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# Towards zero energy buildings: retrofitting an existing recreational facility

A case study of a sauna facility on Styrsö

*Master's thesis in Infrastructure and Environmental Engineering*


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DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
DIVISION OF BUILDING TECHNOLOGY



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MASTER’S THESIS ACEX30

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Cover:
An image displaying the seaside of the facility, supplied by Styrsö Hafsbad & Vänner.
Department of Architecture and Civil Engineering.
Gothenburg, Sweden, 2022

## ABSTRACT

A resolution by the European Union adopted in 2010 designates that all new buildings in the EU must be classified as nearly-zero energy buildings (nZEB) by the end of 2020. A recent proposal by the Commission specifies that by 2030, all new buildings are to be zero-energy buildings (ZEB). A nZEB is defined as a building with a very high energy performance where the total net energy consumption is nearly zero, whereas a ZEB is defined as a building with a total net energy consumption equal to zero. The directive also includes that every member state in the EU has to present a renovation plan for the existing building stock to decrease their environmental impact and achieve the goals of the EU. Sweden has introduced a climate policy framework aiming to have net zero emissions by 2045 and is developing a long-term renovation strategy in line with the EU. This study investigates the energy reduction potential and the energy performance of a very energy-consuming building. The project focuses on a recreational facility on Styrsö in the southern archipelago of Gothenburg, Sweden. Moreover, the project aims to create awareness and convert the sauna facility at Styrsö Hafsbad into a nZEB using European and Swedish criteria and definitions, with the ultimate goal of achieving ZEB. In addition, a cost-benefit analysis was conducted to ensure that the proposed actions could be implemented economically.

The existing sauna facility Styrsö Hafsbad was analyzed by means of a case study. Using thermal and electrical measurements, data will be partly gathered on-site. Furthermore, building measurements and layers will be recovered off-site using prior construction blueprints, while total water and energy use will be estimated using older receipts. A literature review was conducted to address the research questions by collecting and analyzing information acquired by keyword searches on selected databases, including Google Scholar, Mendeley, government agencies, and published theses. Understanding building energy balance, energy demands, energy-reduction strategies and measures, and other relevant terminologies are crucial for the literature review chapter. The building was simulated using the energy simulation software IDA-ICE.

The results demonstrate that both nZEB and ZEB status are possible. The simulations showed that the change of ventilation system and installation of an air-to-air heat pump resulted in a total energy reduction of 71%, enough to achieve nZEB. The remaining reduction came from installing solar cells and changes in the building envelope, including lowering the temperature. A combination of the measures mentioned has to be applied to achieve ZEB.

The initial strategy for achieving net-zero in the building is to reduce its primary areas of demand, with heat loss reduction measures having the most significant impact, followed by energy-efficient appliances and solar cells. Simulations demonstrated a slight reduction in energy usage when the roof was insulated, or the windows were replaced. Setting up a new air-to-air heat pump is more economical and prudent from a cost-benefit perspective. According to all economic performance approaches, it is a good metric. Additionally, ventilation systems are economically beneficial. On the other hand, alterations to the building envelope proved inefficient both econonomically and energy-performance-wise.



**Keywords:** *Climate-neutral building, energy footprint, energy renovation, NZEB, ZEB*

# SAMMANFATTNING

Ett beslut från Europeiska unionen som antogs 2010 anger att alla nya byggnader i EU måste klassificeras som nästan-nollenergibyggnader (nZEB) i slutet av 2020. Förslaget från kommissionen specificerar att år 2030 ska alla nya byggnader som byggs vara nollenergibyggnader (ZEB). En nZEB definieras som en byggnad med mycket hög energiprestanda där den totala nettoenergiförbrukningen är nästan noll mgedan en ZEB definieras som en byggnad med en total nettoenergiförbrukning på noll. Direktivet innehåller också att varje medlemsland i EU ska presentera en tydlig renoveringsplan för det befintliga byggnadsbeståndet för att minska deras miljöpåverkan och uppnå EU:s mål. Sverige har infört ett klimatpolitiskt ramverk med målet att ha nettonollutsläpp till 2045 och utvecklar en långsiktig renoveringsstrategi i linje med EU. Denna studie undersöker energireduktionspotentialen och energiprestandan hos en mycket energikrävande byggnad. Projektet fokuserar på en rekreationsanläggning på Styrsö i Göteborgs södra skärgård. Dessutom syftar projektet till att skapa medvetenhet och omvandla bastuanläggningen vid Styrsö Hafsbad till en nZEB med hjälp av europeiska och svenska kriterier och definitioner, med det yttersta målet att uppnå ZEB. Dessutom genomfördes en analys kring kostnad-nytta för att säkerställa att de föreslagna åtgärderna kunde genomföras ekonomiskt.

Den befintliga bastuanläggningen Styrsö Hafsbad analyserades med hjälp av en fallstudie. Med hjälp av termiska och elektriska mätningar samlades data delvis på plats och delvis via datorsimuleringar. Användning av tidigare konstruktionsritningar fungerade som mall för byggnadsmått och lager utanför anläggningen, medan den totala vatten- och energianvändningen uppskattades med hjälp av äldre kvitton och fakturor. För att ta itu med forskningsfrågorna genomfördes en litteraturgenomgång genom att samla in och analysera information som förvärvats genom nyckelordssökningar i utvalda databaser inklusive Google Scholar, Mendeley, statliga myndigheter och publicerade avhandlingar. Att förstå att bygga energibalans, energibehov, energireducerande strategier och åtgärder och ytterligare terminologier är avgörande för kapitlet om litteraturöversikt. Byggnaden simulerades med hjälp av energisimuleringsmjukvaran IDA-ICE.

Resultaten visar att både nZEB- och ZEB-status är möjliga. Simuleringarna visade att byte av ventilationssystem och installation av luft-luftvärmepump resulterade i en total energireduktion på 71 %, tillräckligt för att uppnå nZEB. Resterande minskning kom från installation av solceller och förändringar i byggnadens klimatskal inklusive sänkning av temperatursänkningen. För att uppnå ZEB måste en kombination av de ovan nämnda åtgärderna tillämpas.

Den initiala strategin för att uppnå nettonoll i byggnaden är att minska dess primära efterfrågeområden, där värmeförlustreducerande åtgärder har störst effekt, följt av energieffektiva apparater och solceller. Simuleringar visade på en liten minskning av energianvändningen när taket isolerades och eller fönstren byttes ut. Att sätta upp en ny luft-till-luft värmepump är mer ekonomiskt och försiktigt ur ett kostnads-nyttoperspektiv. Enligt alla ekonomiska resultatmetoder är det ett bra mått. Dessutom är ventilationssystem ekonomiskt fördelaktiga. Ändringar av klimatskalet visade sig å andra sidan vara ineffektivt både ekonomiskt och energimässigt.

## Acknowledgments

We want to express our gratitude to our supervisor, Holger Wallbaum, who greatly encouraged us throughout this project. Furthermore, we would like to thank the organization & board from Styrsö Hafsbads & Vänner for the trust and opportunity to perform this study, as well as their subsequent support and help during the work process.

Lastly, we would like to give special thanks to our family and friends for their unwavering support and understanding during the project.

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Bertil Bwira & Tarek Khalayli
Gothenburg, June 2022

# Table of Contents

# 1 Introduction

For years to come, attaining sustainability and ensuring climate stability is a topic of highest relevance. Sweden's climate policy framework states that by 2045 the country will have zero net emissions released into the atmosphere (Government, 2021). To achieve such results, every sector must accept responsibility for its environmental impact and take steps to mitigate its emissions and energy consumption. The building sector makes up approximately 40% of the total energy use, totaling 140 TWh annually, of which residential and non-residential buildings consume 77 TWh for heating and warm water. Sweden has imposed strict requirements regarding new buildings' energy performance and plans to renovate the existing building stock to current standards are due. The regulations are a part of a broader initiative by the EU and its member states to limit greenhouse gas (GHG) emissions under the Paris Agreement. As of 2019, the building sector accounts for 21% of all domestic GHG emissions (Boverket, 2021). Measures to decrease the energy consumption of buildings are required to decrease GHG emissions. The plans to renovate the existing building stock has a central role in the EU energy and climate targets. However, the implementation requires a high level of knowledge and financial commitment. As a result, further study in this sector is necessary to discover both reasonably priced and acceptable solutions for implementation on a broader scale. Zero-energy buildings have become a recurrent theme of discussion and eventual implementation in recent years. A zero-energy building is defined as a building characterized by a net energy consumption equal to zero on an annual basis. This study will investigate to what extent the energy consumption and the greenhouse gas emissions of an existing and high energy-consuming building can be reduced. The study object will be a recreational facility located on Styrsö in the southern archipelago of Gothenburg.

## 1.1 Background

Climate change and global warming have become major topics of concern in the world. In 2016, 191 nations plus the European Union (EU) signed the Paris Agreement (United Nations, n.d.). The treaty aims to limit the global average temperature increase to 2°C by the end of the 21$^{st}$ century while pursuing efforts to limit the increase to 1.5°C. To not exceed an increase of 1.5°C, greenhouse gas (GHG) emissions must be reduced by 45% by 2030 (UNFCCC, 2021). In line with the Paris Agreement, the EU aims to be climate-neutral by 2050. In other words, GHG emissions are set to be reduced to net-zero (European Commission, n.d.). The EU has required its member states to develop national long-term plans and strategies regarding emission reduction and the transition to renewable energy. Sweden aims to be climate-neutral by 2045, 5 years before the EU's target. To achieve its goal, the country plans to reduce GHG emissions by 85% by 2045 relative to 1990. With imminent climate change, buildings have become a strategic focus in national and international policymaking. EU member states have developed and set criteria based on primary energy usage for new buildings. In addition, the EU requires strategies for energy renovation of existing buildings (European Commission, 2020). The EU proposed that as of 2030, all new buildings must be zero-emission, requiring the worst-performing 15% of the building stock from an energy perspective to be upgraded from grade G to a minimum grade F for non-residential and residential buildings by 2027 and 2030, respectively (European Commission, 2021). The grading scale divides buildings into classes from A to G, where C is the current requirement for new buildings.

| Energy class | % of the new energy requirements for new buildings |
|---|---|
| A | $\leq 50$ |
| B | $50 \leq 75$ |
| C | $75 \leq 100$ |
| D | $100 \leq 135$ |
| E | $135 \leq 180$ |
| F | $180 \leq 235$ |
| E | >235 |

*Table 1. Energy classes in relation to the EP-value in percentages for a non-residential building (Boverket, 2021).*

As of 2019, the existing building stock in Sweden is distributed according to Figure 1 (Regeringen, 2020).

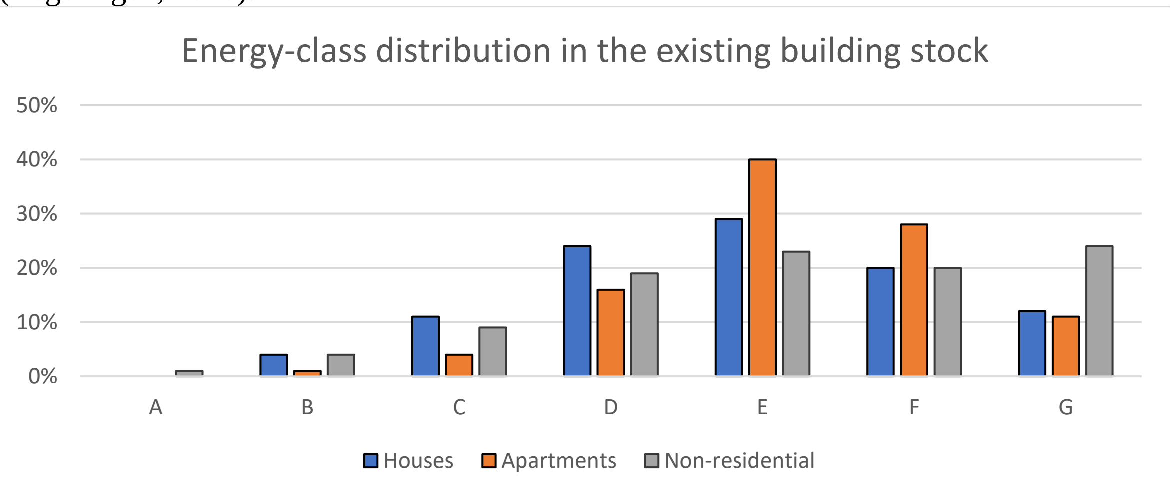


*Figure 1. Distribution of energy classes in the existing Swedish building stock.*

A study conducted by IPCC (2007) found that the building sector has the highest potential for energy reduction globally out of all the sectors. CAN Europe (2020) presented a scenario in line with the Paris Agreement, which reduced two-thirds of the current demand in the building sector by 2050. The Swedish real estate sector accounts for 34% of the total energy usage and 21.7% of GHG emissions as of 2019 (Boverket, 2021). Since the total energy usage, real estate has a high potential of reduction proportionate to the share. According to the EU (2020), renovating existing buildings can reduce the EU's total energy usage by 5%. However, studies such as *Total Concept* have shown up to 56% reduction in energy demand in the Nordic countries (Total Concept, 2015).

The Energy Pyramid (Buffington, 2010) lists factors contributing to energy and emissions savings. Figure 2 illustrates that energy conservation is possible through behavioral changes by understanding energy consumption as a baseline measure. Understanding energy consumption refers to identifying the energy-consuming units and raising the general awareness of the impact of excessive energy consumption. As a result, energy conservation becomes more apparent by limiting excessive energy use through behavioral practices, such as turning radiators off during summer. Energy efficiency refers to renovation measures and efficient appliances. Efficient materials are included in this pyramid layer, such as double-or triple-paned windows or additional insulation in the building envelope. Buffington also explains that the cost-effectiveness over the lifetime of a measure has to be evaluated. He argues that it is essential for increased energy efficiency to yield financial gains. The final layer of the energy pyramid is renewable energy, both as a source of delivered energy to and renewable energy technologies.

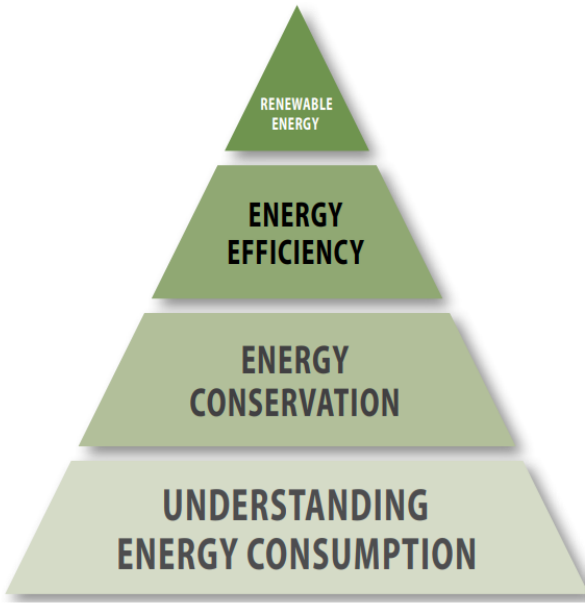


*Figure 2. The Energy Pyramid (Buffington, 2010)*

The major non-renewable energy source (coal) in the EU has been steadily declining since 2013, overtaken by nuclear energy in the same year. On the other hand, the minor renewable energy sources (biofuel, waste, wind, and solar) in the EU continue to develop steadily, having already overtaken oil between 2007 and 2013. The supply of natural gas has increased since non-renewable sources (coal, oil) began to decline. This is intended to demonstrate the transition from fossil fuels to the most preferred renewable energy source as the primary energy source for consumption.

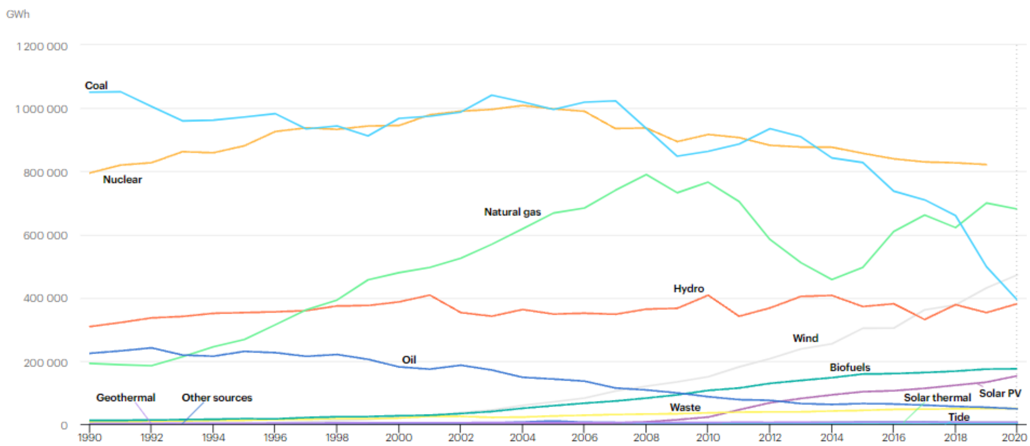


*Figure 3. Energy supply in the EU is indicated by electricity generation by source from 1990-2020 (IEA, 2020).*

In Sweden, renewable energy sources are very much relied on. These consist of nuclear energy, hydro energy, wind energy, solar energy, and biofuels. Moreover, nuclear energy and biofuels are imported, and fossil fuels like oil and natural gas.

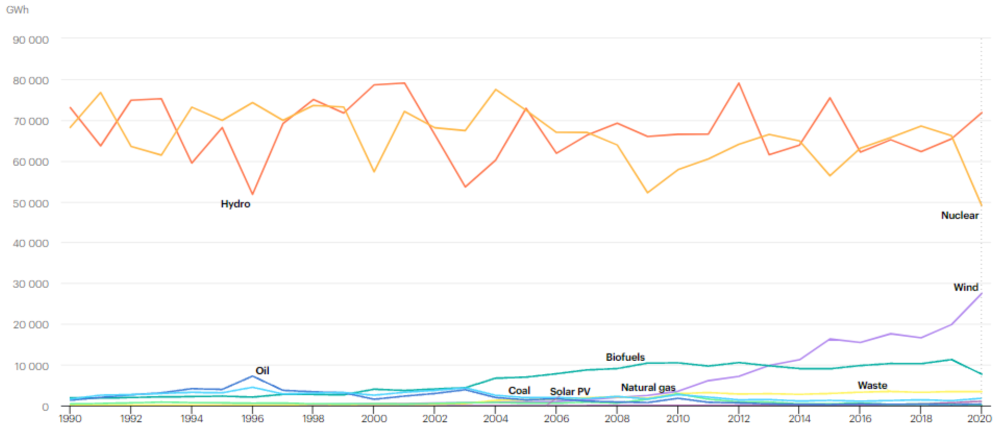


*Figure 4. Energy supply in Sweden is indicated by electricity generation by source from 1990-2020 (IEA, 2020).*

It has become a governmental desire in European countries to minimize the built environment's non-renewable content and energy footprint and create "smart buildings" equipped with low-cost surveillance and self-diagnostic capacities to monitor the development of the building's energy performance, as a consequence of the European Green Deal agreement (Haines & Scheelbeek, 2020).

However, designers and engineers have had little incentive to incorporate newer material technologies into building designs because of the legal liability associated with unpredictable lifespan performance (Fernandez, 2007). For instance, similarities could be drawn to the initial building process. The introduction of digitalization has stalled since many businesses are unwilling to abandon established practices and routines. Specific procedures go more quickly on paper, based on the extent of expertise of the workers, which is related to a widespread reluctance to learn new methods and the habit of working in traditional ways (Samsaliev & Rauf, 2018).

The cumulative mass of all fixed objects within the building, the people who use it, the building components themselves, snow and rain, as well as dynamic pressures from the wind pressing on the building's façade and roof, earthquakes, long-term foundation settlement, and a wide variety of local conditions all contribute to the stresses that pass through these components of the building envelope (Haile, 2021).

The materials available for the sauna building, labeled as a recreational premise, are somewhat restricted economically and often include wood, steel, concrete, stone, clays, and masonry materials. The building design has an essential role in the net energy consumption of a building. To be more environmentally beneficial, buildings should be built and constructed following the local climate (Alwetaishi, 2022). Other factors to consider include the windows and façade area ratio, the cardinal orientation of the building, U-values of the components, and HVAC systems.  When it comes to energy loss in a structure, windows are typically the weakest link. Generally, glass transmits heat rather well: One could, for example, try touching a window against a wall on a chilly day and observe how much colder the glass is. Typically, exterior walls have a U value of between 0.5 and 2.5 W/m$^2$C. A typical solid brick wall, which is notoriously inefficient in terms of insulation, performs at roughly 2.2 W/m$^2$C. Regarding U-values, the lower the value, the less heat the material conducts and, therefore, the "better."

$$WWR(\%) = \frac{Sum\ of\ glazing\ area\ [m^2]}{Sum\ of\ gross\ exterior\ wall\ area\ [m^2]}$$

*Eq. 1*

The glazing area is the total area consisting of glass, including the frames. The ideal WWR value minimizes the total yearly energy consumption for heating, cooling, and lighting. Most optimum WWR values are found within a very limited range, ranging from 0.30 to 0.45, even for structures in extreme climates.

The façade – and, more broadly, the entire building envelope – may be considered as the primary mechanism for solar energy conversion on a building scale. The shape of the façade affects how solar energy is utilized within the structure. The balance of glazing and opaque regions alone affects several components of the energy balance, impacting solar gain (and consequently energy consumption for heating and cooling) and heat loss (primarily energy consumption for heating), but also sunlight accessibility (with implications on energy use for artificial light).

Furthermore, solar shading systems enhance the façade's capacity to dynamically manage solar gain and daylighting, significantly improving the building's overall energy performance and passive solar energy use. Finally, selecting materials and components with adequate optical and thermal properties significantly impacts all aspects of the total energy balance (Goia, 2016). Although calculating with WWR is disregarded in the study, it is very much an aspect to consider when designing the energy performance of the building.

The capacity of a structure to utilize solar radiation for heating and lighting purposes may influence its energy efficiency, which is frequently dictated by the direction of the building. Therefore, orienting a structure to obtain a significant solar input is critical. The usage of lighting and heating systems are two significant elements affecting energy consumption in buildings, and both are related to the structure's orientation. To maximize solar gain (which is critical during the colder seasons), it is critical to properly orient a structure so that it receives the maximum amount of solar energy. Additionally, optimizing the orientation and design of buildings can result in a 36 % decrease in energy use (Aksoy & Inalli, 2006).

The net energy gain from glazings and windows in buildings depends on the thermal transmittance (U-value) and the total solar energy transmittance (the g-value). The U-value is also strongly related to thermal conductivity, a material attribute that affects how well a material transmits heat. For example, windows, doors, and skylights each have a U-value that indicates how well they insulate. Due to the necessity of covering thermal bridges and identifying a building's weak places in terms of energy losses, evaluating them is crucial (Nielsen, Duer, & Svendsen, 2001).

To achieve energy efficiency in Heating, Ventilation, and Air Conditioning (HVAC) systems, it is critical to improve the design of their different integrated mechanical and electrical components and regulate and run the plant efficiently. More efficient HVAC systems result in a large decrease in building energy consumption, which is noteworthy given that buildings account for over 40% of total energy consumption in many industrialized nations, such as in this specific case study of Sweden (Vogt, Buchholz, Thiede, & Herrmann, 2022).

## 1.2 Aim

This thesis aims to analyze the building's current energy performance and make recommendations for improvement for the existing building in Styrsö, Gothenburg. The principal objective of the study will be targeted with answering the following research questions:

- How to develop a Zero-energy building approach for an existing recreational building?
- Can this goal be achieved from a cost-benefit perspective?

## 1.3 Limitation

The thesis and the case study aim is a single recreational sauna facility. The building does not represent most of the building stock in Sweden, whether residential, non-residential, or other types of recreational facilities. Thus, the results from the study might not apply to other buildings. Furthermore, aspects such as architectural or judicial limitations will not be investigated regarding the facility. The input data for the energy simulations were based on a specification sheet and a blueprint collected from the board of Styrsö Hafsbad.

Due to time constraints and limited access to data from the energy distributor, exploring the other definitions of zero-energy buildings, such as primary energy consumption or embodied carbon emissions, was not considered. It would be an extra issue to evaluate in our case study due to the possibility of transitioning to performing a study based on the perspective of primary energy factors. Tests to measure building airtightness could not be performed. Furthermore, measures that include changes in user behavior were not simulated due to the complexity of predicting factors that would alter the usage behavior.

Considering our limited knowledge of the program and use of technical instruments, the results from the thermal imaging camera were used as the typical value of each building component from IDA-ICE, ranging from 0.07 to 0.5 W/K/m. We chose to neglect energy from minor sources. However, the software automatically considers energy gained from solar radiation based on the area's climate data, the facility's cardinal direction, and energy from human activity.

# 2 Case Study

This chapter will thoroughly introduce and assess Styrsö Hafsbads & Vänner.

## 2.1 History

As a result of forming the "Brända Tomten" organization, a group of friends with similar interests came together to form Styrsö Hafsbad Vänner. Magnus Lagström was the group's leader and was responsible for conceptualizing the recreational framework. Previously, the edifice served as a cold-bath facility for the local community. Since 1997, Lagström had been attempting to obtain a permit to use the facility for sauna repair. However, he had encountered opposition from members of the organization, regulators and neighbors, and government authorities. It took until 2000 for a group of Styrsö residents to form a temporary board of directors with Lagström to construct the sauna building. The particular location was chosen because of Styrsö Bratten's historical significance as the location of the aforementioned cold-bath facility. Additionally, to accommodate conflicting ideas, the sauna was expanded to include a smaller conference/meeting room suited for small groups or gatherings of people. (Styrsö Hafsbads Vänner - Historia, 2021).

The funding was estimated to be roughly 700,000 SEK, distributed among four major actors. These are further presented in Table 2.

| Source of funding | Funding sum (SEK) |
|---|---|
| EU & District Committee | 390 000 |
| Sports & Association Management | 160 000 |
| Styrsö Hafsbad & Vänner | 100 000 |
| Local (Styrsö) Property Owner's Association | 50 000 |

*Table 2. Distribution of the funding for Styrsö Hafsbad*

After the funding confirmation, there was an additional green light for the project to be carried out. It was necessary to submit the final drawing and an application for a construction permit. Applications for water and electricity connections were made and received an offer for a prefabricated home. Building construction took an estimated one and a half years, and it was ultimately completed and ready for use. Land preparation and establishment began in early 2002, with the structure's construction beginning in March 2003 and finished by the end of the year (Styrsö Hafsbads Vänner - Historia, 2021).

## 2.2 Objectives

One of the key objectives of this research is to enhance knowledge and convert the Styrsö Hafsbad's sauna facility into a zero-energy building. Applying national and European standards, one of which is described by European (EU) rules as a continual objective of establishing a low-carbon economy that is economically competitive, ecologically beneficial, and environmentally sustainable (D'Agostino, Zangheri, & Castellazzi, 2017). Since this is a case of renovation of an existing building rather than an initial establishment, emphasis is put on the term renovation. Different levels of renovation are possible, depending on the sort of intervention and the number of financial means that are aimed to be saved. The topics may include replacing or upgrading all building components influencing energy consumption and installing renewable energy sources (RES) to reduce energy consumption to zero or less.

Specific to the case of Styrsö, the problem assessment was divided into the following:

1. Current state analysis
2. Financial limitations

Two important concepts were presented by the Directive of the European Commission: cost-effectiveness and nearly zero-energy buildings (nZEB). Additionally, it specifies the main objective - to construct all new buildings and, over time, renovate the existing building stock to NZEB. As a result, when meeting stipulated performance criteria, building design, which frequently encompasses the envelope, energy systems, and interconnections, is critical to consider (European Commission, 2016).

The Styrsö sauna will be analyzed from an energy-demand-and-supply perspective. This study describes energy performance as the energy required to fulfill the energy demand associated with a building's average usage. It includes the energy used for heating, cooling, ventilation, warm water, and lighting. This means that energy consumption and production are equal for a zero-energy building, adding the dimension of it being sustainable from a financial point of view.

## 2.3 Building properties

Buildings and related sectors release more greenhouse gases, generate more waste and natural resources than other human functions or industries, and require more energy (Sozer, 2010). As a result, a comprehensive examination of the building envelope for this particular facility is required. The foundation is built on a slab towards the ground with one layer of dense fiber and ground sill**.**

The building's outer walls are composed of cover panels, nailing batten, and windboard. Additionally, to protect against climatic pressures, the isolation is reinforced with foil and gypsum. The computed U-Value for the outer walls is 0.20 W/m$^2$K. Decomposing the main roof's components reveals the following pontoon, paperboard, and two isolation layers, one for sound isolation and another for climatic protection. These are critical for examining thermal bridges and determining the associated energy loss. The typical average and calculated U-Value for the roof is 0.17 W/m$^2$K. The sauna facility is ventilated using air valves, five located throughout the building. The valves operate similarly to natural ventilation.
Additionally, two humidity-controlled blowers are added to extract humid air. The humidified fan is the most effective in reducing moisture build-up and damage. The U-values for the construction parts are presented in Table 3.

| **Construction part** | **U-value [W/m$^2$K]** | **Area [m$^2$]** |
|---|---|---|
| External walls | 0.20 | 88.5 |
| Roof | 0.17 | 96.6 |
| Slab on ground | 0.2 | 75 |

| | | |
|---|---|---|
| Windows | 1.9 | 11.2 |
| Total | 0.4 | 170 |

*Table 3. Input data and current values for the sauna facility*

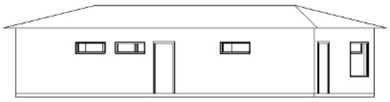

*Figure 5. The frontside of the building drawn on Revit.*

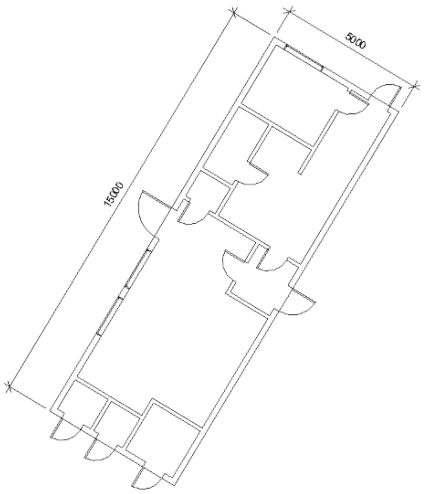


*Figure 6. A plane view of the building drawn on Revit.*

The Swedish Energy Agency is in command of the country's official energy statistics. They provided statistics demonstrating that Sweden primarily relies on renewable resources such as water and wind (Energimyndigheten, 2021). All city residents receive power in the same manner via Ellevio, which runs the island's sole electricity network. Additionally, the facility receives electricity via a monthly subscription from Nordic Green Energy, a company focused on renewable energy resources. According to Nordic Green Energy, the electricity supplied to the facility is divided according to Figure 8.

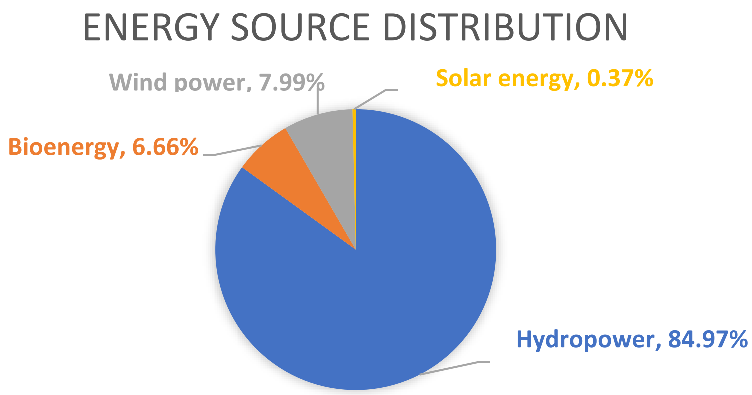


*Figure 7. Distribution of energy sources from Nordic Green Energy.*

An assessment of the current measurements in the Styrsö Hafsbad indicates that the energy use is average for a facility used as a residency building of double the area size (Vattenfall, 2020). The building uses, on average, 22381 kWh annually. Distributing warm water throughout the building without being continually activated is a possibility. It operates on average for three hours per day and can provide the required amount of water to each room in the building.

*Table 4. The average energy and water consumption of the sauna facility.*

| Year | Water consumption | Energy consumption |
|---|---|---|
| 2017 | 221 $m^3$ | 22 555 kWh |
| 2018 | 175 $m^3$ | 22 372 kWh |
| 2019 | 117 $m^3$ | 22 217 kWh |
| Average | 196 $m^3$ | 22 381 kWh |

According to a statistical interpretation of the data, the reduction in consumption is linked to the pandemic in 2020, which led to a significant decline in use. As a result, forecasting the current situation becomes slightly more complicated.

# 3 Methodology

A literature study was conducted by gathering and analyzing information obtained from keyword searching (see abstract) through relevant databases such as Google Scholar and Mendeley, governmental institutions, and published theses to address the research questions. Understanding concepts such as the energy balance of buildings, energy requirements, energy effectivizing processes, and definitions are critical for the literature review chapter. Literature regarding energy optimization measures and energy reduction strategies will also be gathered. Furthermore, hermeneutics has been used to establish data reliability further. The substance, or empiricism, is not gathered in the conventional sense of gathering established data. Instead, with recurrent measurements, it is developed and generated in cohesion between the researcher and the studied object.

A case study will be conducted to assess the condition of an existing sauna facility in Styrsö called Styrsö Hafsbad. On-site, data will be collected with the help of thermal equipment and electricity meters. Off-site, the building measurements will be obtained from older construction blueprints with building dimensions and layers, whereas the total water and energy consumption is taken from older invoices. These are essential to understanding which measures are relevant and needed to answer the study's main findings. The reference object will be simulated using the energy simulation software IDA-ICE version 4.8. The building will first be drawn on Revit, a CAD software, later imported to IDA-ICE as a 3D model. The simulations will be conducted with different energy-reducing measures as input (e.g., additional insulation). The software has an extensive database with climate data from the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) as the source. Climate data from the nearest city, Gothenburg, will be used for the simulations. The results from the energy simulations will be compared with current requirements for (nearly) zero-energy buildings from Boverket and Forum för Energieffektivt Byggande (FEBY) to assess if any energy-reducing measure achieves the current requirements from an energy-performance perspective. The measures will also be assessed from a cost-benefit perspective to build an approach toward zero-energy buildings.

## 3.1 Qualitative & Quantitative research data

The procedure for acquiring data varies according to the format in which it will be presented. Quantitative or qualitative methods are the common approaches used. Qualitative methodology refers to the collection and analysis of data gained via observation. Whereas quantitative analysis depends on a large quantity of data, frequently numerical values, to reach conclusions. While the quantitative model focuses on numerical and physical principles, predicting the human aspect of a remodeling project is challenging. The remodeling process may be viewed as a complicated network of interconnected actions that may result in different results due to a random human component.

# 4 Literature review

A literature study has been conducted to define zero-energy buildings and new current requirements for buildings from Boverket both literally and mathematically. The chapter will also present strategies and measures for energy reduction for buildings using technical solutions by examining the existing building stock.

## 4.1 Zero-energy building

### 4.1.1 Definition

The definition of a zero-energy building (ZEB) varies depending on the boundaries. However, every definition has a common denominator — increased energy efficiency by sustainable means. The purpose of boundaries is to highlight energy flow in a specified site. Changing the boundary impacts the energy performance, thus altering the definition of a ZEB.

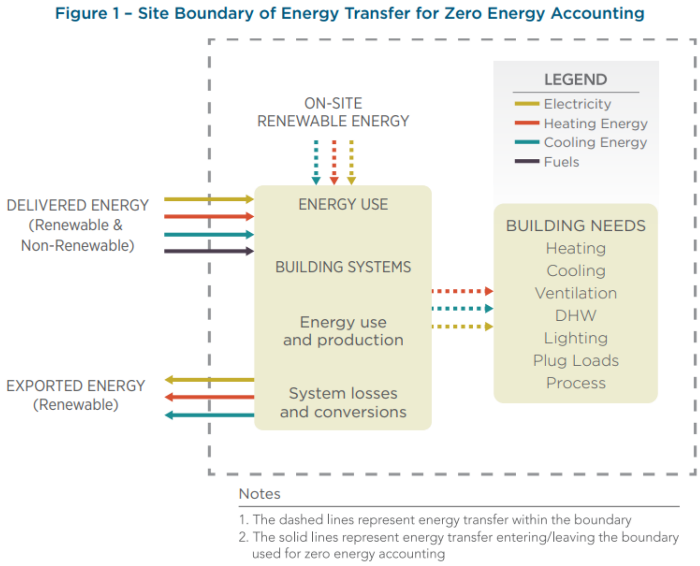


*Figure 8. Overview of site boundary of energy transfer for energy accounting (US Department of Energy, 2015).*

It is essential to set definitive boundaries when defining the term since the measurements can be in cost, emissions, and energy, where the source is a factor to consider. Torcellini et al. (2006) point out that the definition varies due to each stakeholder's different interests. Thus, a ZEB can be defined in the following ways:

1. The energy production on-site is equal to the energy consumption.
2. The energy production at the source is equal to the energy consumption.
3. The emissions spared from renewable energy production are equal to the emissions released from energy consumption.
4. The income from energy production is equal to the expenses from energy consumption.

The American Department of Energy's (2015) definition corresponds to the second definition above, proving Torcellini's point regarding stakeholder interest. They argue that in a small-scale perspective, on-site energy production and cost matter more to a building owner and building designer, respectively. In contrast, source energy is of higher interest from a large-scale perspective.

As of January 1, 2021, the Energy Performance of Buildings Directive (EPBD) requires new buildings to be classified as nearly-zero energy buildings (NZEB) in every member state of the European Union (2016). The EU defines the term in Article 2 (2016) in the second clause as a very high energy performance building, as determined per Annex I. The EU further explains the definition as ‘’the nearly zero or very low amount of energy required should be covered significantly by energy from renewable sources, including energy from renewable sources, produced on-site or nearby’’. The EU directive includes a framework for the energy performance calculations with benchmarks for what is considered an NZEB. The calculations take into account source energy, concurring with Torcellini's argument. Furthermore, it mandates the member states, including Sweden, to develop national plans regarding NZEBs. While the legislation applies to all new buildings, the article also mentions that the existing building stock should be converted gradually to similar standards.

The Swedish National Board of Housing, Building, and Planning, also known as Boverket, has adopted the new directive and defines the term similarly. Boverket has set its own requirements for achieving NZEB, similar to the other members of the EU.

### 4.1.2 National requirements

The minimum requirements for all new buildings in Sweden are presented in the latest revision of the building code, BBR 29. There are four factors and values to consider for buildings built after January 1, 2021. Residential buildings and non-residential buildings have to consider the following:

- the primary energy demand ($EP_{pet}$)
- average heat transfer coefficient ($U_m$)
- installed electrical power for heating purposes
- building envelope's average air leakage

Boverket has set a maximum value that the four mentioned factors cannot exceed. The values are presented in Table 5.

| Building type | $EP_{pet}$ [kWh/m$^2$ y] | $U_m$ [W/m$^2$K] | installed electrical power for heating purposes [kW] | Building envelope’s average air leakage [l/sm$^2$] |
|---|---|---|---|---|
| Residential (50-90 m$^2$) | 100 | 0.33 | $4.5+1.7(F_{geo}-1)$ | Enough to be airtight |
| Non-residential | $70+40(q_{avg}-0.35)$ | 0.50 | $4.5+1.7(F_{geo}-1)$ | Enough to be airtight |

*Table 5. Current requirements for new buildings from Boverket (Boverket, 2020). $q_{avg}$ is 1 l/s per m$^2$.*

The primary energy demand is a measure of a building's energy performance. It is based on the delivered energy to the building, where each energy carrier has a weighting factor presented in Table 6. Boverket has divided Sweden into different climate zones to account for climatic differences during calculation (see Figure 10). The calculation of $EP_{pet}$ consists of the building's annual energy usage, heating, cooling, domestic water usage, and electricity usage multiplied by the weighting factor of the energy carrier and divided by the area. Heating must be adjusted for with a geographical factor ($F_{geo}$). $EP_{pet}$ is calculated using the following equation:

$$EP_{pet} = \frac{\left(\frac{E_{heating,wf}}{F_{geo}}\right) + E_{cooling,wf} + E_{dw,wf} + E_{el,wf}}{A} \quad [\frac{kWh}{m^2 y}]$$

*Eq. 2*

The weighting factors are presented in Table 6.

*Table 6. Weighting factors for each energy carrier*

| Energy carrier | Weighting factor (WF) |
|---|---|
| Electricity | 1.8 |
| District heating | 0.7 |
| District cooling | 0.6 |
| Biofuel | 0.6 |
| Oil | 1.8 |
| Gas | 1.8 |

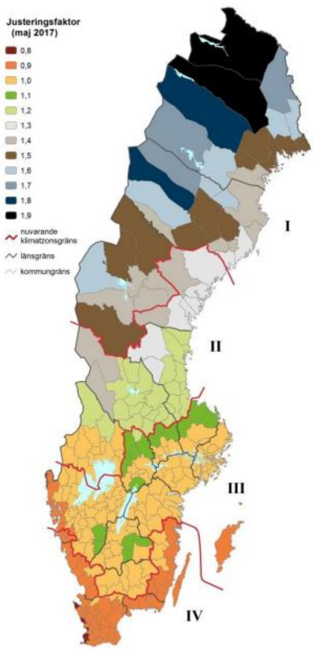


*Figure 9. Map of the climate zones in Sweden (Boverket, 2021).*

Forum för Energieffektivt Byggande (FEBY) is an organization that issues and develops energy performance standards and criteria for buildings in Sweden. FEBY has divided the homes into four different classes: Gold Plus, Gold, Silver, and Bronze, and each one of them corresponds to a particular type of house (FEBY, 2018).

- Gold Plus – Energy-plus building or Zero-energy building
- Gold - Passive building
- Silver - Low-energy building
- Bronze - Energy-efficient building

The classes above vary depending on location, how much delivered (purchased) electricity the building uses, and the total heat loss via transmission, ventilation, and infiltration at the outdoor dimensioning temperature during wintertime. However, regarding the annual usage of the delivered energy, location (climate-zone) does not affect the classification. Annual delivered energy is limited to 26 kWh/m$^2$ for Gold, 32 kWh/m$^2$ for Silver, and 38 kWh/m$^2$ for Bronze. The limit for Gold Plus is the same as for Gold. However, the delivered energy to the building has to be less or equal to the delivered energy from the building annually.

$$VFT_{DVUT} = Q_{loss} * \frac{21 - DVUT}{A} \quad \left[\frac{W}{m^2 A_{temp}}\right]$$

*Eq. 3*

| | Zone I | Zone II | Zone III | If $A_{temp} < 400$ m$^2$ |
|---|---|---|---|---|
| $VFT_{DVUT}$ [W/m$^2$$A_{temp}$] | 17 | 16 | 15 | +2 |

*Table 7. VFT-values for different zones (FEBY, 2018).*

### 4.1.3 Energy optimization strategies and guideline measures

There are several strategies for energy optimization and reduction in a house. Petersson (2017) suggests that the building envelope has to be designed to minimize heat loss while retaining comfort. To achieve that, increasing the thermal insulation and airtightness is advised regarding the building fabric. Peterson also mentions ventilation optimization as a measure, which is also impacted by the design choices and materials used. In addition to mentioned above, reducing and optimizing electricity and heat usage by, for example, installing solar panels and HRV systems are recommended.

Another strategy that aligns with Peterson's suggestions is The Kyoto pyramid. Developed by the Norwegian research institute, Sintef, the pyramid is an interpretation of the Kyoto Protocol and is based on the method Trias Energitica (Heiselberg, Andresen, Perino, & van der Aa, 2006). It is an energy-reduction strategy that instructs on orders of levels which measure is the most efficient and reduces the total energy consumption the most in a building.

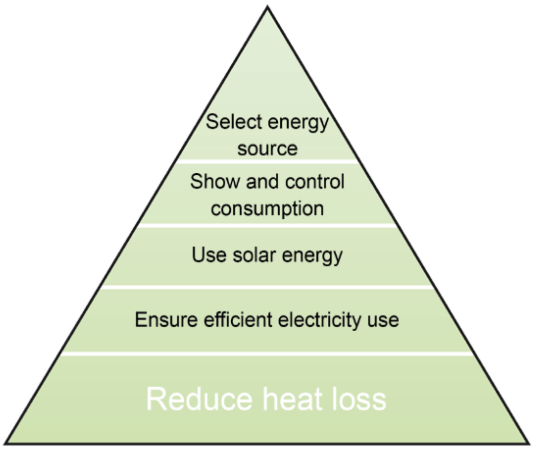

*Figure 10. The Kyoto Pyramid (Paroc, n.d.).*

The pyramid consists of 5 steps starting from the pyramid's base to the top. It is designed in ascending order where the base has the most impact on energy reduction, which lessens with each ascending step. Starting from the base, the steps are:

1. **Reduce heat loss**.
   Examples include thicker thermal insulation, increased airtightness, and heat recovery ventilation.
2. **Ensure efficient electricity use.**
   Examples include efficient appliances and heat pumps.
3. **Use solar energy.**
   Examples include installing solar panels and a higher window area.
4. **Show and control consumption.**
   Examples include installing a monitoring device for consumption.
5. **Select energy source.**
   Examples include reducing the primary energy consumption by choosing a more efficient source and, as a consequence reducing the $CO_2$ emissions.

(Högberg, Lind, & Grange, 2009) have divided energy reduction measures in existing buildings into three categories. Similar to the Kyoto pyramid, the first category aims to reduce heat leakage from the envelope, which can be done by sealing leaks (thermal bridges and windows) and replacing windows. The second category is aimed at heat recovery, which can be attainable by installing an FTX-system or exhaust air heat pump. The third and last category aims to limit the energy distribution by installing control-and-monitoring devices such as temperature adjustments, individual metering, and energy-efficient equipment.

Mata, Sasic Kalagasidis, & Johnsson (2010) developed a methodology for assessing energy efficiency in the existing building stock. Their study was based on grouping several measures suggested by Boverket (2009) due to the unavailability of detailed knowledge about the existing building stock parameters. The measures can be summarized in the following:

- Change in U-value in the envelope (incl. basement)
- Replacement of windows
- Upgrade of ventilation system with heat recovery
- Reduction of power for lighting and appliances

- Replacement of hydro pumps with more efficient ones
- Lowering indoor air temperature from 22°C to 20°C

Presented in a later study by Mata et al. (2013), retrofitting the existing building stock by installing a ventilation system with heat recovery has 22% and 14% energy savings for lowering the temperature. Furthermore, upgrading the U-value and the windows showed a 7% reduction, respectively. In total, the selected measures had the potential to reduce the energy demand of the residential sector by 53%.

The TABULA project identified the building typology in Sweden (Intelligent Energy Europe, 2012). Their report presented guidelines with retrofitting measures for several types of buildings in different climate zones. The recommendations were split into two categories – *better* and *low-energy*. The measures included renovation of the building envelope and HVAC systems. For a single-family house built between 1996-2005 with an area of 125 m$^2$ using district heating and exhaust air as a ventilation system, they recommended the following measures:

*Table 8. The listed values in the "current' column are the typical U-values for a building from 1996-2005. The U-values in the third and fourth columns are from when the report was published between 2009 and 2012.*

| | | **Guideline measures** | |
|---|---|---|---|
| **Layer** | **Current** | **Better** | **Low energy** |
| External wall | 0.20 [W/m$^2$K] | 45 mm of additional insulation: 0.16 [W/m$^2$K] | 45 mm of additional insulation: 0.14 [W/m$^2$K] |
| Roof | 0.12 [W/m$^2$K] | 200 mm of additional insulation: 0.07 [W/m$^2$K] | 500 mm of additional insulation: 0.05 [W/m$^2$K] |
| Slab towards ground | 0.18 [W/m$^2$K] | 40 mm of additional insulation: 0.15 [W/m$^2$K] | 45 mm of additional insulation: 0.15 [W/m$^2$K] |
| Windows | Triple glazed: 1.87 [W/m$^2$K] | Triple glazed: 0.9 [W/m$^2$K] | Low-energy triple glazed: 0.76 [W/m$^2$K] |
| Door | 1.5 [W/m$^2$K] | New door: 1.2 [W/m$^2$K] | New door: 0.9 [W/m$^2$K] |

For the heating and ventilation systems, the following was recommended:

*Table 9. Guideline measures and recommendations for improvement in terms of energy performance based on the current HVAC system in a building.*

| | | **Guideline measures** | |
|---|---|---|---|
| **System** | **Current** | **Better** | **Low energy** |
| Heating | Direct electricity | Air heat pump & direct electricity | Rock (geothermal) heat |

| | | | |
|---|---|---|---|
| Water | Water heater | Air heat pump & direct electricity | Rock (geothermal) heat |
| Ventilation | Natural ventilation | Exhaust air ventilation (FT-system) | Exhaust air ventilation (F-system) |

## 4.2 Heat loss

Heat loss, or energy loss, in a building occurs due to the building fabric and ventilation system. In the form of heat, energy dissipates through the fabric, and vents must be supplied through consumption. The total energy loss $Q_{loss}$ is calculated according to the following equation

$$Q_{loss} = Q_T + Q_V + Q_I \left[\frac{\text{kWh}}{\text{m}^2}\right]$$

*Eq. 4*

$Q_T$ transmission heat loss [kWh/m$^2$]
$Q_V$ ventilation heat loss [kWh/m$^2$]
$Q_I$ infiltration heat loss [kWh/m$^2$]

The purpose of the building fabric from an energy performance perspective is to create a comfortable and habitable indoor environment all year-round while minimizing the demand for heating. The difference between a building fabric and a building envelope is that the latter is the physical separator. In contrast, the fabric is the components and materials of the building. In a building, the fabric consists of the roof, floor, doors, windows, walls, and subcomponents that make up the respective component. Each component has a defined and limited technical service life, and paired with the significant economic investments, choosing the suitable materials from the beginning highly impacts the overall energy consumption. As of 2019, the Swedish residential sector is accountable for 23% of the total final energy usage (Energimyndigheten, 2020). On average, heating accounts for approximately 60% of the total energy consumption, whereas hot water and electricity for household purposes account for 23% (Energimyndigheten, 2021).To reduce the energy consumption in a building, there are several measures one can apply to effectivize the usage and reduce the total energy balance, one of which is choosing the optimal components for the building fabric and the ventilation system. According to Energimyndigheten (2018), approximately 35% of the total heat loss in a building happens through doors and windows, 20% through walls, and the remaining components are attributed to 15% each, as seen in Table 10.

*Table 10. Average heat loss per fabric component in percentage (Energimyndigheten, 2018)*

| Component | Heat loss |
|---|---|
| Doors and windows | 35% |
| Walls | 20% |
| Roof | 15% |
| Floor | 15% |
| Ventilation and infiltration | 15% |

The quality of the building fabric and the optimal material have, therefore, a significant impact on the total overall energy balance of a building. The heat loss can be divided into two sub-categories — transmission and infiltration. The transmission heat losses comprise approximately 85% of the total loss, while heat loss due to ventilation accounts for 15% (see Table 10). Losses through transmission happen through the building fabric, and losses due to ventilation (infiltration) happen through openings in the building fabric. The components are characterized by a certain U-value, also known as the thermal transmittance, which is the coefficient describing the heat transfer rate through matter. Thermal bridges, also known as cold bridges, are specific details in building components characterized by lower insulation, creating a path of least resistance for the heat to travel through from the inside out.

### 4.2.1 Transmission

Transmission losses are dependent on the type of construction material and the surface area of the material. The essential properties of the material that impact the thermal transmittance are the thickness of the layer and the thermal conductivity, λ. Thermal bridges are also included in the transmission losses. A thermal bridge has a higher thermal conductivity than the rest of the building components. There are two types of thermal bridges: linear and point thermal bridges. The former occurs in junctions between construction elements, such as a wall and a door. The latter occurs at a select point in construction, such as mounting brackets. The total transmission heat loss (including thermal bridges) $Q_t$ is defined as

$$Q_t = \sum (U_i A_i + \psi_k l_k + \chi_j) * \Delta T \quad [W]$$

*Eq. 5*

| | |
|---|---|
| $U_i$ | thermal transmittance of component *i* [W/m$^2$K] |
| $A_i$ | the surface area of component *i* [m$^2$] |
| $\psi_k$ | heat transfer coefficient for linear thermal bridge *k* [W/mK] |
| $l_k$ | length of the linear thermal bridge *k* [m] |
| $\chi_j$ | heat transfer coefficient for point thermal bridge *j* [W/K] |
| $\Delta T$ | difference in outdoor and indoor air temperature [K] |

The thermal transmittance or the U-value is the coefficient that describes the transfer of heat that passes through a building component. In other words, it is an indication of how well a building component insulates (Strandberg, 2016). The inverse of the U-value is equal to the sum of the thermal resistance for each layer in the building component. In turn, the thermal resistance is equal to the thickness of the layer divided by the thermal conductivity. Thus, a thicker layer results in a lower U-value. The thermal transmittance is calculated using the following

$$U = \frac{1}{R_T}$$

*Eq. 6*

| | |
|---|---|
| $U$ | thermal transmittance [W/m$^2$K] |

$R_T$ thermal resistance [m$^2$K/W]

The thermal resistance $R_T$ for a component can be calculated using the following

$$R_T = R_{si} + R_{se} + \sum_{i}^{n} \frac{d_i}{\lambda_i}$$

*Eq. 7*

$R_{se}$ external thermal resistance [m$^2$K/W]
$R_{si}$ internal thermal resistance [m$^2$K/W]
$d_i$ the thickness of layer i [m]
$\lambda_i$ specific thermal conductivity of layer i [W/mK]

$U_m$ is the average sum of the U-values for each component that makes up a building, including the thermal bridges. The $U_m$ is defined as:

$$U_m = \frac{\sum(U_i A_i + \psi_k l_k + \chi_j)}{A_{total}} \quad [W/m^2K]$$

*Eq. 8*

$A_{total}$ the sum of all building components' area [m$^2$].

### 4.2.2 Ventilation

Heat losses due to ventilation happen when the air ventilates out of the building. According to the equations below, the properties which affect the heat loss are the ventilation rate and the relative operating time. The ventilation rates $q_{vent}$ The heat loss from ventilation $Q_v$ is defined as:

$$Q_v = \rho_{air} * c_p * q_{vent} * d(1 - \eta) \quad [W/K]$$

*Eq. 9*

$\rho_{air}$ density of air [kg/m$^3$]
$c_p$ specific heat capacity of air [J/m$^3$K]
$q_{vent}$ *air volume flow* [m$^3$/s]
$V$ air volume of the building [m$^3$]
$d$ relative operating time, constant operation equals 1
$\eta$ efficiency of the ventilation heat recovery [-]

### 4.2.3 Infiltration

Infiltration occurs through gaps and holes in the building fabric triggered by pressure differences caused by temperature differences. The amount of infiltration that occurs directly correlates with the building fabric. Thus, to limit the infiltration, the fabric must have a higher degree of airtightness (Petersson, 2017), and for that reason calculating the amount of infiltration becomes difficult. The heat loss from infiltration $Q_i$ is calculated using the following equation:

$$Q_i = \rho_{air} * c_p * q_{inf} \quad [W/K]$$

*Eq. 10*

| | |
|---|---|
| $\rho_{air}$ | density of air [kg/m$^3$] |
| $c_p$ | specific heat capacity of air [J/m$^3$K] |
| $q_{inf}$ | air leakage flow [m$^3$/s] |

## 4.3 Energy supply

To balance the energy heat losses from the building fabric, additional energy must be delivered to the building for consumption. The energy supply of a building can be calculated using the following:

$$E_{consumption} = E_{water} + E_{electricty} - E_{solar} - E_{internal} - E_{technology}$$

*Eq. 11*

| | |
|---|---|
| $E_{water}$ | water consumption |
| $E_{electricty}$ | electricity consumption |
| $E_{solar}$ | solar radiation |
| $E_{internal}$ | internal heat |
| $E_{technology}$ | conversion of energy using technology, e.g., photovoltaic cells |

### 4.3.1 Electricity

Electricity in detached homes or buildings can be divided into two sub-categories, property electricity, and tenant electricity. The first sub-category is electricity, which keeps a building in operation for essential services such as the ventilation system and heating purposes. The latter category is the electricity consumed in the household, for example, by TVs, ovens, lights, and other home appliances. The consumption varies over the year, with increases and decreases of 30% compared to the annual average during wintertime and summertime, respectively (SVEBY, 2012). The standard value for household electricity is 30 kWh/m$^2$, where 70% of the standard value converts to heat.

### 4.3.2 Water

The demand for heated water varies depending on consumer behavior. The technologies used to heat water are, for example, a water heater, heat pumps, and direct heating. According to SVEBY (2012), the standard value for the energy used for hot water in households is 20 kWh/m$^2$ $A_{temp}$ per year, with 20% of the value turned into heat energy. FEBY (2012) recommends verification of the annual hot water consumption $V_{vv}$ (m$^3$) provided that $E_{vv}$ is known, and no other more accurate measurement method is possible.

$$V_{vv} = \frac{E_{vv}}{55} \quad \left[\frac{m^3}{m^2}\right]$$

*Eq. 12*

where $E_{vv}$ [kWh/m$^2$$A_{temp}$] is the annual energy consumption for hot water.

### 4.3.3 Solar heat

The majority of the solar heat passes through the windows during the day and helps with the heating of the building. The distribution of solar heat gain over the year is naturally uneven. It is highly dependent on both the geographical location and the orientation of the building, where south-facing windows are a benefit. Well-insulated buildings can utilize a minimum amount of sunlight per the construction of retaining heat. In contrast, poorly insulated buildings need more considerable and constant sunlight (Gajbert, 2008).

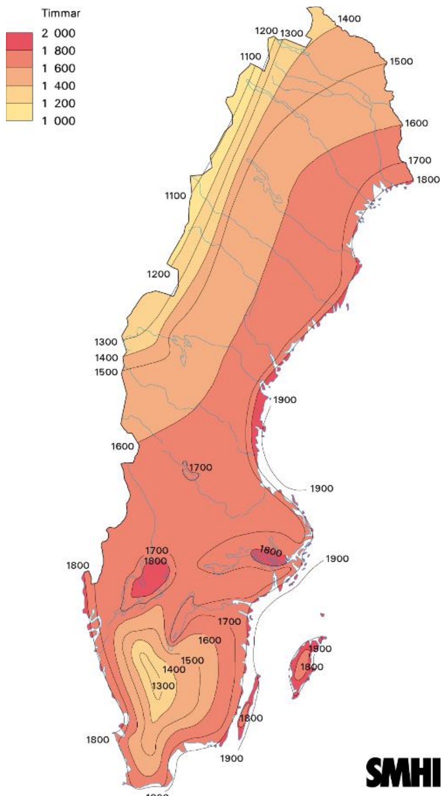


*Figure 11. Distribution of the total annual sunshine hours in Sweden (SMHI, 2017).*

FEBY (2012) has a requirement of SVF ≤ 0.036 $W/m^2$, where the solar heat gain coefficient, SVF, measures how solar heat from windows affects the indoor climate in the summertime.

$$SVF = g * \frac{A_{windows}}{A_{floor}} \quad [-]$$

*Eq. 13*

| | |
|---|---|
| $g$ | solar factor [-] |
| $A_{windows}$ | window area [$m^2$] |
| $A_{floor}$ | floor area [$m^2$] |

### 4.3.4 Internal heat

The average human internal heat gain varies depending on activity level and age. SVEBY (2012) recommends a value of 100 W for adults and 60 W for children, totaling an average standard value of 80 W per person. However, the standard value has been set with an attendance time of 14h per day and person. If the building area is known, an internal heat gain of 1 $W/m^2A_{temp}$ or 8.76 $kWh/m^2$ per year as a standard value can be used for calculation.

### 4.3.5 Photovoltaic cells

Photovoltaic cells can convert direct sunlight into electricity. The energy conversion occurs with no carbon pollution once the cells are installed. The manufacturing process of the panels naturally requires energy and thus emissions of carbon dioxide. However, compared to fossil alternatives, the emissions can be up to 20 times lower. According to the Swedish Energy Agency, the $CO_2$ emissions from solar energy sources equate to 41 $gCO_2/kWh$, whereas energy from coal and natural gas emits 820 $gCO_2/kWh$ and 490 $gCO_2/kWh$, respectively (Energimyndigheten, 2021).

The energy conversion from sunlight to electricity using photovoltaics depends on the geographical location (see Figure 12), the efficiency of the cells, the cardinal direction, roof slope, and temperature. The efficiency of solar panels varies between 16-18% at a panel temperature of 25 degrees Celsius, which lessens by 0.4% with every degree increase. The most optimal cardinal direction is between the southeast and southwest, where the south is the best for maximizing exposure to sunlight with a roof slope between 35°-50° (Vattenfall, 2021). In Sweden, solar cells have an average annual electricity production of 1000 kWh per installed kilowatt power (kWp).

## 4.4 Indoor Climate

### 4.4.1 Thermal Comfort

Enescu (2017) expresses that one of the most critical aspects of the basic theme of comfort experienced in human life and activities is maintaining thermal comfort for individuals. To maintain suitable quality and sustainability of the living environment, thermal comfort is studied with visual comfort, acoustic comfort, electromagnetic radiation protection, and air quality. The rapid increase in cooling & heating demand in buildings and the current global climate emergency have increased the demand for research on thermal comfort. Thermal comfort is described as the altogether perception of the indoor climate.

1. Air temperature
2. Humidity in the air
3. The average indoor temperature
4. The air velocity.
5. Radiation

Two additional significant determinants are rather on a personal level, an individual's activity level and clothes.

### 4.4.2 Air temperature & humidity

Temperature and air humidity are two factors that directly influence perceived comfort in an interior space. Humidity is proportional to the air vapor created by indoor activity and air movement, whereas temperature is adjusted to the desired level.

Temperatures are changed according to the operations carried out on the premises. For example, households and workplaces should be kept between 18 and 20 °C. Exceptions may be given in certain circumstances, such as gyms and retirement homes for the elderly.

The difference between internal and exterior temperatures is the source of the building's heat losses, impacting transmission and infiltration losses via the facade. While lowering the indoor temperature results in energy savings, these savings must be consistent with perceived comfort.

Additionally, air humidity influences the perceived temperature inside. The term "operative temperature" is frequently used to refer to this. The following equation describes its relationship to other factors such as the ambient air temperature and the average temperature of the surrounding walls:

$$T_{op} = \frac{\left(T_{luft} + T_{area}\right)}{2}$$

*Eq. 14*

$T_{op}$ = Operative temperature
$T_{air}$ = Air temperature
$T_{area}$ = Temperature of surrounding wall area

This simplified formula does not regard the surface heat conductivity or air circulation (Petersson, 2017).

Water vapor in the indoor air is considered the primary source of humidity stresses on a structure. Generally, the vapor is initiated by external air humidity that enters the facility via ventilation. Other sources include showering, dishwashing, cleaning, and cooking, as well as humans in general. In exceptional circumstances, leakage from the foundation and the facade may also influence the ultimate air humidity. The following equation clarifies how it is calculated:

$$v_i = v_e + \Delta v \ \ [kg/m^3]$$

*Eq. 15*

$v_e = Outside\ steam\ content$
$\Delta v = Total\ extra\ steam\ within$

For new structures, more building humidity is induced by inward drying, which should be properly examined. This is counterbalanced by ventilation, which reduces the increased humidity indoors. Additionally, the larger the room volume, the lower the air vapor level, as demonstrated by this equation:

$$\Delta v = \frac{G}{(n \times V)} \ [kg/m^3]$$

*Eq. 16*

G = Humidity production rate [g/h].
n = Air circulation [1/h]
V = Volume

As a point of comparison, one may suppose that a human produces around 50 g/h of water vapor at rest. However, regular indoor activity, including occasional standing and walking, nearly doubles the amount, while more strenuous physical activities can increase to 500 g/h.

### 4.4.3 Lighting

According to (Boverket, 2021), a building structure must have the technical qualities necessary to preserve hygiene, health, and the environment. When it comes to light, it is about both safety and wellness. As a result, light is vital in both residential and commercial settings. Access to and exposure to sunlight has psychological and medical health consequences in the long run.

According to the Planning and Building Ordinance, PBF Chapter 3, Section 9, "unacceptable danger to the health of users or neighbors" indicates that "homes and public premises must be maintained and used in a manner that does not cause health difficulty." By health inconvenience, we mean a condition that, based on medical or hygienic evaluation, has the potential to have a negative effect on health and is neither minor nor transient. According to the Swedish Public Health Agency's recommendations for a healthy environment, a dwelling must supply appropriate natural light, among other things. For many segments of society, having both natural and artificial light in the home is vital (Boverket, 2021).

### 4.4.4 Ventilation

Regulated technologies such as heating, ventilation, and air conditioning significantly impact thermal comfort in the indoor environment, referred to as HVAC (Enescu, 2017). To provide a comfortable indoor atmosphere, constructions must have an air circulation system in sync with the outdoor air. Additionally, there is a necessity for the building fabric to act as a barrier to excessive vapor, ensuring that materials are not loaded beyond their capacity. On the other hand, indoor air circulation is highly reliant on the material composition of the ventilation system, as well as the modest air leakage caused by the building textiles. Compared to supply and exhaust air, air leakage is unregulated, implying that heat may be recovered from ventilation air but not from leakage. When a space is in operation, it should have active ventilation, and the typical guideline value for exterior air flow is 0.35 $l/s/m^2$ (Boverket, 2011).

Ventilation systems must be maintained in order to continue providing healthy indoor air. Eventually, the house may develop moisture and mold problems. Then you may experience health complications. The building's owner is responsible for ensuring that the ventilation system operates correctly and making operating and maintenance instructions readily available. As the owner of a building, you may occasionally require the services of a corporation with the necessary capabilities.

Mandatory functional control of ventilation systems (OVK) was implemented in 1992 in residential structures. All freshly constructed dwellings and newly installed systems must undergo an initial inspection. Following that, inspections must be conducted regularly, according to the intervals established for various building classifications and ventilation system types. It is the obligation of the building owner to guarantee that OVK is implemented and that any problems are corrected. However, older single- and double-family dwellings with natural draft ventilation or exhaust air ventilation without heat recovery are exempt from the OVK regulation. Mold on the bathroom walls and ceiling, and moisture on the inside of windows are indications that the ventilation system is not functioning correctly or is insufficient (Boverket, 2021).

The term efficiency is relevant in every element of contemporary society (financial, engineering, and others). In the area of HVAC, efficiency is very much dependent on assuring the circle between use, need, and cost is ideally achieved. Configuration is one of the early stages of HVAC system design that considerably impacts the final system's performance, covering design variables such as equipment selection, air circulation arrangement, and operating strategy. Additionally, a ventilation system can be configured in either a Constant Air Volume (CAV) system or a Variable Air Volume (VAV) system. A CAV system provides constant airflow to the rooms; meanwhile, a VAV system supplies the airflow based on the need.

Mechanical supply and exhaust air systems are equipped with heat recovery, commonly referred to as FTX-systems. A mechanical exhaust air system with heat recovery is called an FX-system. A mechanical exhaust air system (F-system) utilizes a fan to expel the exhaust air. Supply air is introduced by valves in the wall, behind the elements, or within the window frame. Exhaust air systems can be used in conjunction with other technologies, such as an exhaust air heat pump, to recover part of the heat generated by the ventilation. The FX-system is a mechanical exhaust air ventilation system with heat recovery. Without heat recovery, exhaust air cannot be integrated with the energy-efficient building and does not comply with current Swedish national guidelines (Boverket, 2021).

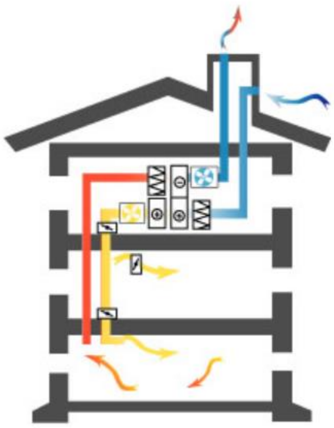

*Figure 12. F-system*

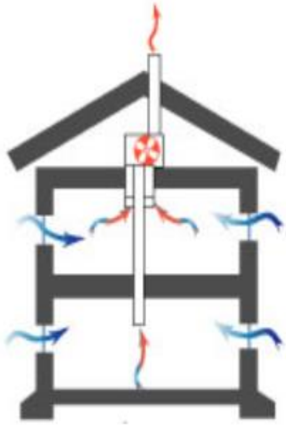

*Figure 13. FT-system*

*Figure 14. FTX-system*

Natural ventilation is not fan-driven, often found in older detached homes and apartment complexes constructed before 1976. Self-contained ventilation works by establishing a ventilation flow of heat differential between the interior and outside of the building (hot air expands and becomes lighter than cold air, which causes it to rise) and influences the building's wind direction. Thus, self-contained ventilation operates without the use of fans (Boverket, 2021)

### 4.4.5 Heat

Effectivization strategies in heating buildings, such as increased insulation or window replacement, have been implemented recurrently throughout the construction sector, although emissions from construction and renovation have not decreased significantly (Boverket, 2020). Each apartment's typical temperature should be around 21 degrees, with a few degrees cooler in an eventual bedroom. Each degree of temperature increase (or reduction) results in a 5% increase (or decrease) in energy use. The heating system must be set correctly for each apartment to have the same temperature. Regular adjustments should be performed every 10-15 years (Lindberg & Magnusson, 2021). Energy usage in apartment buildings differs widely and is influenced by construction year, climatic zone, kind of construction, and tenant behavior. Different construction eras require varying amounts of specific energy for space heating and cooling (Zalejska-Jonsson, 2011).

Generally, the energy requirements for heating and cooling follow a pattern that may be summarized in the following four steps:

1. The most energy-intensive type of building is a standard structure.
2. The energy performance of new buildings complies with the Building Codes' average level or is equivalent to the regional level.
3. The specific energy consumption of sophisticated retrofit buildings for space heating and cooling is typically somewhat greater than that of advanced new buildings.

4. Once a building achieves an advanced performance level, it may be copied in other buildings of the same kind and climate zone (Staniec, Petrichenko, Urge-Vorsatz, & Antal, 2013).

## 4.5 Cost analysis

The profitability of an investment can be measured by using the return-on-investment (ROI) method. ROI is a measure or ratio of the rate of return of an investment over a set period. It can be calculated using the following equation:

$$ROI = \frac{gain\ from\ investment - cost\ of\ investment}{cost\ of\ investment} \times 100\%$$

*Eq. 17*

Another method similar to the ROI is the net present value (NPV) method. NPV compares the future value of the cash flow in comparison to its present value. The method is based on calculating the expected future cash flow in relation to an investment at a given time, taking into account the discount rate. The cash flow is the difference between the benefit and the investment cost.

$$NPV = \sum_{t}^{n} \frac{R_t}{(1-i)^t}$$

*Eq. 18*

Where $R_t$ is the difference between the net cash inflow (benefit) minus the initial investment cost, *i* is the discount rate, and *t* is the number of periods in years.

The payback period is defined as the time it takes to recover the initial investment. The payback period is also known as the break-even point. A lower payback period means more cost-effectiveness and more attractiveness to investors. It can be calculated using the following equation:

$$Payback\ period = \frac{Investment\ cost}{net\ cash\ inflow}$$

*Eq. 19*

# 5 Energy reducing measures

To adequately analyze and evaluate a solution, the constraints on which options were extensively examined were determined by three factors in the specific case of Styrsö. These are determined through the assessment of:

1. Feasibility
2. Budget and lifespan
3. Recommendations from other studies

Personal considerations such as investment costs and the general requirement of severe modifications were made. When evaluating the sustainability of zero-energy renovation methods for a house, the zero-energy performance of the house serves as the central component for the various solutions.

There are several approaches to energy renovation of a building, some of which will not be evaluated in the latter sections. The possible measures have been identified from several sources in the literature review (see chapter 4.1.3). The measures are:

| Energy-reducing measures (ERM) | Assessed | Description |
|---|---|---|
| 1 | ✓ | Additional insulation in the external walls |
| 2 | ✓ | Additional insulation in the roof |
| 3 | | Additional insulation in the slab towards the ground |
| 4 | ✓ | Replacement of windows |
| 5 | ✓ | Change of ventilation system from S to F |
| 6 | ✓ | Change of ventilation system from S to FT |
| 7 | ✓ | Change of ventilation system from S to FTX |
| 8 | ✓ | Installing photovoltaics |
| 9 | ✓ | Lower indoor temperature |
| 10 | ✓ | Change to air-to-air heat pump |
| 11 | | Change of water heater to geothermal heating |
| 12 | | Change of water heater to district heating |
| 13 | | Change to efficient appliances |
| 14 | | Installing control-and-monitoring device |
| 15 | | Increased airtightness of the building |
| 16 | | Change of door |
| 17 | | Change of sauna aggregate |

The measures evaluated are changes in the building envelope, different ventilation systems, solar panels, and lower indoor temperature. To achieve the aim of the thesis, additional measures could have been evaluated. These (non-evaluated) measures include geothermal (rock) heat and district heating. Geothermal heating (ERM 11) can be complicated in implementation due to the ocean's proximity. Furthermore, IDA-ICE lacks the settings for simulating geothermal heating, and the unavailability of online offers ruled out the measure.

District heating (ERM 12) cannot be implemented in Styrsö because the island is outside the district heating network. Behavioral changes (ERM 14) for the consumers were ruled out due to the purpose of the premises as a sauna house with several hundred members and the difficulty of measuring the impact. Detailed knowledge of the building, such as airtightness and insulation of the slab, is inaccessible data therefore, ERM 14 and ERM 3 were ruled out. The door change (ERM 16) was ruled out due to the minimal effect the change would have per equation 5. Lastly, the change of the sauna aggregate to a different type (pellet or infrared) was ruled out since that could potentially be unattractive to the building's current members. Infrared saunas perform and heat the air differently from a traditional sauna, and a pellet sauna offers impracticality to the members of the sauna building.

# 6 Results

## 6.1 Simulations

The building consumes 22381 kWh per year with an average energy cost of 1.53kr/kWh. The measures simulated consist of additional insulation in the building envelope, replacement of the windows, and new HVAC. The results from IDA-ICE simulations are presented below.

### 6.1.1 Envelope

The additional insulation was simulated as three different measures. The first measure was an extra 220 mm of insulation in the external walls, resulting in a total energy reduction of 1.5%. The second measure was an additional 360 mm of insulation in the roof, resulting in a total energy reduction of 0.82%. The third measure combined the first and second measures, resulting in a total reduction of 2.3%. Replacing all the windows resulted in a 2.2% energy reduction. Lastly, the temperature decrease resulted in a 1.6% energy reduction.

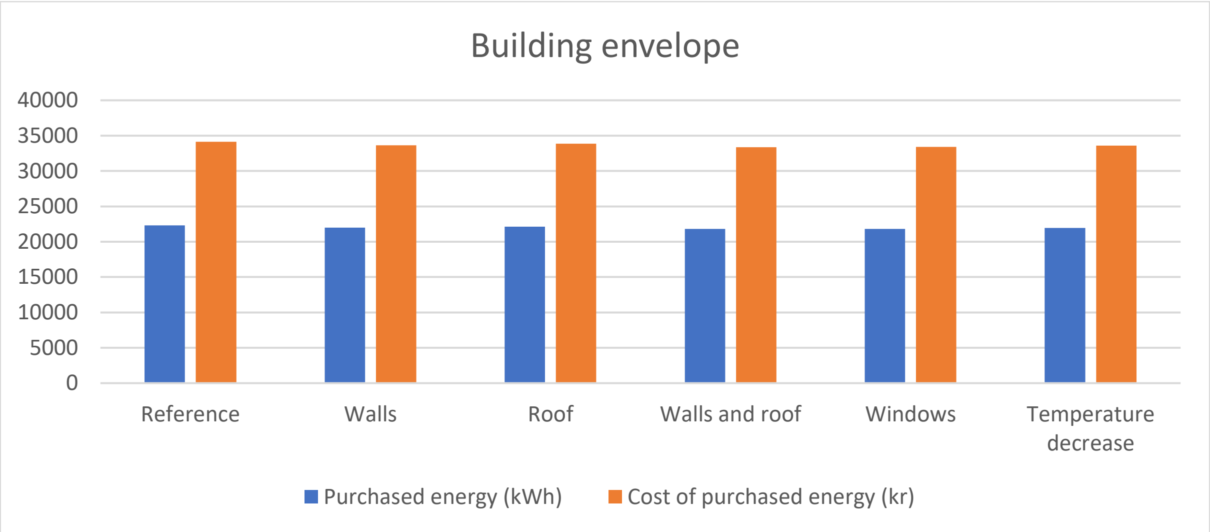


*Figure 15. Comparison of different measures in the building envelope, including temperature decrease.*

### 6.1.2 HVAC

The change of the HVAC from natural ventilation to the other types of mechanical ventilation systems significantly impacted the consumption. The lowest reduction simulated was with an FT(CAV)-system with a total reduction of 32.77%. The highest reduction in purchased energy comes with an FTX(CAV)-system, with a total reduction of 39.18%. In addition, the air-to-air heat pump reduced the total energy by 35%.

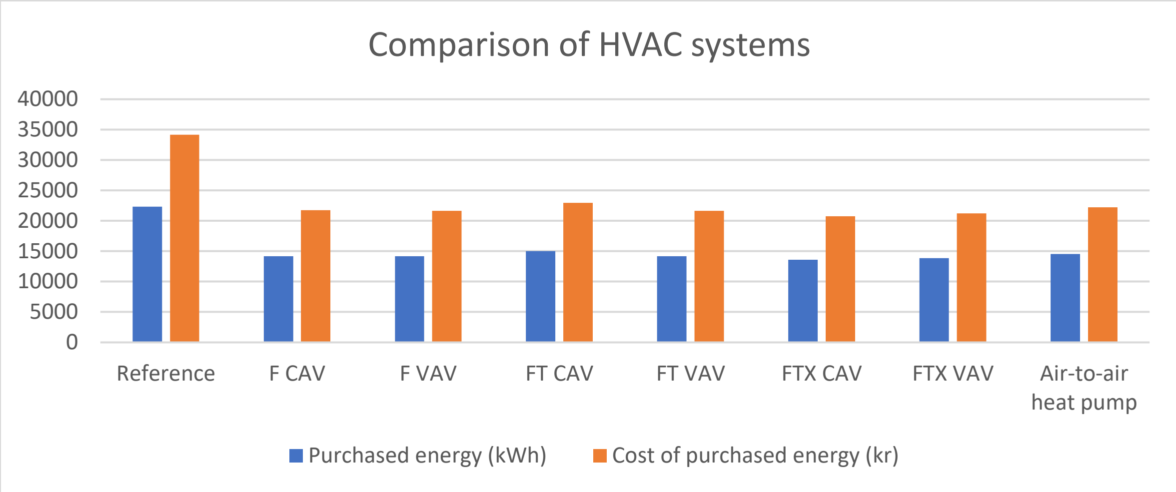


*Figure 16. Comparison of different ventilation systems and air-to-air heat pump.*

## 6.2 Photovoltaics

A solar panel generates on average 200 W per $m^{2,}$ equating to 200 kWh/year per installed $m^2$. The approximation made by Vattenfall on their website using relevant data regarding the reference building resulted in an online offer costing 82 000 kr for 16 solar panels where the solar panels produce 6000 kWh/year, which results in savings of 9180 kr using an average electricity price per kWh. Other sources and retailers, such as EON (2022), offered more watts per panel. However, the panel was physically smaller, resulting in the same approximate total production of 6000 kWh/year from the panels.

## 6.3 Cost-analysis

The annual savings in each measure's energy and investment costs are presented in Figure 18. The savings are also referred to as benefits.

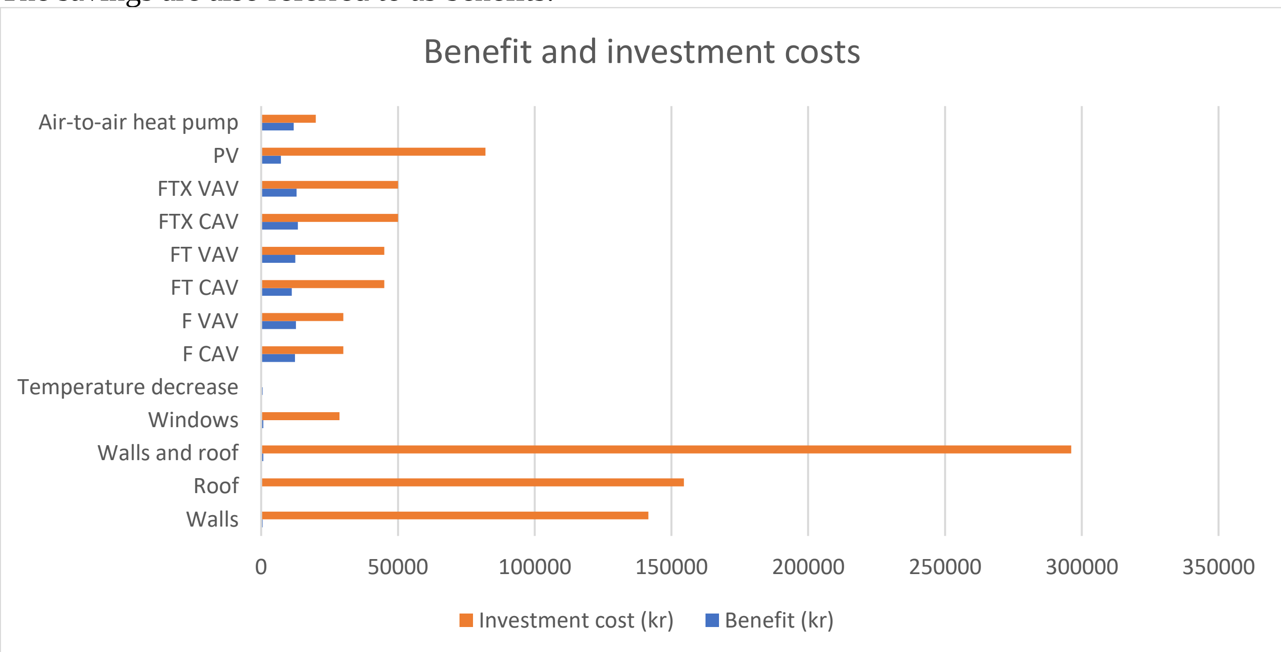


*Figure 17. The benefit and investment costs of the measures.*

The return on investment (ROI) over 30 years is presented in Table 11. The net present value was calculated using a discount rate of 2% for inflation adjustments over 30 years. The payback method is also presented in Table 11 below. The temperature decrease has no ROI or payback time since the investment costs are equal to 0. The cost of energy used is 1.53 SEK/kWh.

| Measure | NPV [KSEK] | Annual ROI | ROI over lifetime | Payback (yrs) |
|---|---|---|---|---|
| Walls | -129.823 | -2.98% | -89.3% | 281.3 |
| Roof | -148.045 | -3.15% | -94.6% | 555.0 |
| Walls and roof | -277.796 | -3.07% | -92.0% | 377.3 |
| Windows | -11.404 | -0.76% | -22.8% | |
| Temperature decrease | 12.7 | - | - | - |
| F CAV | 260.5 | 38.1% | 1141.9% | 2.4 |
| F VAV | 266.5 | 38.9% | 1167.3% | 2.4 |
| FT CAV | 216.7 | 21.5% | 646.0% | 4.0 |
| FT VAV | 247.2 | 24.4% | 732.8% | 3.6 |
| FTX CAV | 262.9 | 23.4% | 702.6% | 3.7 |
| FTX VAV | 252.2 | 22.5% | 675.2% | 3.9 |
| PV | 132.7 | 7.9% | 235.9% | 8.9 |
| Air-to-air heat pump | 259.1 | 56.3% | 1689.9% | 1.7 |

*Table 11. Cost-benefit analysis for each measure in terms of net-benefit value, return on investment, and payback years calculated with an energy cost of 1.53 SEK/kWh.*

Similar to Table 11, the cost analysis in Table 12 presents similar results regarding which measures are cost beneficial, however, with an increased energy cost of 3 SEK/kWh. Every positive measure using the different analysis methods doubles in terms of NPV and ROI and halves the payback time. The negative measures (insulation in the walls and roof) remain almost unchanged.

| Measure | NPV [KSEK] | Annual ROI | ROI over lifetime | Payback (yrs) |
|---|---|---|---|---|
| Walls | -118.5 | -2.6% | -79.1% | 143.5 |
| Roof | -141.7 | -3.0% | -89.4% | 283.1 |
| Walls and roof | -260.1 | -2.8% | -84.4% | 192.4 |
| Windows | 5.170 | 1.7% | 51.4% | 19.8 |
| Temp. decrease | 25.1 | - | - | - |
| F CAV | 539.7 | 77.8% | 2335.1% | 1.2 |
| F VAV | 543.1 | 78.3% | 2349.4% | 1.2 |
| FT CAV | 468.3 | 45.4% | 1362.7% | 2.1 |
| FT VAV | 528.1 | 51.1% | 1532.9% | 1.8 |
| FTX CAV | 563.6 | 49.1% | 1473.7% | 1.9 |
| FTX VAV | 542.7 | 47.3% | 1420.0% | 2.0 |
| PV | 339.1 | 25.2% | 756.0% | 3.5 |
| Air-to-air heat pump | 527.4 | 331.4% | 3409.6% | 0.3 |

*Table 12. Cost-benefit analysis for each measure in terms of net-benefit value, return on investment, and payback years calculated with an energy cost of 3 SEK/kWh.*

## 6.4 National & FEBY requirements

The selected measures were chosen to highlight the differences between the measures. The different ventilation systems had similar results in terms of energy reduction (see Figure 17). The results from the combination of measures and how that applies to Boverket's current requirements for new buildings are presented in Table 13. It is possible to achieve an NZEB energy classification (energy class C) when combining any new ventilation system with an air-to-air heat pump. It is impossible to achieve NZEB status when combining any new ventilation system with only PV. However, an FTX system with solar cells and changes in the building envelope resulted in just 1 unit below the maximum required value (EP = 96) for new buildings, i.e., NZEB.

*Table 13. Energy performance of combined measures compared to the current national requirements from Boverket for new buildings.*

| Combination of measures: | Energy demand | EP | Energy class |
|---|---|---|---|
| FTX(CAV), Windows | 13060 kWh | 183.84 | F |
| FTX(CAV), PV | 7573 kWh | 105.91 | D |
| FTX(CAV), PV, Windows | 7091 kWh | 102.10 | D |
| FTX(CAV), PV, Windows, Temperature decrease | 6591 kWh | 95.25 | C |
| FTX(CAV), Air-to-Air heat pump | 6400 kWh | 83.05 | C |
| FT(CAV), Air-to-Air heat pump | 7203 kWh | 88.91 | C |

The results from FEBY's requirements are presented below.

*Table 14. Energy performance of combined measures from FEBY.*

| Combination of measures: | Weighted energy [kWh/m$^2$] | Energy class |
|---|---|---|
| FTX(CAV), Windows | 348.27 | <Bronze |
| FTX(CAV), PV | 201.95 | <Bronze |
| FTX(CAV), PV, Windows | 189.09 | <Bronze |
| FTX(CAV), PV, Windows, Temperature decrease | 175.76 | <Bronze |
| FTX(CAV), Air-to-Air heat pump | 170.67 | <Bronze |
| FT(CAV), Air-to-Air heat pump | 192.08 | <Bronze |

Additionally, the VFT was calculated for the combined measures with the highest and lowest energy consumption (13060 kWh and 6400 kWh, respectively). For the highest, the VFT was calculated to be 34.8 W/m$^2$A, while the lowest was 36.3 W/m$^2$A.

# 7 Discussion

Assumptions had to be made regarding the annual energy consumption of the building. Due to COVID-19, the annual energy consumption during 2020 was low compared to the previous years. Therefore, a decision was made to exclude 2020 as representative data, and the average from the three prior years was used instead. Similarly, the water consumption was approximated in the same manner. Furthermore, parametric assumptions were made in the calculations of the current energy consumption on IDA-ICE. The slab towards the ground was approximated to have a U-value of 0.2 $W/m^2K$ and the external door with the default value of 1.5 $W/m^2K$. The windows were assumed to be 1.9 $W/m^2K$ and the roof to be 0.17 $W/m^2K$. The assumed values of the envelope were taken from Tables 8 and 9 in conjunction with a specification sheet of the materials used in the building. The specification sheet was not fully detailed, thus the completion from the tables. It should be noted that the input data may have been incorrect in some cases, which can affect the results from the simulated measures. It must be stressed that determining a building's energy performance is also dependent on knowledge of the climatic context. Therefore, the final evaluation may be imprecise if the energy diagnosis phase is simplified during the design stage. However, simulated results should have the exact percentages even if some numbers are incorrect.

The results show that it is possible to achieve an NZEB status. Using simulations and the selected combined measures, the energy demand was most reduced from 22381 kWh to 6400 kWh. Furthermore, the changes in the envelope, including the temperature decrease, can reduce the total energy demand by 1000 kWh. Therefore, ZEB is possible when installing any mechanical ventilation system combined with an air-to-air heat pump, solar cells, and the earlier mentioned changes in the building envelope. Another option to potentially achieve ZEB is to change the sauna aggregate. However, no simulations were made for the reasons mentioned in chapter 5.

The first approach to achieving net-zero in the building is to reduce the significant areas of consumption in the building as mentioned in section 4.1.3, heat loss reduction measures with the highest impact, followed by efficient energy appliances and solar cells. The simulations showed a slight reduction in energy demand when insulating the roof and changing the windows. Contrary to Mata et al.'s (2013) result, the reduction for the envelope was only 2.3% compared to the 7% they had, whereas changing the ventilation system resulted in a significant energy reduction ranging from 32.8% to 39.2% compared to their 22%. The air-to-air heat pump reduced the energy demand significantly, with a 34.9% reduction. The first approach can be summarized as changing the HVAC system in the building, either by installing a new ventilation system, a new air-to-air pump, or both. Similar to the Kyoto Pyramid and other energy-reducing strategies, the study's findings suggest that installing solar cells is the second-best implementation measure (second approach). The building benefits from having an optimal cardinal direction, a gable roof, and roof angles for installing solar cells and efficient energy conversion. The first and second approaches are the measures that significantly reduce the building's energy demand. The other options are changes in the envelope or a decrease in the indoor temperature, which slightly impact the energy demand compared to the measures mentioned earlier.

In summary, to achieve NZEB status according to the results, there are two options:

1. New ventilation system + PV + Windows + Temp. decrease
2. New ventilation system + Air-to-air heat pump

Combining the options mentioned earlier makes it possible to achieve ZEB.

3. New ventilation system + Air-to-air heat pump + PV + Windows + Temp. decrease

The simulations show that a new ventilation system is essential for both routes. The initial objective (NZEB) can only be achieved either by making changes in the building envelope (incl. temperature decrease) and installing solar panels or the installment of an air-to-air heat pump. By combining the first and second options, ZEB indeed becomes achievable.

Installing a new air-to-air heat pump from a cost-benefit perspective is more efficient and logical. All economic performance methods suggest it is a good measure. In addition, the ventilation systems are also beneficial from an economic point of view. On the other hand, the changes in the building envelope proved to be highly inefficient both economically and energy-performance-wise. Additional insulation for the external walls and roof resulted in a 2.3% energy reduction, and the windows changed to 2.2% energy reduction. However, the results present no need for changes in the building envelope to achieve nZEB. There are two approaches in the combined measure simulations. The first one is only to change the heating methods, and the second is to combine the heating method with changes in the envelope and production of energy. The first approach proved to be highly efficient and attractive in every economic calculation, whereas the second approach is less optimal due to the changes in the building envelope. Regarding economic efficiency for the changes in the envelope, the high investment costs for a minimal reduction in energy resulted in negative financial gains. Additionally, from a practical point of view, additional insulation in the roof may be more invasive and costly since the roof may be limited in space for any additional insulation.

The equation used for calculating EP favors heating methods with lower multipliers. Therefore, switching to other forms of heating, such as district heating or biofuel, makes the transition to ZEB easier with the current requirements for the energy classes. However, since district heating is not available in Styrsö, the only other alternative is biofuel. Additionally, the current definition of EP does not consider the sauna aggregate's energy consumption. The implication is that buildings can have the same energy class and thus be classified as NZEB or ZEB while having significant differences in annual energy consumption.
The classification method from FEBY is stricter than Boverket's since the building did not achieve any criteria presented by them. FEBY uses higher values on the multipliers for the energy carriers when calculating $E_{weighted}$ and adds another layer of requirement by introducing the VFT, which is their method of measuring heat losses.

Indirectly, the Kyoto Pyramid has served as a reference, as seen by the results of our studies. For instance, the first and most significant stage in optimizing the energy performance of a building was lowering heat loss, which was a result of our research and an essential step in achieving this goal. Photovoltaics, the third step in the Kyoto Pyramid, was one of, if not the main factor in reaching the study’s goal. One could say that steps 1 and 3 in the pyramid were the main protagonists for the building to achieve ZEB classification.

Similar to this study, previous research has concluded that boosting thermal energy efficiency through effective thermal insulation or installing solar thermal collectors (STC) is a step toward achieving all NZEB balances. Different findings might have been feasible if any of the approaches had been modified. For example, having access to technology and tools such as a thermal camera would have provided another dimension to the discussion topics. Unfortunately, this was not possible due to time restrictions. Another alternative would be to conduct research simply based on the literature. This would imply that conclusions and assessments would be made entirely based on prior studies on the subject. We employed primarily primary data collected through our simulations; however, the issue remains whether secondary data collection would have been more pertinent to the cause. However, to adequately address the study issues, a combination of qualitative and quantitative data was chosen as the technique. Other approaches for the study could have been examining and analyzing buildings similar to the case study – either through literature or primary data collection. This study has only investigated a single object. The benefits of comparing to other similar case studies could be to evaluate the possible errors in the simulation of the reference object or investigate how applicable the results from this study are to other buildings.

The project has investigated an approach from an economic perspective. Future studies based on this project could investigate an approach for ZEB from a $CO_2$ emissions perspective. It would have to be conducted by investigating the primary factors of the energy carriers at the source. The project would also compare the differences and losses between the primary energy source, the secondary energy, and the end-use consumption. Each energy conversion stage in the supply chain could be analyzed from an economic-and-emissions perspective and the energy-performance perspective. Additionally, analyzing the recommended measures from this project from other perspectives and how the results can vary depending on the definition of zero-energy buildings can also be investigated.

A possible direction for future study would be to conduct a life cycle analysis (LCA) to identify and debate specific future economic and sustainability measures. Comparing measures in terms of economic viability would be an excellent way for the owners of Styrsö Hafsbad to choose the most appropriate actions to ensure the building's best quality. This would include the assessment of CO2 emissions, the avoidance of financial loss, and the forecast of building performance.

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