formula above are the following:

- A : windows area $[m^2]$
- q : sum of the energy of the day $\left[\frac{W \cdot h}{m^2}\right]$
- r : sun radiation factor
- c : cloudy factor
- d : days of sun rays per month $\left[\frac{days}{month}\right]$

2.5 Energy losses

In this sub-chapter, the energy losses will be defined.

2.5.1 Energy losses from transmission

As stated in the literature review conducted in the previous chapter, the major thermal losses in the building are attributed to transmission through the building envelope (Dodoo et al. 2017). This envelope includes the walls, windows, floor, and roof. To calculate the energy losses from transmission ($E_{transmission}$), the following Equation 5 will be used:

$$E_{transmission}\ [W \cdot h] = \sum_{i=0}^{n}(A_i \cdot U_i) \cdot {}^{\circ}h \quad (5)$$

Where the main factors of the equation are defined below:

- A_i : Area of heat transmission i $[m^2]$
- U_i : U-value of heat transmission area i $\left[\frac{W}{m^2 \cdot {}^{o}C}\right]$
- ${}^{o}h$: Degree hours $[{}^{o}C \cdot h]$

As shown in Equation 5, the areas and the U-values have a subindex ‘i’ because there can be several different values for them within the same house. This variation is due to the influence of the materials used. Depending on the surface under study, such as walls or other parts of the building like windows, the values of these parameters will vary.

However, the building envelope is not the only area where heat losses occur. Thermal bridges, which are the areas where different materials merge, can also lose energy since the difference between the thermal conductivity of each material leads to a reduction of resistance and an increase of thermal losses. To calculate these losses, the following Equation 6 is used:

$$E_{transmission} = \left(\sum_{i=0}^{n}(A_i \cdot U_i) + \sum_{i=0}^{n}(\psi_i \cdot l_i) + \sum_{i=0}^{n} X_i\right) \cdot {}^{\circ}h \quad (6)$$

Where the main factors of the equation are defined below:

- A_i : Area of heat transmission i $[m^2]$
- U_i : U-value of heat transmission area i $\left[\frac{W}{m^2 \cdot {}^{o}C}\right]$
- ψ_i : Coefficient of thermal transmittance for the linear thermal bridge i $\left[\frac{W}{m \cdot K}\right]$
- l_i : Length of the thermal bridges i towards heater indoor air $[m]$
- X_i : Coefficient of thermal transmittance for the point thermal bridge i $\left[\frac{W}{K}\right]$
- ${}^{o}h$: Degree hours $[{}^{o}C \cdot h]$

2.5.2 Energy losses from ventilation

When calculating the thermal losses caused by ventilation ($E_{ventilation}$), it is important to specify the type of building under study, as there may be some changes for the calculation method. The building of study is a residential single-family house, which implies that there is no mechanical ventilation.

The equation to calculate the energy losses from ventilation is the following:

$$E_{ventilation}\,[W \cdot h] = q \cdot \rho \cdot \ C_p \cdot \ {}^{o}h \ (7)$$

The factors of the formula above are the following:

- q : Airflow $\left[\frac{m^3}{s}\right]$
- ρ : Density of the air $\left[\frac{kg}{m^3}\right]$
- C_p : Specific heat capacity $\left[\frac{J}{kg \cdot {}^{o}C}\right]$
- ${}^{o}h$: Degree hours $[\ {}^{o}C \cdot h]$

2.5.3 Energy losses from uncontrolled ventilation

Another source of thermal losses is from uncontrolled ventilation, which is calculated in a similar manner to controlled ventilation but with slightly differences. This type of losses, represented as $E_{unc.ventilation}$, are caused by leakages, that can happen because of cracks, gaps, open doors and windows and also due to bad sealing of them.

$$E_{\ unc.ventilation}\,[W \cdot h] = q_{leakage} \cdot \rho \cdot \ C_p \cdot \ {}^{o}h \ (8)$$

The factors of the formula above are the following:

- $q_{leakage}$: Air leakage flow $\left[\frac{m^3}{s}\right]$
- ρ : Density of the air $\left[\frac{kg}{m^3}\right]$
- C_p : Specific heat capacity $\left[\frac{kJ}{kg \cdot {}^{o}C}\right]$
- ${}^{o}h$: Degree hours $[\ {}^{o}C \cdot h]$

The air leakage flow is calculated as the Equation 9 states:

$$q_{leakage}\left[\frac{m^3}{s}\right] = \frac{n \cdot V}{3600\left[\frac{s}{h}\right]} \ (9)$$

The factors of the formula above are the following:

- n : Air changes per hour $[h^{-1}]$
- V : Total volumen of the house $[m^3]$

Since it was very complicated to measure accurately the air leakage flow, in this project, the uncontrolled ventilation will be calculated as the difference from the energy entering the house and the energy leaving it.

2.5.4 Energy losses from hot tap water

Another relevant way of losing heat comes from the hot tap water ($E_{hot\ tap\ water}$). In order to calculate these losses, the following Equation 10 is used:

$$E_{hot\ tap\ water}\,[W \cdot h] = \frac{q \cdot \rho \cdot C_p \cdot \Delta T}{3600\left[\frac{s}{h}\right]} \quad (10)$$

The factors of the formula above are the following:

- q : Water flow volume $\left[\frac{m^3}{s}\right]$
- ρ : Density of the water $\left[\frac{kg}{m^3}\right]$
- C_p : Specific heat capacity $\left[\frac{kJ}{kg \cdot {}^oC}\right]$
- ΔT : Difference between the temperature on which the water is heated (55 ^oC) and the temperature on which the water is supplied (5 ^oC). $[{}^oC]$.

2.5.5 Energy losses from the heater

In this project, the last kind of source to lose energy is from the heater of the workshop (E_{heater}). This value is calculated in the following way:

$$E_{heater}[W \cdot h] = \frac{E_{used\ by\ the\ heater}}{corr\ factor} \quad (11)$$

Basically, it is the energy used by the heater divided by a correction factor.

2.6 Present value equation

With all this relevant data gathered, some initial calculations referring the current energy status of the house can be carried out. After this step, and as stated before, the measures will be analyzed and discussed from an economic perspective. To do so, the present value equation will be used. This equation helps to estimate if an improvement is worth the investment or not. The calculus of the profitability of the measure is done with the Equation 11:

$$N = B \cdot n - K \quad (12)$$

The factors of the formula above are the following:

- N : Profit of the measure. If its value is positive, then it is worth the invesment. $[SEK]$
- B : Money saved per year $\left[\frac{SEK}{year}\right]$
- n : Coefficient that depends on the number of maximum years wished for the profitability of the measure
- K : Initial investment cost $[SEK]$

3 Method

For this energy audit, a low-complexity method was applied. First of all, information related to energy audit and energy saving measures in Sweden was collected. The main sources for this step were found in websites such as Science Direct and also asking to the supervisors of this project, Nawzad Mardan and Roland Forsberg. The keywords used were the following: ‘energy audit’, ‘building energy efficiency’, ‘renewable sources’, ‘building envelope’ and ‘isolation of houses in Sweden’. Moreover, the information from the bills and the house diagrams was collected.

Secondly and once the relevant data was gathered, temperature measurements were made in the house. With all this data, calculations about the energy usage were made. Even if the calculus could be done by the software IDA-ICE, the recommendation of the assistant supervisor was to make them manually, since the knowledge acquired would be greater than using the program. It must be mentioned that for this step the energy balance equation was used taking into account all the possible energy losses that the building could have and also other factors such as the location, weather, and materials used for this house.

Later, the proposed energy-saving measures were studied by doing an evaluation of their effect on the energy usage. Finally, the results were discussed.

This methodology of research was suitable for this kind of project since if it was necessary it would be easy to replicate the experiment.

3.1 Case study

The house of study seen in Figure 1 was a single-family house build in 1908 in Skutskär, a Mid-Sweden city. The temperatures of each room of the house were measured with a thermal camera so proper calculations of thermal losses could be made. It is important to remark that these measurements were taken in a cold day, since the camera does not work very well when the outside temperature is higher than 10°C. Therefore, the measures were taken on March of 2023, when the average temperature was still below this temperature. Furthermore, the dimensions of each room were measured with the help of a tape measure. Other relevant data such as the invoices of heating and electricity, the wood usage and hot tap water usage were given by the owners.

FIGURE 1 : HOUSE OF STUDY. [OWN WORK]

3.2 Calculations of energy losses, energy gains and energy supplied

Once all the information of each heat transfer of the energy balance equation was gathered, the calculations were done in this sub-chapter.

3.2.1 Energy losses from ventilation

In order to calculate the energy losses from ventilation, the areas of both floors of the house were measured. These measurements allowed to calculate the areas of each floor. For further detail, the house blueprints can be seen in Figure 6, Figure 7 and Figure 8 in the Appendices.

$$A_{1st\,floor} = 9{,}25 \cdot 7{,}7 + 3 \cdot 2 = 77,2[m^3]$$

$$A_{2nd\,floor} = 9{,}25 \cdot 7{,}7 = 71{,}2[m^3]$$

Moreover, considering that it was a residential house, the following value was taken into account for the air flow for controlled ventilation (SVEBY,2023).

$$q_{air\,ventilation} = 0{,}00025 \left[\frac{m^3}{s \cdot m^2}\right]$$

From the area of each room and the air flow, the total air flow of the house could be calculated as it is shown below.

$$q_{air\,ventilation} = (77{,}2 + 71{,}2) \cdot 0{,}00025 = 0{,}037 \left[\frac{m^3}{s}\right]$$

Furthermore, from the temperature measurements, the following degree hours were obtained from Figure 9 of the Appendices. To calculate them, an interpolation was done considering a general outdoor temperature of 6,5 ^oC (SMHI, 2023) and an indoor temperature of 20 ^oC for each floor.

$$^oh_{1st\,floor} = {}^oh_{2nd\,floor} = 107050[\,^oC * h]$$

Therefore, the energy from ventilation for each floor was the following. It must be stated that an air density of 1,225 [kg/m^3] (Wikipedia 2023) and a specific heat capacity of air of 1,003 [kJ/$(kg \cdot K)$] (Bartleby 2023) were taken into account for the calculations.

$$E_{ventilation} = 0{,}037 \cdot 1{,}225 \cdot 1{,}003 \cdot 107050 = 4.881{,}4\ [kWh]$$

3.2.2 Energy losses from hot tap water

In order to estimate the energy losses coming from the hot tap water, it was important to know how much water was consumed annually in the house. The invoices provided by the owners stated that there was an annual use of 35 m^3. However, the whole usage of hot tap water equaled to a 33% of this amount, in other words, 11,7 m^3 of hot tap water is annually used by the owners. Moreover, as mentioned before, the temperature of the water coming from the pipes and the temperature of the hot tap water were assumed to be 5 ^oC and 55 ^oC respectively. In this way, there was a temperature difference of 50 ^oC, as used in the equation below. The calculation of the energy can be seen below, where the density and specific heat capacity for the water are 1000 [kg/m^3] and 4,18 [kJ/(kg· ^oC)], respectively.

$$E_{water} = \frac{11{,}7 \cdot 1.000 \cdot 4{,}18 \cdot 50}{3.600} = 677{,}3\ [kWh]$$

3.2.3 Energy losses from transmission

Transmission energy losses account for a great part of the total thermal losses of the building (Dodoo et al. 2017). These energy losses come from the walls, the windows, the roof and the doors. In order to calculate them, the following aspects were taken into consideration: the areas of thermal transmission, the U-value of each area and the difference of temperatures.

As stated before, the dimensions and the temperatures were measured with a tape measure and a thermal camera respectively.

Regarding the U-value calculation, the following aspects were taken into account such as the fact that the windows were made of 2-panels, the floor was usually better isolated than the roof and the doors, and the walls were formed by 70 [mm] insulation of concrete and 200 mm of wood.

In this way, the U-value of transmissions for the windows ($U_{windows}$) equals to 2,9 [W/m^2·°C] since they are formed by 2-panels. This value was taken from Figure 10 in the Appendices. The U-value of transmissions for the floor (U_{floor}), the doors (U_{doors}) and the roof (U_{roof}) equal to 0,35[W/m^2·°C], 1 [W/m^2·°C] and 0,47 [W/m^2·°C] respectively. This data was given by Professor Roland Forsberg from his experience.

Finally, to calculate the U-value of transmissions for the walls (U_{walls}), resistance for indoors and outdoors surfaces had to be calculated since there was radiation from the walls to the surroundings. For this calculation, data given by Professor Roland Forsberg was taken, as it can be seen in Table 10 in the Appendices.

$$R_{walls} = \frac{1}{0{,}47} + \frac{0{,}07}{0{,}036} \cdot \left(1 - \frac{45}{600}\right) + \frac{0{,}025}{0{,}14} \cdot \frac{45}{600} + \frac{0{,}015}{0{,}14} = 4{,}05\ [(m^2 \cdot °C)/W]$$

Then, applying the following equation, the U_{walls} could be calculated.

$$U_{walls} = \frac{1}{R_{walls}} = \frac{1}{4{,}05} = 0{,}25\ [\mathrm{W}/(\mathrm{m}^2 \cdot {}^{\circ}\mathrm{C})]$$

Once the U-values and the areas of the house were calculated, the transmission losses of the windows, floor, main door, the roof and the walls could be obtained as Table 1 shows. Another fact that must be mentioned and taken into account is that the energy transmission losses coming from the roof have been timed by 1,15 in order to compensate the radiation effect that the roof suffers.

TABLE 1 : TRANSMISSION LOSSES OF THE CURRENT STATUS OF THE HOUSE. [OWN WORK]

	First floor				Second floor				TOTAL
	Area [m^2]	U [W/(m^2·°C)]	^oh [°C ·h]	Result [kWh]	Area [m^2]	U [W/(m^2·°C)]	^oh [°C ·h]	Result [kWh]	Result [kWh]
Windows	12,1	2,9	107050	3756,4	12,5	2,9	107050	3865,0	7621,4
Floor	77,2	0,35	107050	2893,4	0,0	0,35	107050	0,0	2893,4
Door	2,1	1	107050	224,8	0,0	1	107050	0,0	224,8
Roof	0	0,47	107050	0,0	71,2	0,47	107050	3583,6	4121,1
Walls	93,4	0,25	107050	2471,1	70,7	0,25	107050	1858,7	4329,9
TOTAL				9345,7				9307,4	19190,6

3.2.4 Energy losses from the heater

As stated in the literature review, the energy losses from the heater was calculated in the following way, resulting in a value of 2427,2 [kWh].

$$E_{heater} = \frac{2500}{1{,}03} = 2427{,}2\ [kWh]$$

3.2.5 Energy gains from solar radiation

When carrying an energy audit of a building, not only the heat losses are taken into account but also the energy gains, as for example the thermal transfer coming from the sun rays that go through the windows, experiencing the phenomenon of radiation.

For the calculation of this energy gain, several aspects were taken into account. First of all, the orientation of the windows was an important factor when calculating the energy gain from solar radiation. In this way, the windows positioned towards the south experience a greater heat transfer than the ones that are located to the north, east or west (Sommerfelt et al. 2016).

A second aspect to pay attention was if the windows were made of one, two or three panels. In the case of this single-family house, all the windows were 2-glazed windows, which is very common in this type of building. For the 2-glass windows, the normal sun factor was 0,8. This value was taken from Figure 10 in the Appendices.

Another feature to take into account was the cloudy factor of the place where the house of study is located. The weather of the zone could significantly determine the amount of energy gains coming from solar radiation. This factor varied depending on the month, and were in the range of 0,42 to 0,63. The value of this factor was taken from Figure 11 in the Appendices. It is important to mention again that the solar radiation is a feature that is only considered from January to mid of May and from mid of September to December.

The last, but not least, feature to take into account was the orientation of the building, which went from -150 to -120 degrees. This was an important fact to determine the energy sum coming from the different orientations (South-East, South-West, North-East and North-West). Figure 13 in the Appendices shows the values of the energy sum for each orientation.

Table 2 shows the data of several factors depending on the month and also the calculation of the total energy gain coming from solar radiation.

TABLE 2 : SOLAR GAINS THROUGH THE WINDOWS OF THE CURRENT STATUS OF THE HOUSE. [OWN WORK]

	January	February	March	April	May	September	October	November	December
Sun factor	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
Cloudy factor	0,45	0,49	0,58	0,58	0,63	0,58	0,51	0,42	0,43
Days per month (days)	31,0	28,0	31,0	30,0	15,0	15,0	31,0	30,0	31,0
Area windows S-E (m^2)	5,9	5,9	5,9	5,9	5,9	5,9	5,9	5,9	5,9
Area windows S-W (m^2)	2,7	2,7	2,7	2,7	2,7	2,7	2,7	2,7	2,7
Area windows N-E (m^2)	10,0	10,0	10,0	10,0	10,0	10,0	10,0	10,0	10,0
Area windows N-W (m^2)	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0
Energy sum from S-E ($(W\cdot h)/m^2$)	1900,0	3590,0	5130,0	6110,0	6065,0	5290,0	4265,0	2475,0	1415,0
Energy sum from S-W ($(W\cdot h)/m^2$)	1900,0	3590,0	5130,0	6110,0	6065,0	5290,0	4265,0	2475,0	1415,0
Energy sum from N-E ($(W\cdot h)/m^2$)	145,0	505,0	1310,0	2655,0	3755,0	1715,0	770,0	235,0	85,0
Energy sum from N-W ($(W\cdot h)/m^2$)	145,0	505,0	1310,0	2655,0	3755,0	1715,0	770,0	235,0	85,0
TOTAL (kWh)	207,2	425,6	932,4	1318,5	846,2	505,8	617,0	251,2	143,5

In order to obtain the annual solar energy production, the last row of Table 2 was summed up and resulted in 5.247,5 [kWh] per year.

3.2.6 Energy gains from house holding

To do an estimation of the energy gains coming from the house holding energy, the following calculation was done, using some data given by Professor Roland Forsberg:

$$E_{house\ holding} = 2[people] \cdot 80 \left[\frac{\text{kW}}{\text{people} \cdot \text{h}}\right] \cdot 18 \left[\frac{\text{h}}{\text{day}}\right] \cdot 250 \left[\frac{\text{days}}{\text{year}}\right] = 720\ [kWh]$$

In this way, an annual energy generation of 720 kWh resulted from the house holding energy.

3.2.7 Energy supplied for heating

The single-family house of study used 12.502 [kWh] of purchased energy per year. From the bills of the house it could be seen that from this amount of energy, 4.100 [kWh] were considered to be used for domestic electricity, 1.500 kWh for the electrical radiator, 677,3 [kWh] for hot tap water and 2.500 [kWh] for the heater of the workshop of the house. Furthermore, there was an annual wood usage of 5 [m^3], which equaled to 4.000 [kWh], but this energy was not part of the 12.502 [kWh].

In order to calculate the energy coming from the heat pump, a COP of 3 was assumed.

$$E_{heat\ pump} = (12.502 - 4.100 - 1.500 - 677{,}3 - 2.500) \cdot 3 = 11.174{,}1\ [kWh]$$

Finally, the energy for heating was calculated, where a correction factor of 1,03 was taken into account. It must be mentioned that the COP and the correction factor values were given by Roland Forsberg based on his experience.

$$E_{heating} = \frac{11.174{,}1\ + 1.500 + 2.500}{1{,}03} = 14.732{,}1\ \ [kWh]$$

3.2.8 Energy balance

Once all the energy losses and gains were calculated, the energy balance equation was used. It must be stated that for the domestic usage, only a 70% was considered to enter the house since there are losses due to the efficiencies of the machines. The value was given by Roland Forsberg based on his experience.

$$E_{in} = E_{solar} + E_{house\ holding} + E_{heating} + E_{domestic} + E_{wood}$$

$$E_{in} = 5.247,5 + 720 + 14.732,1 + 4.100 \cdot 0,7 + 4000 = 27.569,6\ [kWh]$$

$$E_{in} = E_{out} = 27.569,6\ [kWh]$$

Then, the energy losses coming from uncontrolled ventilation could be calculated, resulting in a value of 393 [kWh].

$$E_{unc.ventilation} = E_{transmission} + E_{ventilation} + E_{hot\ tap\ water} + E_{heater} - E_{out}$$

$$E_{unc.ventilation} = 19.190,6 + 4.881,4 + 677,3 + 2.427,2 - 27.569,6 = 393,0\ [kWh]$$

In Table 3, a summary of all energy losses and gains can be seen.

TABLE 3 : ENERGY BALANCE FOR THE CURRENT STATE OF THE HOUSE. [OWN WORK]

Energy gains and energy supplied [kWh]		**Energy losses [kWh]**	
Solar	5247,5	Transmission	19190,6
Heating	14732,1	Hot tap water	677,3
House holding	720,0	Ventilation	4881,4
Domestic	2870,0	Heater	2427,2
Wood	4000,0	Uncontrolled ventilation	393,0
TOTAL	27569,6	TOTAL	27569,6

3.3 Calculations of the possible saving measures

As stated before, the main objective of this energy audit was to reduce the energy usage and to improve the efficiency of the building. For this reason, the following measures were studied:

- Measure 1: Replacing 2-panels windows with 3-panelswindows
- Measure 2: Reinforcing the insulation of the roof
- Measure 3: Installing solar panels
- Measure 4: Reducing the usage of the electric radiator

3.3.1 Measure 1: Replacing 2-panels windows with 3-panels windows

As seen in the literature review, a great amount of the heat losses come from the transmission losses through the windows. As explained before, the factors that influence this kind of energy losses were the U-value, the areas of transmission and the difference of temperatures. The easiest way to reduce the transmission losses was decreasing the U-value, which could be achieved by increasing the number of panels of the windows. Currently, all the windows of the house were formed by two panels, which implied a U-value of 2,9 [W/m^2·°C]. This value could be reduced to 1,9 [W/m^2·°C] if the 3-glazed-windows were installed. This value was taken from Figure 10 in the Appendices.

It must be stated that even if 3-panels-windows reduce the transmission losses, the solar radiation gains would also be reduced since the sun factor would decrease from 0,8 to 0,72. This value was taken from Figure 10 in the Appendices.

In order to analyze if this measure was worth the investment, the new transmission losses were studied in the following way. First of all, the new transmission losses were calculated in Table 4.

TABLE 4 : TRANSMISSION LOSSES OF THE FIRST MEASURE. [OWN WORK]

	First floor				Second floor				TOTAL
	Area [m^2]	U [W/(m^2·°C)]	^oh [°C ·h]	Result [kWh]	Area [m^2]	U [W/(m^2·°C)]	^oh [°C ·h]	Result [kWh]	Result [kWh]
Windows	12,1	1,9	107050	2461,1	12,5	1,9	107050	2532,3	4993,3
Floor	77,2	0,35	107050	2893,4	0,0	0,35	107050	0,0	2893,4
Door	2,1	1	107050	224,8	0,0	1	107050	0,0	224,8
Roof	0	0,47	107050	0,0	71,2	0,47	107050	3583,6	4121,1
Walls	93,4	0,25	107050	2471,1	70,7	0,25	107050	1858,7	4329,9
TOTAL				8050,4				7974,6	16562,6

As Table 4 shows, the new transmission losses equaled to 16.562,6 kWh. Then, the savings from the initial value was calculated.

$$\Delta E_{transmission} = 19.190,6 - 16.562,6 = 2.628,1\ [kWh]$$

The second step was to calculate the solar savings applying the new sun factor of 0,72. Table 5 shows it.

TABLE 5 : SOLAR GAINS OF THE FIRST MEASURE. [OWN WORK]

	January	February	March	April	May	September	October	November	December
Sun factor	0,72	0,72	0,72	0,72	0,72	0,72	0,72	0,72	0,72
Cloudy factor	0,45	0,49	0,58	0,58	0,63	0,58	0,51	0,42	0,43
Days per month (days)	31,0	28,0	31,0	30,0	15,0	15,0	31,0	30,0	31,0
Area windows S-E (m^2)	5,9	5,9	5,9	5,9	5,9	5,9	5,9	5,9	5,9
Area windows S-W (m^2)	2,7	2,7	2,7	2,7	2,7	2,7	2,7	2,7	2,7
Area windows N-E (m^2)	10,0	10,0	10,0	10,0	10,0	10,0	10,0	10,0	10,0
Area windows N-W (m^2)	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0
Energy sum from S-E ($(W\cdot h)/m^2$)	1900,0	3590,0	5130,0	6110,0	6065,0	5290,0	4265,0	2475,0	1415,0
Energy sum from S-W ($(W\cdot h)/m^2$)	1900,0	3590,0	5130,0	6110,0	6065,0	5290,0	4265,0	2475,0	1415,0
Energy sum from N-E ($(W\cdot h)/m^2$)	145,0	505,0	1310,0	2655,0	3755,0	1715,0	770,0	235,0	85,0
Energy sum from N-W ($(W\cdot h)/m^2$)	145,0	505,0	1310,0	2655,0	3755,0	1715,0	770,0	235,0	85,0
TOTAL (kWh)	186,5	383,0	839,0	1186,7	761,6	455,2	555,3	226,1	129,2

The new solar radiation gains equaled to 4.722,7 [kWh]. Then the reduction from the initial value was calculated.

$$\Delta E_{solar} = 5.247{,}5 - 4.722{,}7 = -524{,}7\ [kWh]$$

In order to see the total thermal savings when applying this measure, the transmissions losses and solar radiation saving were summed up. It could be seen that the reduction of losses was greater than the reduction of gains, so the measure was useful to reduce the energy usage.

$$E_{saved} = \Delta E_{transmission} + \Delta E_{solar} = 2.628{,}1 - 524{,}7 = 2.103{,}3\ [kWh]$$

The next step was to calculate the new energy of the heating and the energy of the heat pump.

$$E_{heating} = \frac{11.174{,}1 + 1.500 + 2.500 - 2.103{,}3}{1{,}03} = 12.690{,}0\ \ [kWh]$$

$$E_{heat\ pump} = 12.690{,}0 \cdot 1{,}03 - 1.500 - 2.500 = 9.070{,}7\ [kWh]$$

Once the energy for the heating and for the heat pump were calculated, the energy from the bill could be determined and its variation.

$$E_{Bill} = \left(\frac{9.070,7}{3}\right) + 1.500 + 4.100 + 677,3 \ + 2.500 = 11.800,9 \text{ [kWh]}$$

$$\Delta E_{bill} = 12.502 - 11.800,9 = 701,1 \ [kWh]$$

As it can be seen from the equations above, the energy saving with the implementation of this measure equaled to 701,1 [kWh/year]. Then, a study to calculate which was the maximum investment allowed was done. To analyze it, the following aspects were taken into consideration:

- Electricity price of 1,8 [SEK/kWh]
- A maximum of 30 years to make profit of the measure, which implied a value of n=13,765. See Figure 12 in Appendices.

So firstly, the money saved annually from this measure was calculated.

$$Money\ saved = 701,1 \cdot 1,8 = 1.262,0 \left[\frac{\text{SEK}}{\text{year}}\right]$$

Then, a calculation of the maximum investment allowed to make it profitable was done. The result was that the measure should not cost more than 17.371,4 [SEK].

$$N = B * n - K = 1.262,0 \cdot 13,765 - K = 17.371,4 \ [SEK] - K]$$

Finally, a calculation of the reduction of CO2 emissions was done, considering that in Sweden the average value for emissions is 0,028 kg CO2 per kWh (Nowtricity,2023). There was a decrease of 19,6 [kg / year].

$$CO2\ emissions\ saved = 701,1 \cdot 0,028 = 19,6 \left[\frac{\text{kg}}{\text{year}}\right]$$

3.3.2 Measure 2: Reinforcing the insulation of the roof

Another possible measure focused on reducing the transmission losses was to reinforce the roof insulation with 200 mm of mineral wool. This would allow to increase the resistance of the roof and consequently to diminish the U-value of it.

To calculate the new transmission losses, a new U-value of 0,13 [W/m^2·°C] was obtained. This result came from the following calculations using data of the materials that can be seen in Table 10 in the Appendices.

$$R_{roof} = \frac{1}{0,47} + \frac{0,02}{0,036} = 7,68 \ [(\text{m}^2 * °\text{C})/W]$$

$$U_{roof} = \frac{1}{R_{roof}} = \frac{1}{7{,}68} = 0{,}13\ [W/(m^2 \cdot °C)]$$

Table 6 shows the new transmission losses when applying this measure.

TABLE 6 : TRANSMISSION LOSSES OF THE SECOND MEASURE. [OWN WORK]

	First floor				Second floor				TOTAL
	Area [m²]	**U [W/(m²·°C)]**	**°h [°C ·h]**	**Result [kWh]**	**Area [m²]**	**U [W/(m²·°C)]**	**°h [°C ·h]**	**Result [kWh]**	**Result [kWh]**
Windows	12,1	2,90	107050,0	3756,4	12,5	2,90	107050,0	3865,0	7621,4
Floor	77,2	0,35	107050,0	2893,4	0,0	0,35	107050,0	0,0	2893,4
Door	2,1	1,00	107050,0	224,8	0,0	1,00	107050,0	0,0	224,8
Roof	0,0	0,47	107050,0	0,0	20,4	0,47	107050,0	1023,9	1177,5
Roof improved	0,0	0,13	107050,0	0,0	50,9	0,13	107050,0	708,8	815,2
Walls	93,4	0,25	107050,0	2471,1	70,3	0,25	107050,0	1858,7	4329,9
TOTAL				9345,7				7456,5	17062,2

The energy savings obtained were the following.

$$\Delta E_{transmission} = 19.190{,}6 - 17.062{,}2 = 2.128{,}5\ [kWh]$$

Now, the new energy for heating and for the heat pump were calculated.

$$E_{heating} = \frac{11.174{,}1 + 1.500 + 2.500 - 2.128{,}5}{1{,}03} = 12.665{,}6\ [\ kWh]$$

$$E_{heat\ pump} = 12.665{,}6 \cdot 1{,}03 - 1.500 - 2.500 = 9.045{,}6[kWh]$$

$$E_{Bill} = \left(\frac{9.045{,}6}{3}\right) + 1.500 + 4.100 + 677{,}3 + 2.500 = 11.792{,}5\ [\text{kWh}]$$

$$\Delta E_{bill} = 12.502 - 11.792{,}5 = 709{,}5\ [kWh]$$

The implementation of this measure lead to a reduction of 709,5 [kWh/year]. Once again, an electricity price of 1,8 [SEK/kWh] and a maximum of 30 years for profitability were considered.

$$Money\ saved = 709{,}5 \cdot 1{,}8 = 1.277{,}1\ \left[\frac{\text{SEK}}{\text{year}}\right]$$

$$N = B \cdot n - K = 1.277{,}1 \cdot 13{,}765 - K = 17.579{,}2\ [SEK] - K$$

It can be seen from the previous equations that there would be an economic saving of 1.277,1 [SEK/year] and the maximum investment for this improvement should be 17.579,2 [SEK].

Finally, a calculation of the reduction of CO2 emissions was done, considering that 0,028 kg CO2 were emitted per kWh (Nowtricity,2023). There was a decrease of 19,9 [kg / year].

$$CO2\ emissions\ saved = 709{,}5 \cdot 0{,}028 = 19{,}9 \left[\frac{\text{kg}}{\text{year}}\right]$$

3.3.3 Measure 3: Installing solar panels

The measure decided to reduce the energy usage from the grid was installing solar panels in the house. It was not only expected to reduce the purchased energy from an external source, but it would as well significantly reduce the carbon footprint of the single-family house since it is a renewable energy source.

To study this improvement, the software WINSUN was used. This program requests for relevant data of the building such as the location, the tilt angle of where the photovoltaic modules are located, the ground reflection, the horizontal shading and the direction. Furthermore, another aspects such as the power of the photovoltaic cells and the available area to install them were introduced in the software. All the values used are shown in Table 7.

TABLE 7 : DATA INTRODUCED IN WINSUN. [OWN WORK]

Information of the place	
Tilt [o]	35
Direction[o]	45
Ground reflection	0,2
Horizontal Shading [o]	10
Code Post	84141
Information of the modules	
Pmax [kWp]	4
Area modules[m2]	24
Efficiency	0,19

Once the software WINSUN was run, the distribution of energy converted by the solar cells for each month of the year was given by the program. This electricity production is shown in Figure 2.

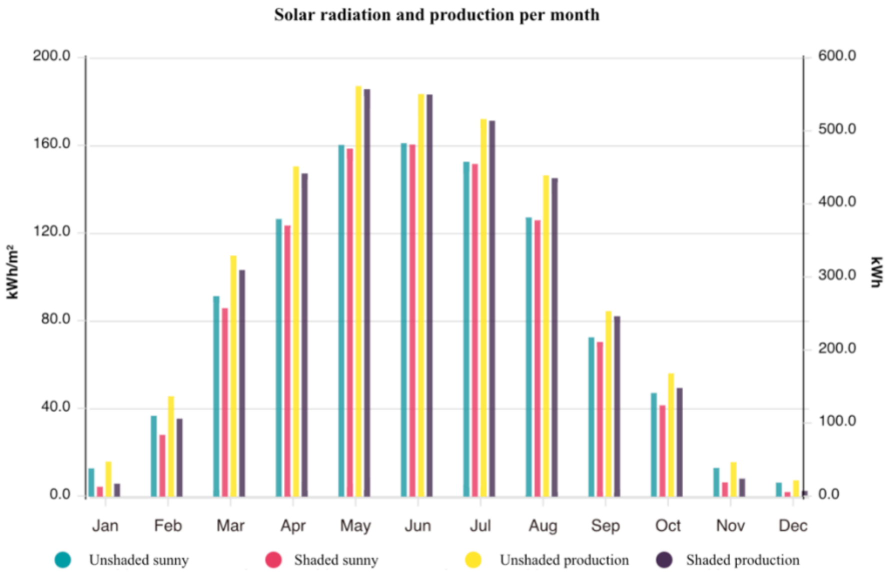

FIGURE 2 : ELECTRICITY PRODUCTION FOR EACH MONTH. [WINSUN 2023]

The distribution clearly showed that during the warm season, the solar cells could make a significant impact in the energy usage of the house. Table 8 shows in detail the electricity production for each month, doing a differentiation of the production if there were shadows or not.

TABLE 8 : SOLAR ENERGY PRODUCTION FOR EACH MONTH. [WINSUN 2023]

Month	Unshaded solar radiation [kWh/ m^2]	Shaded solar radiation [kWh/ m^2]	Unshaded production [kWh]	Shaded production [kWh]
January	12,9	4,5	48	17,8
February	36,9	28,2	137,4	106,7
March	91,5	86	329,9	310,2
April	126,7	123,7	452,1	442,4
May	160,5	158,8	562,1	557,8
June	161,3	160,7	551,1	550,4
July	152,8	151,8	517	514,6
August	127,4	126,1	439,8	436
September	72,7	70,6	254	247
October	47,3	41,7	168,8	148,8
November	13,1	6,5	47,2	24,6
December	6,4	2,1	22,3	7,9
TOTAL	1002,5	960,7	3529,7	3364,2

In this project, the solar energy was considered to be converted without the presence of shadows, so the value was 3.529,7 [kWh / year]. Furthermore, a suggestion of 70 % of the electricity production was used, resulting in an annual solar energy conversion of 2.470,8 [kWh].

$$\Delta E_{bill} = 12.502 - 2.470,8 = 10.031,2\ [kWh]$$

Moreover, the author of this project suggested selling the 30 % left of the total amount of electricity produced. This suggestion resulted in 1058,9 [kWh] sold annually.

Taking into account an electricity price of 1,8 [SEK/kWh], an electricity price for sold electricity of 1,5 [SEK/kWh] and a payback period of 15 years to make the measurement profitable, the money saved annually and the investment allowed were the following:

$$Money\ saved = 2.470,8 \cdot 1,8 + 1.058,9 \cdot 1,5 = 6.035,8\ [\frac{\text{SEK}}{\text{year}}]$$

$$N = B \cdot n - K = 6.035,8 \cdot 9,712 - K = 58.619,6\ [SEK] - K]$$

Finally, a calculation of the reduction of CO2 emissions was done, considering that 0,028 kg CO2 were emitted per kWh (Nowtricity,2023). There was a decrease of 98,8 [kg / year].

$$CO2\ emissions\ saved = 3.529,7 \cdot 0,028 = 98,8\ \left[\frac{\text{kg}}{\text{year}}\right]$$

3.3.4 Measure 4: Reducing the usage of the electric radiator

As seen in the literature, reducing the indoor temperature could make a positive impact in the energy bill. According to the European Commission (2022), a reduction of 1°C in ambient temperature leads to energy savings of 7 %. Then, the average inside temperature would result to be around 19 °C. This decrease could be achieved by reducing the amount of hours the electric radiator is used. Therefore, if the 1500 [kWh] that the electric radiator use decrease a 7 %, there would be a reduction of 105 [kWh].

Taking into account an electricity price of 1,8 [SEK/kWh] the money saved annually was the following:

$$Money\ saved = 105 \cdot 1,8 = 189\ [\frac{\text{SEK}}{\text{year}}]$$

The investment was not calculated since there is no capital needed to carry out this saving measure.

Finally, a calculation of the reduction of CO2 emissions was done, considering that 0,028 kg CO2 were emitted per kWh. There was a decrease of 2,9 [kg / year].

$$CO2\ emissions\ saved = 105 \cdot 0,028 = 2,9\ \left[\frac{\text{kg}}{\text{year}}\right]$$

4 Results

Once the current energy status of the house and all the possible measures have been studied, a summary of their results was done in Table 9. This table includes the energy gains, the energy supplied, and the energy losses which varied from one case to another. Furthermore, it also presents the energy bill, the savings, the investment allowed and the CO2 emissions reduction for each case. In this way, the energy from domestic use, house holding, and wood are not represented in this Table 9 since they remained constant across all cases. The same applied to the energy losses from ventilation, the heater and the hot tap water.

TABLE 9 : COMPARISON OF THE RESULTS OF ALL THE CASES OF STUDY. [OWN WORK]

	Energy gains [kWh]	Energy supplied [kWh]	Energy losses [kWh]	Energy bill [kWh]	Energy savings [kWh]	Annual saving [SEK]	Investment allowed [SEK]	CO2 emissions reduction [kg]
	Solar	Heating	Transmission					
Current status	5247,5	14732,1	19190,6	12502,0	-	-	-	-
Measure 1: Replacing windows	4722,7	12690,0	16562,6	11800,9	701,1	1262,0	17371,4	19,6
Measure 2: Reinforcing the insulation of the roof	5247,5	12665,6	17062,2	11792,5	709,5	1277,1	17579,2	19,9
Measure 3: Installing solar panels	5247,5	14732,1	19190,6	10031,2	2470,8	6035,8	58619,6	98,8
Measure 4: Reducing the usage of the electrical radiator	5247,5	14732,1	19190,6	12397,0	105,0	189,0	-	2,9

First of all, there was the current energy status of the house, where no energy-saving measures were applied. Once the energy balance of the base case was determined, several changes were implemented, which affected the transmission losses, solar radiation gains, and heating supplied. However, the measures studied did not have any impact on house holding gains, hot tap water losses, and ventilation losses. The main reason of this was that the energy losses were mainly due to transmission, and the chosen improvements aimed to directly reduce these losses.

Table 9 also shows the energy savings from an economic perspective. As stated in the objectives chapter, one of the main goals of this project was to conduct a realistic study of possible energy improvements for this old house. This involved evaluating the economic profitability of each case, as measures that saved energy but were not worth the investment would not be implemented. The only measure where the initial capital was not calculated was the improvement of reducing the usage of the electrical radiator since no investment was required.

Based on these results, several aspects can be stated before discussing them in detail in the next chapter:

- All the measures had a positive impact in the house as energy savings could be achieved in all cases.

- The most significant energy savings were achieved with the installation of solar panels.

Regarding the sustainability, when the energy usage is reduced, the climate impact is lowered, as indicated by the reduction in CO_2 emissions. When a measure is implemented, such as improving the glass properties of the windows, it helps reduce cold drafts and outdoor noises. Similarly, measures like installing solar cells increase the share of electricity production from renewable sources, making electricity production more sustainable.

However, it is important to note that when a new measure, such as replacing the windows or installing solar panels is implemented in a building, the carbon footprint can increase due to the impact of the new materials and the energy required to carry out the improvement. Furthermore, the transportation involved also impacts sustainability. Therefore, determining the exact climate impact of these measures can be challenging.

5 Discussion

Once the results have been reviewed, this chapter will discuss the findings in detail. The focus of the discussion will not only be on the potential measures but also the energy gains and losses observed in the current situation of the house.

5.1 Energy losses

Regarding the energy losses, this project confirms that the primary and most significant heat losses are due to transmission (Dodoo et al. 2017). However, there are other losses caused by ventilation and uncontrolled ventilation, hot tap water and the workshop heater as shown in Figure 3. A discussion of these losses is done below.

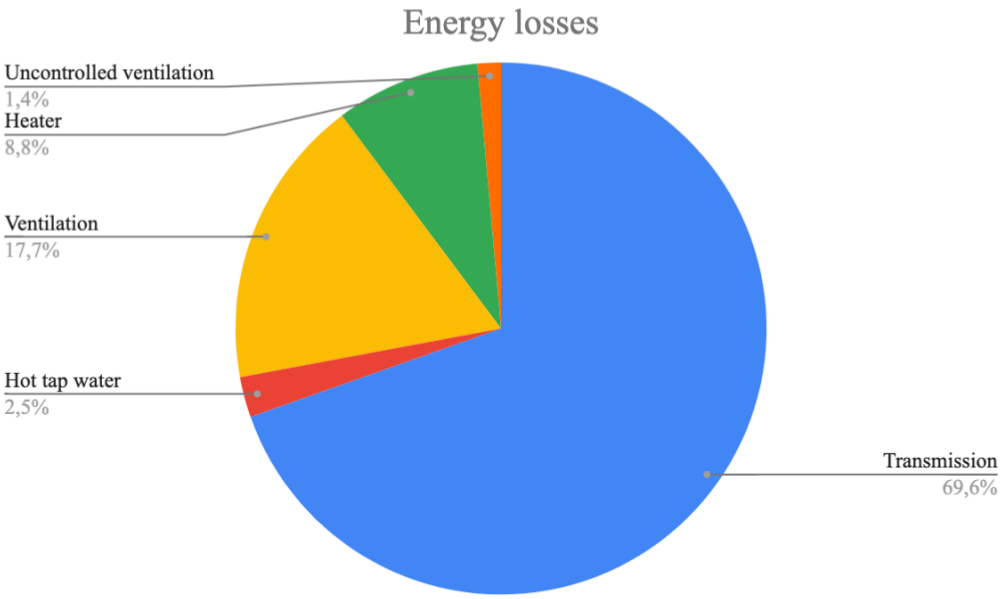

FIGURE 3 : THE PERCENTAGE OF THE ENERGY LOSSES OF THE CURRENT STATUS OF THE HOUSE. [OWN WORK]

5.1.1 Energy losses from transmission

This type of thermal losses accounted for a significant portion of the energy leaving the building, representing 69,6 % of the total energy losses. This high percentage was influenced not only by the age of the single-family house and the poor insulation of its envelope but also by the limited ventilation flow and minimal use of hot tap water by the two occupants of the house.

Upon closer examination of the transmission losses, it becomes evident that they could be caused from various sources, including windows, walls, roof, doors, and floor. The percentage of these losses is shown in Figure 4.

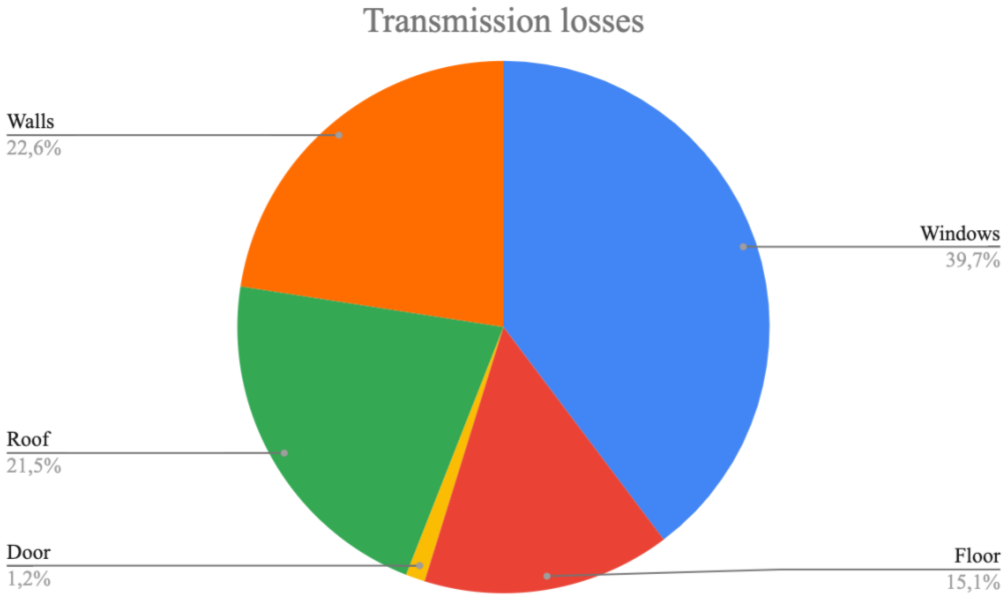

FIGURE 4 : THE PERCENTAGE OF THE TRANSMISSION LOSSES FOR THE WINDOWS, WALLS, ROOF, DOOR AND THE FLOOR FOR THE STUDIED HOUSE. [OWN WORK]

Based on the percentages presented in Figure 4, it can be stated the major transmission losses were attributed to the windows. Therefore, a potential energy-saving measure studied was to replace the windows with ones that had improved glass properties (Gasparella et al. 2011).

Addressing the insulation of all the walls in the house appeared to be a costly endeavor, given their substantial contribution to transmission losses. As a more viable option, the focus of this study was directed towards improving the insulation of the roof, which accounted for 21,5 % of the total transmission losses.

5.1.2 Energy losses from ventilation and uncontrolled ventilation

In other types of buildings, ventilation can contribute for a greater part of the energy losses. However, in the case of this single-family house, ventilation accounts for 17,7 % of the total energy losses. Furthermore, the uncontrolled ventilation losses represent just 1,4% of the total energy losses. As discussed in relation to transmission losses, these values can be attributed to the absence of mechanical ventilation systems in the studied house.

It is important to note that these energy losses were not calculated precisely since it was quite difficult to measure the uncontrolled ventilation of the house. However, an estimation of uncontrolled ventilation was made to achieve the most accurate result possible. While the use of a software such as IDA-ICE may have provided more accurate results, the level of precision attained was sufficient for this project.

It should be mentioned that no measures to specifically reduce ventilation losses were analyzed in this project, as the focus was primarily on decreasing transmission losses, which were nearly four times bigger than ventilation losses.

5.1.3 Energy losses from hot tap water

Hot tap water accounted for only 2,5 % of the energy losses, amounting to 677,3 [kWh/year]. Due to its minimal impact on energy losses, no measures specifically focused on reducing this type of energy were studied.

5.1.4 Energy losses from the heater

The heater in the workshop accounted for 8,8 % of the energy losses. Similar to the ventilation and the hot tap water losses, no measures targeting the reduction of this type of energy were studied, as transmission losses were eight times larger than heater's losses.

5.2 Energy gains and energy supplied

In terms of energy gains and energy supplied, heating accounted for the largest share of the total energy entering the system. However, the house also benefited from energy gained through solar radiation and house holding activities. Additionally, the building was supplied with electricity for domestic use and utilized wood, as shown in Figure 5. A discussion of these aspects follows.

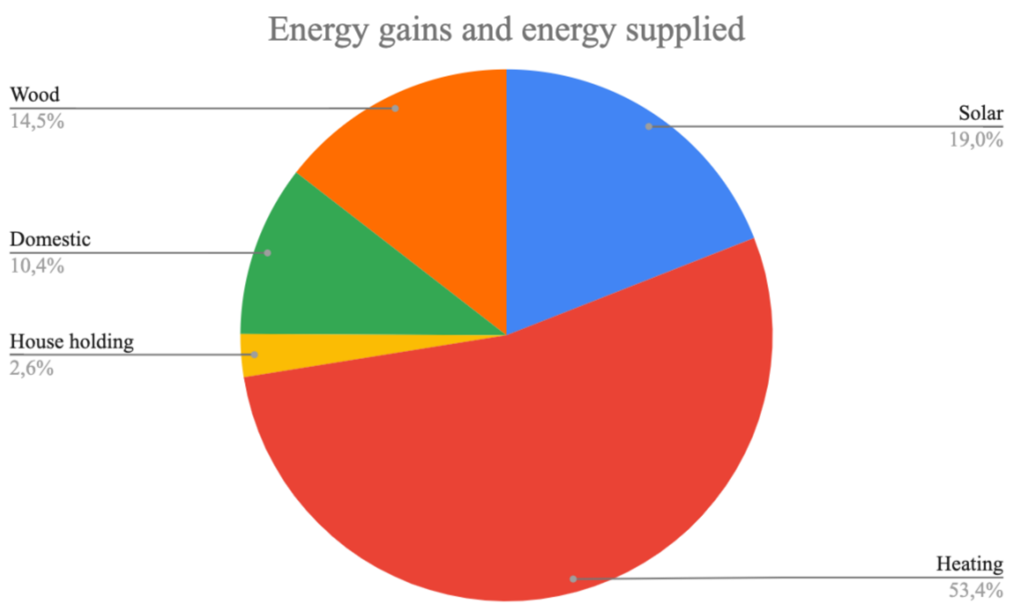

FIGURE 5 : THE PERCENTAGE OF THE ENERGY GAINS AND ENERGY SUPPLIED OF THE CURRENT STATUS OF THE HOUSE. [OWN WORK]

5.2.1 Energy supplied for heating

When conducting an energy audit, the primary economic goal is to minimize the energy purchased from external sources. In the case of the object under study, heating accounted for 53,4 % of the total energy entering the system. To address this energy usage, proposed measures include replacing the windows and improving the roof's insulation. These measures directly reduce the building's energy losses, thereby decreasing the demand for heating energy.

5.2.2 Energy gains from solar radiation

A way to gain energy without incurring costs was through solar radiation entering the windows. Despite being located in a mid-Sweden city with limited hours of sunlight during the cold season, this energy source accounted for 19,0 % of the total energy entering the house.

Among the proposed measures, changing from 2-glazed to 3-glazed-windows was the only one that could affect the solar radiation gains. While this measure has a positive impact on reducing transmission losses (Gao et al. 2014), it had a negative effect on solar radiation gains as the sun factor was reduced. However, the reduction in transmission losses outweighed the decrease in solar gains.

It should be noted that solar radiation was only considered during cold season, from half of September to half of May. This decision was based on the fact that the building already high temperatures in the warmer months, making the solar gains during that period insignificant.

5.2.3 Energy supplied by wood usage

Wood usage accounted for 14,5 % of the energy gains. No measures were focused on decreasing this type of energy, despite the fact that the owners had to pay for it. This decision was based on the fact that the energy purchased for heating was higher that the energy supplied by wood. Therefore, reducing this type of energy would possibly have a lower impact on the overall energy costs of the house.

5.2.4 Energy supplied for domestic electricity use

Another type of energy that needs to be purchased from external sources is domestic electricity use. Similarly to wood, no measures were directly focused on reducing this type of energy, as it accounted for only 10,4 % of the total energy entering the house.

5.2.5 Energy gains from house holding

Lastly, energy gains from house holding, generated by the equipment and the residents, accounted for only 2,6 % of the total energy entering the building. No measures resulted into a variation of the house holding energy, as it was complicate to increase this value.

5.3 Possible measures

Once the current energy balance of the residential building is discussed, several measures were studied and are discussed below.

5.3.1 Measure 1: Replacing 2-panels windows with 3-panels-windows

Increasing the thermal resistance of the windows can lead to a better heat behavior of the system (Gasparella et al. 2011). Therefore, the first measure to study was replacing 2-panels with 3-panels windows, considering the high transmission losses from the windows.

After carrying out the analysis of this potential energy-saving measure, it was observed that the transmission losses reduced by 2.628 $[kWh]$, while the solar radiation gains also decreased by 525 $[kWh]$. These reductions resulted in a bill savings of 701 $[kWh/$year] and a decrease of 20 [kg CO2/year]. Thus, the measure had a positive impact on the system. This study confirms the great influence of glass properties on the thermal behavior of the house. (Gasparella et al. 2011).

Furthermore, when considering the measure from an economic perspective, there was a saving of 1.262,0 [SEK/year]. However, the allowed investment for this improvement should be less than 17.371 [SEK], which seems a very low value for such an expensive measure. Therefore, this improvement does not appear to be a suitable option for this house, as it would not yield a significant profit.

5.3.2 Measure 2: Reinforcing the insulation of the roof

The second measure studied was to improve the insulation of the roof by adding 200 mm of mineral wool. After the calculation, a reduction of 1.277 [SEK/year] was achieved, and the maximum allowed investment was 17.579 [SEK], which seems a low initial capital for this type of improvement. Additionally, there was a decrease of 20 [kg CO2/year], which would have a positive effect on the climate impact. To determine whether this improvement should be implemented, a detailed cost analysis should be conducted.

5.3.3 Measure 3: Installing solar panels

The installation of solar photovoltaic panels proved to be a highly profitable improvement (Sommerfelt et al, 2016), as it would result in a reduction of approximately 2.471 [kWh/year] and a saving of 98,8 [kg CO2/year]. This would lead to a reduction of 6.036 [SEK/year]. Furthermore, the maximum allowed investment would be 58.620 [SEK] with a payback period of 15 years. This investment could be higher if the payback period was extended.

Even if this initial capital does not seem to be high enough for this type of measure, which is usually more expensive than this investment, the Swedish government is providing significant financial subsidies for such projects (Yang et al. 2020). Therefore, it would likely be a highly suitable option for the homeowners.

5.3.4 Measure 4: Reducing the usage of the electric radiator

Finally, the last measure studied was the reduction of the indoor temperature by decreasing the usage of the electrical radiator (Mata et al. 2013). Although this improvement resulted in the lowest energy reduction of only 105 [kWh/year], it is still a recommended energy-saving as it requires no investment. Additionally, it would lead to a decrease of 2,9 [kg CO_2/year] in CO_2 emissions.

However, it is important to note that achieving these results would require the occupants to agree to reduce the indoor temperature, which can be a challenging decision for some individuals. In order to encourage people to implement this measure, some regulations from the government would be beneficial. Currently, there are some countries such as Spain where there are some regulations regarding the limits of indoor temperature in public buildings. This regulation specifies that heaters can not be above 19 °C in winter and air conditioners can not be under 27 °C in summer (Euronews 2022). This type of rules can boost the implementation of this measure in all types of buildings, including residential houses such as the object of study.

6 Conclusions

After discussing the results of this energy audit, several conclusions can be drawn, which are explained in this chapter. Additionally, the project provides an outlook and a system perspective.

6.1 Conclusions of the study

This energy audit studied the energy gains, energy supplied, and the thermal losses of a single-family house located in a city in the middle of Sweden. From the conducted energy balance, a clear conclusion can be drawn: transmission losses account for the majority of the house's energy losses (Dodoo et al. 2017). While this finding is common in most houses, this residential building has a higher prevalence of transmission losses compared to what is typically observed in other houses. This can be attributed to its age, as it was constructed 115 years ago. Therefore, the project's results can be extrapolated to other similar buildings located in cold climates that were built many decades ago.

The measures aimed at reducing transmission losses had a positive impact on energy costs, but not all of them appeared to be sufficiently profitable to justify the investment. For instance, improving the glass properties of the windows was not recommended due to the likely high capital requirement and the insignificant impact on the house's thermal behavior. However, to accurately determine if these measures are worth the investment, it is crucial to study the average implementation costs in detail and analyze whether the allowed investment covers them.

Regarding the installation of photovoltaic solar panels, it was undoubtedly a great improvement for the house since there was a significant energy usage reduction and, subsequently, a noticeable decrease in the energy costs. Furthermore, solar energy offers the advantage of being a renewable and infinite source. Thus, the owners of the house can ensure that this measure will not become obsolete in some years.

Energy audits like this can contribute to increasing the demand for solar energy solutions, especially given the current outlook of supply chain crisis and climate change. Furthermore, this measure has proved that financial assistance is crucial to encourage more people to decide for installing solar cells as an energy source for their homes (Yang et al. 2020).

The last, but not least, measure has highlighted the influence of changing people's behavior at home to reduce energy demand without requiring financial investment. However, implementing such changes can be difficult, and maybe some government regulations on this matter could potentially accelerate this improvement.

Finally, in analyzing the entire project, the absence of specialized energy audit software did not impact the effectiveness of the study. The traditional approach in studying this type of building proved to be enough in obtaining accurate results.

6.2 Outlook

The author of this project highly recommends conducting a detailed analysis of the proposed measures by carrying out an extended comparison between different kinds of windows that were not studied in this project. For example a more energy-efficient 2-panel windows could be beneficial and it has not been studied. Additionally, comparing different materials for wall insulation to improve the thermal behavior would be interesting, as this project only focused on mineral wool for this purpose.

To assess the profitability of these measures more accurately, a detailed study should consider the fluctuation of energy prices and the possible future government subsidies. The profitability of these improvements could vary significantly based on the variation of market costs.

Furthermore, a study regarding the carbon footprint of implementing these measures should be conducted to assess the total CO_2 emissions associated with these improvements. While there is a reduction in the energy usage and emissions, the carbon footprint increases due to the use of new materials, transportation, and energy required for the implementation.

If there is an interest on continuing this project, it would be beneficial to use software such as IDA-ICE to validate that the results of this energy audit and ensure their accuracy.

Finally, when making a decision about implementing these energy-saving measures, it is recommended to compare multiple companies that offer these services to determine if they align with the owner's desired budget.

6.3 Perspectives

One of the main objectives of this project has been to reduce the carbon footprint of the house by decreasing the energy usage. The studied measures have been demonstrated to achieve this goal and would decrease the climate impact of the house and similar properties.

In addition to improving sustainability, this energy audit also benefits the economy of the homeowners. If owners of similar houses, like the one studied, implement these profitable measures, society would experience a positive impact on the economy by reducing the energy usage. This is particularly important in the current energy crisis the world is facing.

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Appendix A

House blueprints

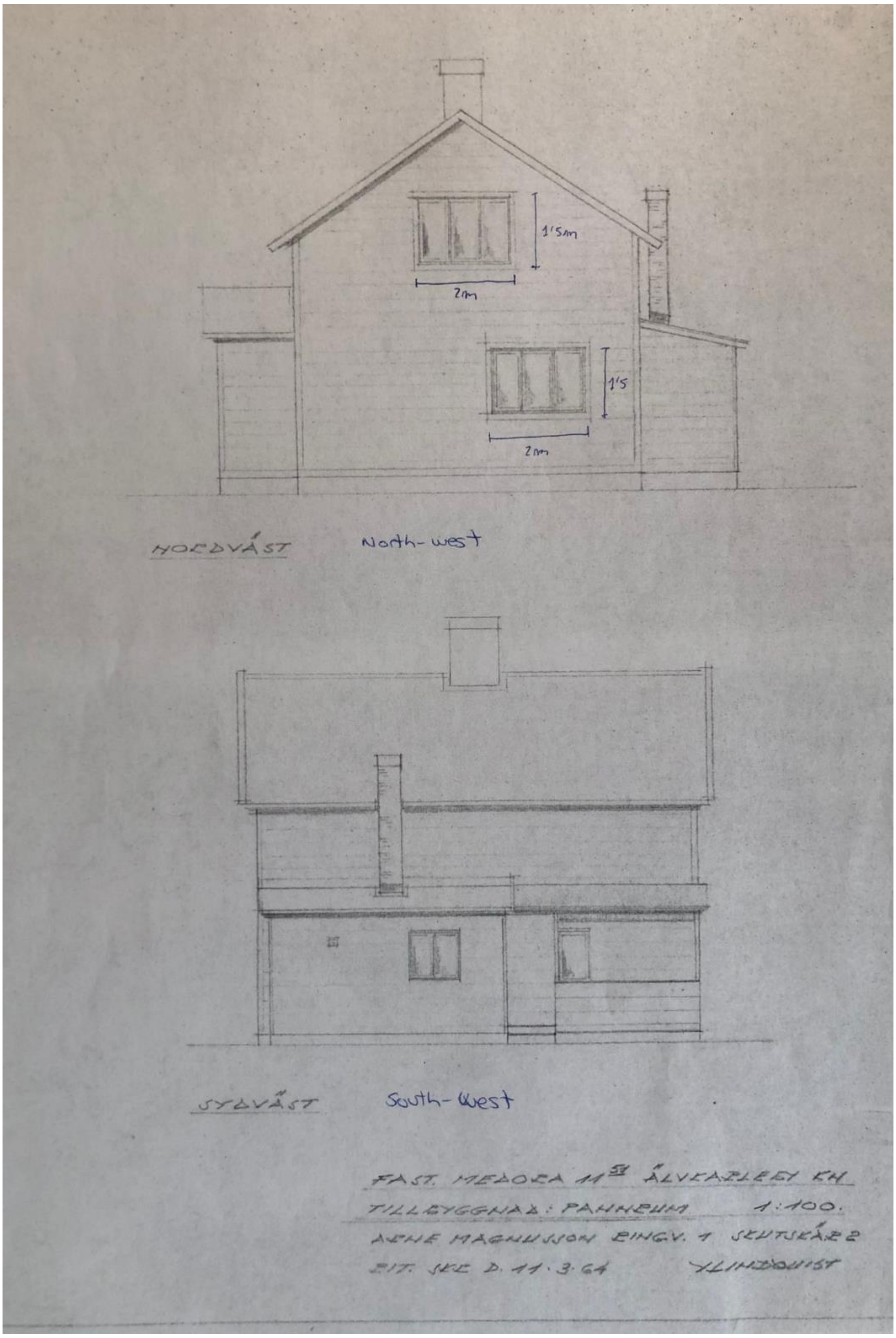

FIGURE 6 : NORTH-WEST AND SOUTH-WEST FACADE. [GIVEN BY THE OWNERS OF THE HOUSE OF STUDY]

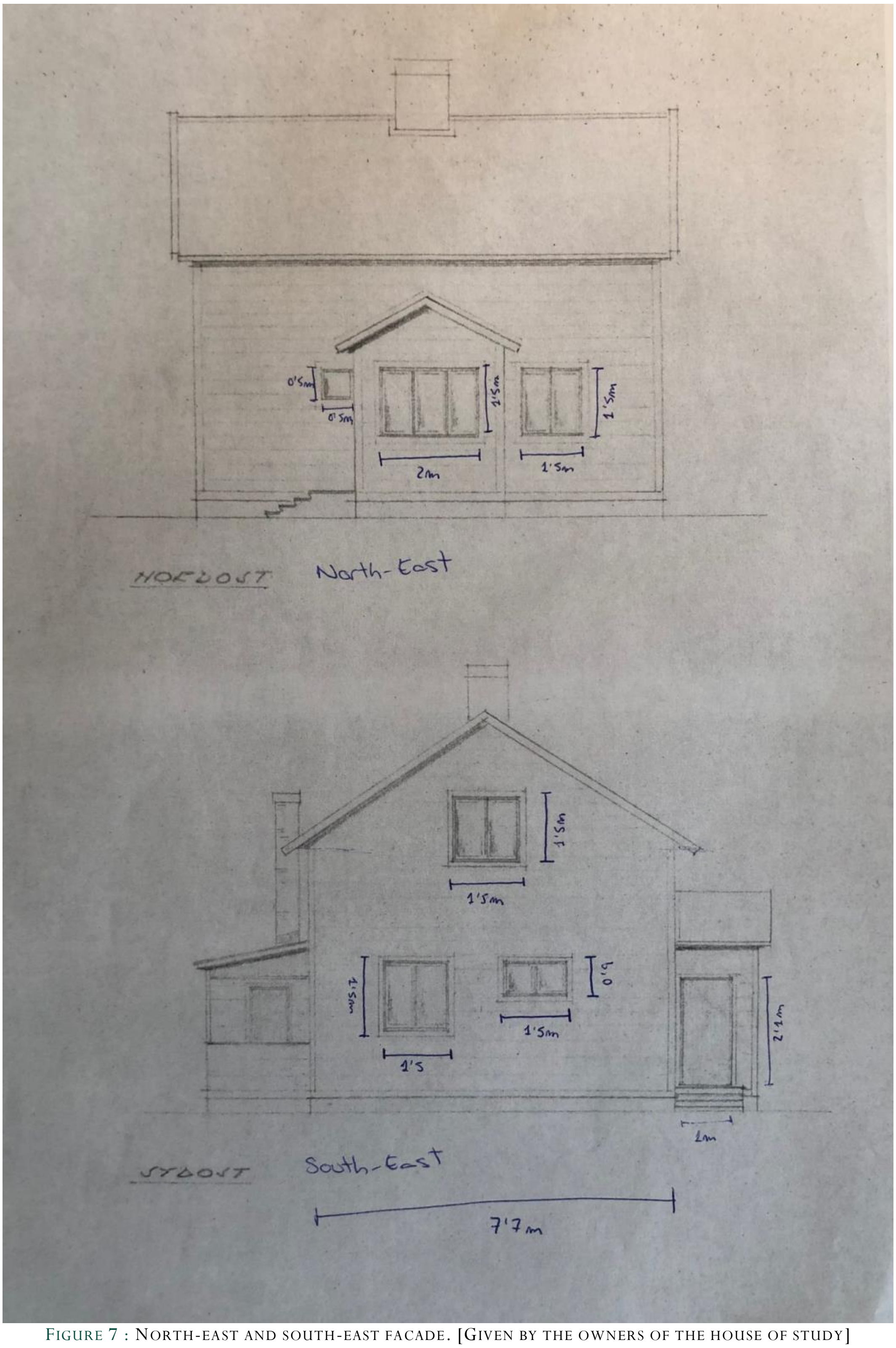

FIGURE 7 : NORTH-EAST AND SOUTH-EAST FACADE. [GIVEN BY THE OWNERS OF THE HOUSE OF STUDY]

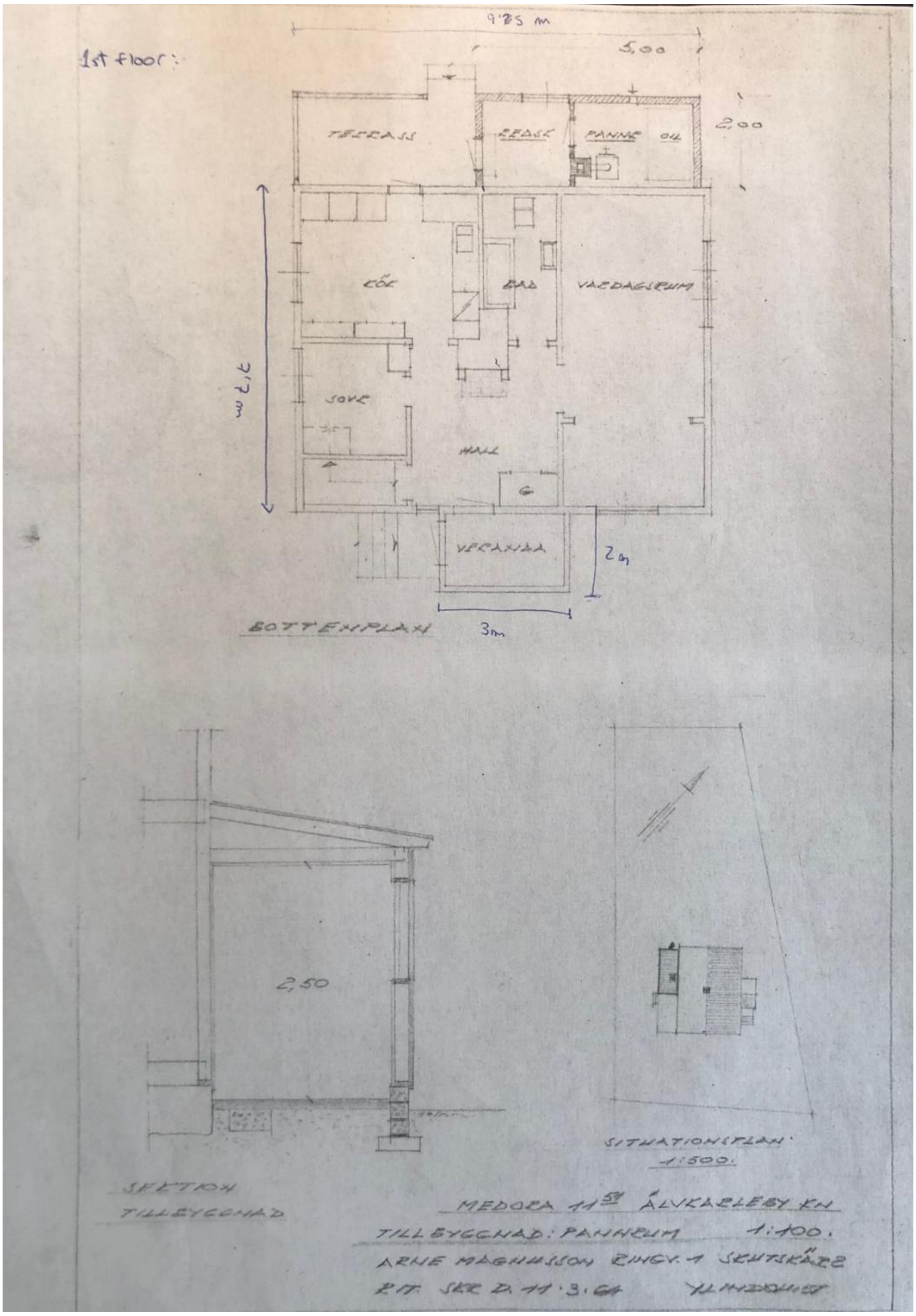

FIGURE 8 : DISTRIBUTION OF THE HOUSE. [GIVEN BY THE OWNERS OF THE HOUSE OF STUDY]

<u>Data for the calculations</u>

ıpvärmning till 11°C och högre temperatur, antas uppvärmningen sluta då utetemperaturen överstiger 11°C.

	Summa gradtimmar, som funktion av årets normaltemperatur i °C										
	−2	−1	0	1	2	3	4	5	6	7	8
	80750	73500	66500	59700	53200	47000	41000	35200	29700	24500	19500
	87000	79500	72300	65300	58500	52000	45800	39700	33900	28400	23000
	93500	85800	78300	71100	64100	57400	50800	44500	38400	32600	26900
	100200	92200	84600	77200	69900	62900	56200	49600	43200	37100	31100
	107200	99000	91200	83500	76000	68800	61800	54900	48200	42000	35500
	114500	106000	98000	90100	82400	74900	67700	60600	53600	47100	40300
	121900	113300	105100	97000	89000	81400	73900	66500	59300	52500	45400
	129500	120700	112300	104000	95800	88000	80200	72600	65100	58100	50700
	137000	128100	119500	111000	102500	94500	86500	78700	70900	63600	55900
	144600	135400	126700	118000	109300	101100	92900	84700	76700	69200	61200
	152100	142800	133900	125000	116100	107600	99200	90800	82500	74800	66500
	159700	150200	141100	132100	122900	114200	105500	96900	88300	80400	71800
	167200	157600	148300	139100	129600	120700	111800	103000	94100	85900	77000
	174800	165000	155500	146100	136400	127300	118100	109100	99900	91500	82300
	182300	172300	162700	153100	143200	133800	124500	115200	105700	97100	87600
20	189900	179700	169900	160100	149900	140400	130800	121300	111500	102600	92800
	197400	187100	177100	167100	156700	146900	137100	127300	117300	108200	98100
	205000	194500	184300	174100	163500	153500	143400	133400	123100	113800	103400
	212500	201900	191500	181100	170200	160000	149700	139500	128900	119300	108600
	220100	209200	198700	188100	177000	166600	156100	145600	134700	124900	113900
	227600	216600	205900	195100	183800	173100	162400	151700	140500	130500	119200
	Drifttid i h/år för värmeanläggning, som funktion av årets normaltemperatur, då uppvärmning sker till minst 11 °C.										
				----	6770	6550	6320	6080	5800	5570	5270

FIGURE 9 : DEGREE HOURS DEPENDING ON THE ANNUAL AVERAGE TEMPERATURE. [GIVEN BY PROFESSOR ROLAND FORSBERG]

CALCULATION FACTORS FOR WINDOWS ACCORDING TO SUN RADIATION

WINDOWS TYPE	U-VALUE	CALCULATION FACTOR
1-glass, normally	5.4	0.90
2-glass, normally	2.9 – 3.0	0.80
3-glass, normally	1.9 – 2.0	0.72
Special glass	1.0 – 1.5	0.69
2-glass, energy glass	1.0 – 1.5	0.70

Example:

If you have 3-glass, normally and you calculate Q (Wh) from the table so is the right value Q x 0.72.

FIGURE 10 : THERMAL COEFFICIENTS FOR EACH TYPE OF WINDOW. [GIVEN BY PROFESSOR ROLAND FORSBERG]

CALCULATION FACTORS FOR WINDOWS ACCORDING TO CLOUDY DAYS

MONTH	CALCULATION FACTOR
January	0.45
February	0.49
March	0.58
April	0.58
May	0.63
June	0,61
July	0,61
August	0,59
September	0.58
October	0.51
November	0.42
December	0.43

FIGURE 11 : SUN FACTOR FOR EACH MONTH. [GIVEN BY PROFESSOR ROLAND FORSBERG]

Investeringskalkyl **18:5**

Nusummefaktor

Nusummefaktorn betecknar summa nuvärde av 1 kr, som utfaller i slutet av varje år under n år.

Tabellen är uppgjord efter

$$\frac{1-(1+i)^{-n}}{i} = \frac{(1+i)^{n}-1}{1\,(1+i)^{n}}$$

Tar man hänsyn till index gäller följande uttryck

$$\frac{b^{n}-1}{(b-1)\,(1+i_{kalkyl})} \text{ där } b = \frac{1+i_{index}}{1+i_{kalkyl}}$$

Om $i_{index} = i_{kalkyl}$ gäller $\frac{n}{1+i}$

Sker utfall i början av året, multipliceras med faktorn $1 + i_{kalkyl}$

Exempel: En investering i år besparar ett företag löpande driftsutgifter om 10 000 kr per år i 5 år. Hur stort är värdet i dag av de samlade besparingarna vid 10 % ränta?

Svar: 3,791 × 10 000 = 37 910

n	Räntesats, %									
år	4	5	6	8	10	12	15	18	20	25
1	0,962	0,952	0,943	0,926	0,909	0,893	0,870	0,847	0,833	0,800
2	1,886	1,859	1,833	1,783	1,736	1,690	1,626	1,566	1,528	1,440
3	2,775	2,723	2,673	2,577	2,487	2,402	2,283	2,174	2,107	1,952
4	3,630	3,546	3,465	3,312	3,170	3,037	2,855	2,690	2,589	2,362
5	4,452	4,329	4,212	3,993	3,791	3,605	3,352	3,127	2,991	2,689
6	5,242	5,076	4,917	4,623	4,355	4,111	3,785	3,498	3,326	2,951
7	6,002	5,786	5,582	5,206	4,868	4,564	4,160	3,812	3,605	3,161
8	6,733	6,463	6,210	5,747	5,335	4,968	4,487	4,078	3,837	3,329
9	7,435	7,108	6,802	6,247	5,759	5,328	4,772	4,303	4,031	3,463
10	8,111	7,722	7,360	6,710	6,145	5,650	5,019	4,494	4,193	3,570
11	8,760	8,306	7,887	7,139	6,495	5,938	5,234	4,656	4,327	3,656
12	9,385	8,863	8,384	7,536	6,814	6,194	5,421	4,793	4,439	3,725
13	9,986	9,394	8,853	7,904	7,103	6,424	5,583	4,910	4,533	3,780
14	10,563	9,899	9,295	8,244	7,367	6,628	5,725	5,008	4,611	3,824
15	11,118	10,380	9,712	8,559	7,606	6,811	5,847	5,092	4,676	3,859
16	11,652	10,838	10,106	8,851	7,824	6,974	5,954	5,162	4,730	3,887
17	12,166	11,274	10,477	9,122	8,022	7,120	6,047	5,222	4,775	3,910
18	12,659	11,690	10,828	9,372	8,201	7,250	6,128	5,273	4,812	3,928
19	13,134	12,085	11,158	9,604	8,365	7,366	6,198	5,316	4,844	3,942
20	13,590	12,462	11,470	9,818	8,514	7,469	6,259	5,353	4,870	3,954
25	15,622	14,094	12,783	10,675	9,077	7,843	6,464	5,467	4,948	3,985
30	17,292	15,372	13,765	11,258	9,427	8,055	6,566	5,517	4,979	3,995
40	19,793	17,159	15,046	11,925	9,779	8,244	6,642	5,548	4,997	3,999
50	21,482	18,256	15,762	12,233	9,915	8,304	6,661	5,554	4,999	4,000

FIGURE 12 : N-VALUE DEPENDING ON THE MAXIMUM OF YEARSS DESIRED TO HAVE PROFIT. [GIVEN BY PROFESSOR ROLAND FORSBERG]

Månad	Horisont-avskärmning,°	Vertikala ytans orientering N −180	−150	−120	E −90	−60	−30	S 0	30	60	W 90	120	150
Latitud 60 ° N													
Januari	0	130	130	160	550	1440	2360	2710	2360	1440	550	160	130
	10	70	70	70	90	140	180	200	180	140	90	70	70
Februari	0	370	370	640	1550	2900	4280	4880	4280	2900	1550	640	370
	10	340	340	400	1030	2240	3530	4020	3530	2240	1030	400	340
Mars	0	730	900	1720	3050	4520	5740	6320	5740	4520	3050	1720	900
	10	710	730	1290	2460	3920	5290	5970	5290	3920	2460	1290	730
April	0	1350	1990	3320	4750	5850	6370	6410	6370	5850	4750	3320	1990
	10	1170	1640	2810	4220	5420	6160	6390	6160	5420	4220	2810	1640
Maj	0	2350	3050	4460	5630	6150	5980	5730	5980	6150	5630	4460	3050
	10	1840	2570	3910	5130	5840	5920	5710	5920	5840	5130	3910	2570
Juni	0	3210	3870	5230	6190	6350	5820	5460	5820	6350	6190	5230	3870
	10	2420	3180	4570	5650	6070	5790	5430	5790	6070	5650	4570	3180
Juli	0	2830	3510	4910	5960	6280	5820	5580	5890	6280	5960	4910	3510
	10	2270	3020	4410	5540	6050	5870	5560	5870	6050	5540	4410	3020
Augusti	0	1700	2380	3720	5020	5850	6070	5970	6070	5850	5020	3720	2380
	10	1400	2020	3240	4550	5520	5950	5940	5950	5520	4550	3240	2020
September	0	900	1230	2200	3520	4820	5760	6130	5760	4820	3520	2200	1230
	10	880	1070	1930	3200	4530	5580	6080	5580	4530	3200	1930	1070
Oktober	0	510	530	1010	2110	3570	4960	5620	4960	3570	2110	1010	530
	10	470	480	650	1500	2850	4290	4870	4290	2850	1500	650	480
November	0	200	200	270	840	1910	3040	3480	3040	1910	840	270	200
	10	160	160	160	300	990	1590	1810	1590	990	300	160	160
December	0	80	80	90	350	1060	1770	2030	1770	1060	350	90	80
	10	40	40	50	60	90	120	130	120	90	60	50	40

FIGURE 13 : ENERGY SUM FOR EACH ORIENTATION. [GIVEN BY PROFESSOR ROLAND FORSBERG]

TABLE 10 : λ VALUES USED FOR CALCULATIONS OF TRANSMISSION LOSSES. [GIVEN BY PROFESSOR ROLAND FORSBERG]

Material	λ [W/mK]
Brick	0,6
Concrete	1,7
Granite	3,5
Gypsum	0,22
Iron	84
Light-weight concrete	0,14
Mineral wool	0,036
Wood	0,14