Improving Energy Grades in Norwegian Dwellings through Local PV and Battery Systems

A Path to Zero-Emission

Master's thesis in Sustainable Energy Systems

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Acknowledgements

You are reading the Master’s thesis on “Improving Energy Grades in Norwegian Dwellings Through Local PV and Battery Systems: A Path to Zero-Emission”. This thesis was completed to fulfill the requirements of the master's program in Sustainable Energy Systems at Chalmers University of Technology. This project was started in January of 2025 and finished in June 2025.

When developing this master's thesis, I wanted to challenge myself with a topic I was somewhat unfamiliar with to broaden my knowledge, in addition to investigating a topic that is relevant and will affect the field in the coming years. It was especially challenging as some of the policies that are very relevant for the thesis were unexpectedly changed in April 2025, which heavily impacted how I had to approach the topic. However, I faced this challenge head-on and managed to find a solution. After completing the thesis work, I feel like it helped me grow professionally and personally.

I want to express my gratitude to my supervisor, Jan-Olof Dahlenbäck, for his patience and competence throughout this thesis.

Finally, I want to thank my family and friends for encouraging me and supporting me throughout this thesis, but also throughout my entire education. Your steady support and love in the hard times this year have made it possible to complete this thesis, and I couldn't have made it this far without your help.

I hope my work contributes meaningfully to the ongoing discussions around this topic.

Synne Gjerde

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Abstract

The EU has introduced the EPBD, which was implemented in 2024, and is a new directive targeting energy performance in buildings, which aims to reach a zero-emission building stock by 2050. Additionally, it states that 55% of the total reduction must come from renovating 43% of the worst-performing buildings. This thesis aims to investigate how to reach a zero-emission residential building stock in Norway, through investigating various energy reduction measures in existing dwellings, and how they will contribute to the energy grading based on the energy labeling system. The study's results are based on literature review, data collection, case studies, as well as utilizing mixed integer linear programming to investigate the intricacies of using PV panels, batteries, and flexible loads. The analysis shows in terms of cost, traditional measures such as insulation remain more economically feasible. But it's PV and hybrid systems that deliver the biggest energy reduction. A major limitation is that battery systems currently receive no Enova subsidies, even though they have a high impact on both grading and self-consumption. That's something worth re-evaluating at the policy level. Overall, PV and battery solutions show strong potential, both in older buildings, like Rørvollveien 17, and in homes already close to grade A, like Jongsåsveien 31 A, and they can play a central role in reaching a zero-emission building stock.

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1. Introduction

1.1. Background

The potential environmental impact of increasing energy efficiency and reducing consumption in the EU is significant. The Energy Performance of Buildings Directive's main aim is to reach a zero-emission building stock by 2050, which is an important step to achieve the EU's climate and energy goals. To reach these goals, the directive focuses on stricter requirements and increasing standards of energy performance. The intention is to increase the rate of renovations in the EU and target the worst-performing buildings[1].

In 2023 and 2024, the revised EPBD sparked controversy in Norway, as public concern and media coverage took off. This controversy stemmed from a common misunderstanding that the directive would require that all buildings be upgraded to an energy label A or B within 2030. This caused people to be concerned, as homeowners were fearful of being forced to complete expensive renovations, especially in areas of lower income, older housing stock, and elderly homeowners. This misunderstanding and backlash of the scope and requirements were not limited to the general public, but also the politicians debating how to implement the directive in Norway. This caused many parties to oppose the directive, and the general debate was based on protecting property rights and high costs for homeowners. In addition, many perceived that the EU directive tried to exploit Norway, arguing that with an energy mix consisting of 98% renewable energy[2], the climate benefits of reducing energy use were minimal. Forcing costly renovations to reduce energy use in households that are already renewable was seen as wasteful and unnecessary[3], [4], [5]. For this reason, one of the main motivations for this thesis is to clarify what the EPBD proposes and how the implementation will affect Norway. A key objective of the thesis is to bring a more technical and evidence-based approach to the debate.

1.2. Framework

At the core of this thesis is the EPBD, which establishes the overarching aim of improving energy efficiency in buildings, as well as reaching a zero-emission building stock in the European Union. In Norway, the national standard NS3031 is used by engineers and professionals and acts as a technical framework that establishes how the energy performance is calculated and assessed. The standard ensures continuity in the methodology of calculating energy performance and is established in a way that gains the same results regardless of the company performing the energy assessment. With this methodology, a building surveyor can assess a building, gathering data to compile an energy performance report, consisting of the breakdown of its energy consumption. The main result of the energy performance in this context is the resulting specific energy consumption, which is a value expressing the annual energy use per square meter of heated floor area, in kWh/m^2. This makes it possible to scale the consumption relative to the size of the building, which enables comparison of various dwellings.

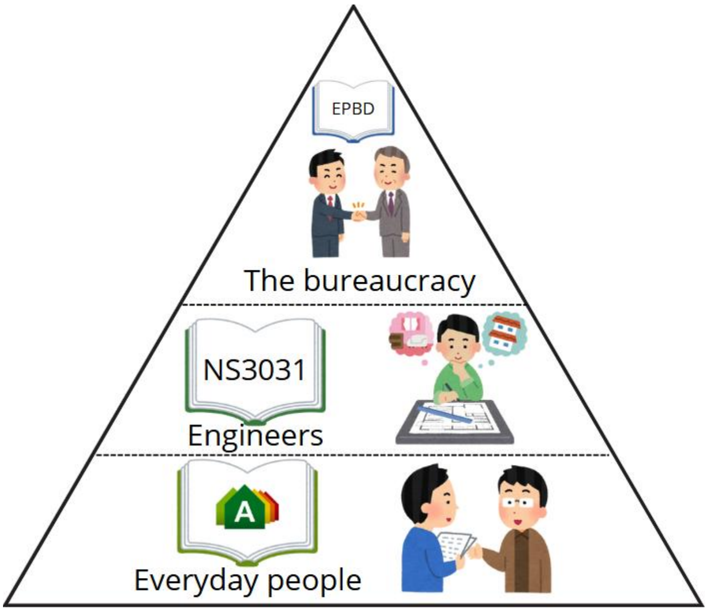


Table 1-1: Hierarchy of the EPBD, NS3031, and the energy labeling system.

Based on the specific energy consumption, the dwelling is assigned a simplified grade from A to G according to a scale that is pre-defined by the energy labeling system. The ranking is a representation of the performance of the dwelling within its dwelling category. This grade system translates the specific energy consumption value to a scale easily understood and accessible by the general public.

In this thesis, the discussion and focus are placed on the NS3031 level, on the technical side, rather than on the simplified system. The objective is to investigate and discuss the methodology and foundation for calculating energy performance and how the cost-effectiveness of energy reduction measures is affected by the energy labeling system.

When investigating possible energy reduction measures, the resulting measures can be divided into three categories. The first is measures that are profitable and beneficial for both the overarching societal goals and the house owner. The second type of measure contributes positively to the broader societal goals, but is not financially viable for the individual homeowner. There are several ways to remedy this, the first is that the government provides subsidies to increase the financial viability of the measures for the homeowners. The second is that the government encourages the desired measure through incentives such as faster permit processing, labels or recognition, or lastly, by implementing minimum requirement standards that force the implementation. The last category of measures is where the cost is far too high for the individual homeowner to be considered, and the measure's contribution to the overall societal goals is marginal and therefore not a good utilization of the available subsidies. In this category, it would be unwise for the government to enforce minimum performance standards, as doing so can provoke public outrage, similar to the response seen in Norway regarding the EPBD.

For this reason, it is essential that the new NS3031 policy and the energy labeling system create conditions that support measures in the first and second measure types. This perspective is a key motivation in the discussions and reasoning of this thesis.

1.3. Thesis Structure

This thesis is structured into three main parts: **1)** introduction (Chapter 1) and literature study (Chapter 2) – establishing the theoretical and regulatory context, **2)** an in-depth case study analysis of the dwelling in Rørvollveien 17 (Chapter 3), including its annual energy consumption, and proposed measures to improve its energy grade, and **3)** how the results in Rørvollveien 17 can be generalized and applied to the broader Norwegian building stock, with the overarching goal of reaching a zero-emission building stock (Chapter 4).

2. Literature study

2.1. Energy Performance of Buildings Directive (2024)

For this thesis, the focus is on the EPBD's impact, therefore, it is essential to have a rudimentary understanding of its content. To summarize the main takeaways from the EPBD's content, the overarching aim is to reach a zero-emission building stock by 2050. However, the EPBD's definition of a zero-emission building is very vague. The definition says that a zero-emission building is a building with a very high energy performance and low emissions, which does not set a very clear boundary or guideline. This overarching aim is intended to be reached through decreasing the average primary energy use (kWh/m^2 per year) with trajectory targets for 2030, 2040, and 2050. It is important to note that while the directive sets overarching ideas and principles for what the member states should aim for in their transposition, it leaves significant flexibility in how member states can implement the measures. This allows the member states to develop pragmatic solutions for the measures, allowing adjustments depending on need, climate, and the building stock's conditions. For a deeper and more detailed outline of the EPBD's articles, see Appendix 7.3.

2.1.1. Implementation of Directives in Norway

Norway is a member of the European Economic Area (EEA) Agreement, connecting it to the European Union's regulatory framework. The EEA is an agreement that connects the three EEA EFTA states, Norway, Iceland, and Liechtenstein, to the EU member states in one market, referred to as the internal market. This agreement includes a commitment to adopt most of the EU directives[10]. The EEA's purpose is to guarantee the free movement of goods, services, capital, and people, as well as competition and state aid rules and certain areas of cooperation such as consumer protection, environment, public health, and education[11].

To incorporate the EU legislation, the EEA Committee uses experts to assess the relevance of the content, and whether to implement them in the EEA Agreement. Similar to the EU member states, the EEA EFTA states must then transpose the legislation into national law, and later controlled by the EFTA Surveillance Authority (ESA)[11].

In the next section, the Norwegian energy labeling system will be introduced and explained. Starting with the framework of the labeling system that has been in practice since 2010, and until today. Followed by the new 2025 implementation and update of the labeling system, which forms the backdrop for the research and investigation in this thesis.

2.2. Norwegian Energy Labeling System 2010

The energy labeling of housing and buildings was implemented in Norway on July 1st, 2010, as a consequence of the 2010 revision of the Building Energy Directive. This directive makes it mandatory for all new buildings, as well as all residential or non-residential buildings sold or rented, to have an energy certificate. In the case of selling and renting, the certificate must be used in the marketing of the building during the sale process. The energy certificate is issued by the governmental company Enova and shall be calculated according to the standard reference climate based on climate data from the Oslo area[6].

To further explain the energy certificate grading, it consists of two ratings that are not correlated, one from A to G, which is the energy rating, and a color, the heating rating. The energy rating of the dwelling is calculated using the specific delivered energy under normal consumption. The delivered energy is the net energy used by the building, including the efficiency of the system components, divided by the useful floor area. The factors included in the specific annual delivered energy consumption are further elaborated in the Norwegian standard NS 3031:2014[7]. However, when officially evaluating a dwelling's energy grade, the assessment is based on normalized values and a simulation of the heating need based on the dwelling's characteristics.

The heating rating is a five-colored scale expressing the share of fossil fuels and electricity used in the dwelling. The scale varies from red to green, where green indicates a low share of fossil fuels and electricity. Heating solutions that can positively contribute to a green heating rating are renewable solutions such as district heating, solar thermal heating, heat pumps, and bio-based heating[8]. The specific color is decided according to the share of the total energy need that is covered by electricity and fossil sources[9].

Figure 2-1 is an example of a Norwegian energy label, and Table 2-1 is the distribution of the energy rating for a single-family home depending on the useful floor area of the house.

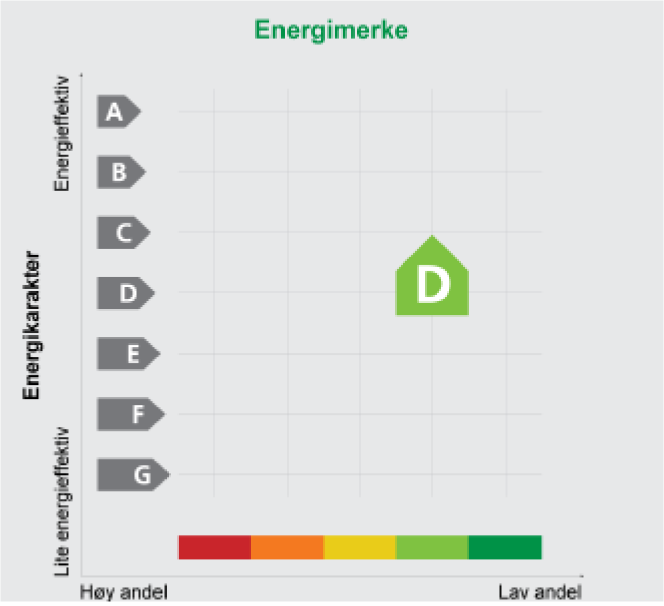


Figure 2-1: Example of an energy rating D, and a green heating rating.

Table 2-1: The energy grade distribution for a single-family home[10].

Single family home	**Delivered energy pr m^2 heated BRA (kWh/m^2)**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
Heated BRA (m^2)	Lower than or equal to	Lower than or equal to	Lower than or equal to	Lower than or equal to	Lower than or equal to	Lower than or equal to	No limit
50	111,00	152,00	195,00	257,00	321,00	410,00	> F
75	105,67	141,33	178,33	229,67	282,33	356,67	> F
100	103,00	136,00	170,00	216,00	263,00	330,00	> F
125	101,40	132,80	165,00	207,80	251,40	314,00	> F
150	100,33	130,67	161,67	202,33	243,67	303,33	> F
200	99,00	128,00	157,50	195,50	234,00	290,00	> F
300	97,67	125,33	153,33	188,67	224,33	276,67	> F
400	97,00	124,00	151,25	185,25	219,50	270,00	> F
500	96,60	123,20	150,00	183,20	216,60	266,00	> F

The official assessment of the dwelling's energy grade is completed by certified experts and companies, and in specialized simulation programs such as Simien. The specific energy consumption is calculated using normalized values for technical equipment, lights, hot water consumption, and people, as well as a simulation of the heating need. The heating needs are calculated through a simulation of the dwelling's heat loss and internally supplied heat. The simulation inputs are the for instance, the building envelope, including U-values in the floor, walls, ceilings, roof, and windows, as well as airtightness, thermal mass, solar gain, internal loads (the normalized values), and climate data for Oslo.

2.3. Norwegian Standard NS3031:2014

This Norwegian standard is named 'NS 3031: Beregning av bygningers energiytelse- metode og data' and means calculation of energy performance – method and data. This standard establishes calculation methods and assumptions for energy performance in buildings, and is used for various purposes, such as for energy labeling and documentation of buildings in accordance with the requirements in technical regulations (TEK). It was originally published in 2007 but has been updated to fit changing standards and technologies, where the latest version is NS 3031: 2014. A revised version was set to be published sometime during 2025, but was published during the writing of this thesis, on March 25th, 2025[11], [12].

2.3.1. Normalized Energy Consumption

In NS 3031, there are normalizations of consumption that can be utilized to calculate a dwelling's energy label. Extracted in Table 2-2 are the normalized values for average power demand during operating hours and annual energy demand for lighting, technical equipment, and hot water for a single-family home[13].

Table 2-2: Net power and energy demand for a single-family home- standard values for average power demand during operating hours and annual energy demand for lighting, equipment, and hot water[13].

	Lighting		Technical equipment		Hot water	
	W/m^2	kWh/(m^{2}year)	W/m^2	kWh/(m^{2}year)	W/m^2	kWh/(m^{2}year)
Single-family home	1,95	11,4	3,00	17,5	5,1	29,8

2.3.2. Calculating Net Energy Energy

For the annual energy, the net energy budget is calculated by summing up seven factors.

$$E_t = \sum_{i=1}^{12}(Q_{H,nd,i} + Q_{C,nd,i} + E_{fan,i}) + Q_{W,nd} + E_p + E_l + E_{eq} \qquad [kWh/year]$$

Where

i	is the month of the year, 1 is January, etc.
$Q_{H,nd,i}$	is the space heating demand for month i, in kWh
$Q_{C,nd,i}$	is the space cooling demand for month i, in kWh
$Q_{W,nd}$	is the annual energy demand for domestic hot water heating, in kWh/year
$E_{fan,i}$	is the energy demand for fans for month i, in kWh
E_p	is the annual energy demand for fans, in kWh/year
E_l	is the annual energy demand for lights, in kWh/year
E_{eq}	is the annual energy demand for technical equipment, in kWh/year

2.3.3. Calculating delivered energy

The calculation of the delivered energy is based on the net energy demand from Section 2.3.2, as well as annual average system efficiencies for the systems. The specific delivered energy is calculated per square meter of heated floor area (BRA). The calculation of the delivered energy is done in primarily six parts, finding how much energy is delivered through electricity, oil, gas, district heating, biomass fuel, and other energy sources. To find the total delivered energy, the six energy types are summarized and divided by the BRA[13].

2.3.4. NS3031:2014 Summary

Based on the calculation method in NS3031:2014, delivered energy is the calculated net energy demand, but adjusted for system efficiency. The net energy demand includes space heating, space cooling, hot water consumption, ventilation, lighting, and appliances. When calculating the delivered energy, the system efficiencies are accounted for. However, electricity produced by PV panels is not seen as a part of the building's energy system. Therefore, PV production does not reduce the calculated delivered energy and will be the same regardless of whether a dwelling has solar panels or not. The case for a heat pump is similar, where both the electrical input and the thermal output are included in the delivered energy, which fails to reflect the efficiency and renewable share of the energy source.

2.4. Norwegian Standard NS3031:2025

In March 2025, the current version of NS3031 was published. With this version, in line with the European standard EN-ISO 52000-1, and the new 2024 version of the EPBD. The 2025 version builds on top of the 2014 version, maintaining the same core methodology for calculating the net energy demand and the delivered energy. The new version includes updates to certain parameters and further elaborates on energy calculation zones, with some including energy produced on-site.

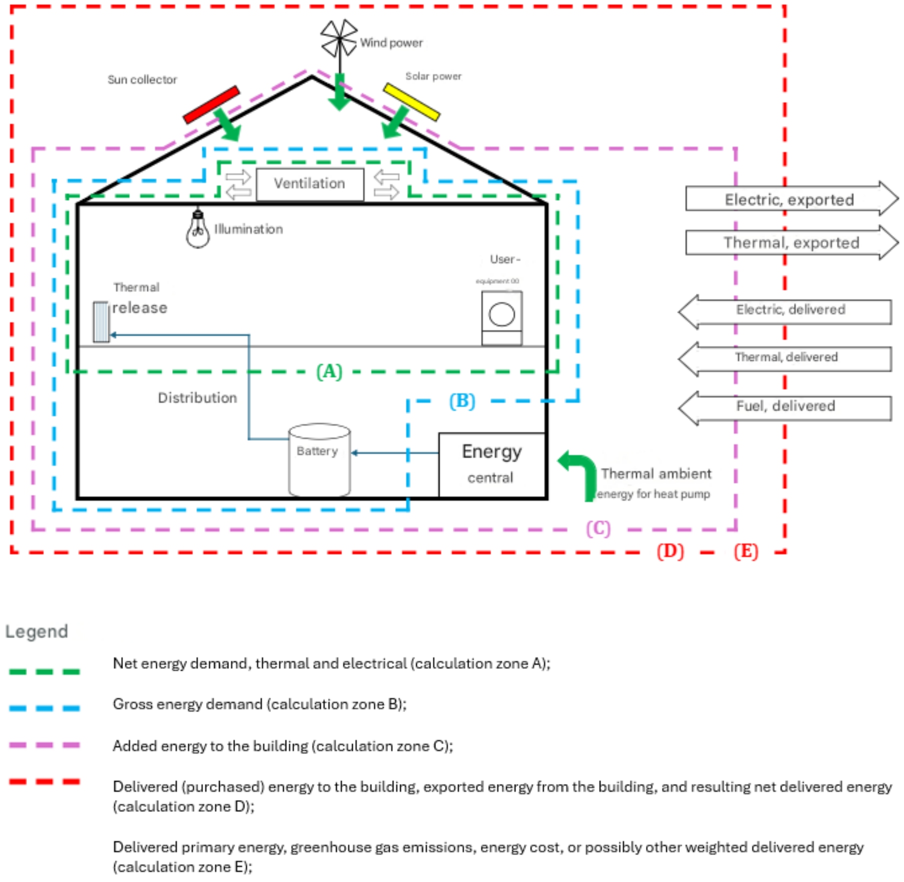


Figure 2-2: Suggested calculation zones NS3031:2025[14].

In Figure 2-2, the suggested calculation zones are introduced. Where calculation zone A is the net energy demand, which is the calculated energy need of the building before system losses. Calculation zone B is the gross energy demand, which is a further calculation including all system and distribution losses inside the building. Calculation zone C, the delivered energy, is all the energy supplied to the building from external sources. Zone D includes the exported electricity and thermal energy. In cases without solar production, the result of calculating zones C and D will be the same. Finally, Zone E introduces weighing factors to the type of energy that is delivered, depending on whether it is electric, thermal, or fossil fuel[14].

2.5. Norwegian Energy Labeling System 2026

On April 2nd, 2025, the government announced an updated draft of the energy labeling system. The main difference in the new methodology is that the energy label will be based on delivered energy, which will then be weighed with weighting factors based on the energy carrier. This means that the energy label is calculated using calculation zone E from NS3031:2025, as opposed to the current calculation zone B from NS3031:2014. These changes are scheduled to take effect on January 1st, 2026[15].

Table 2-3: The established weighing factors for various energy carriers decided by the Norwegian government[15].

Energy carrier	**Electricity**	**District heating**	**District cooling**	**Biomass fuel**	**Other carriers**	**Exported energy**
Weighing factor	1	0,45	0,45	0,45	1	0

2.6. Enova Subsidies

As mentioned briefly, Enova is a governmental company in Norway. It was established in 2001 to guide Norway's transition to a low-emission society. Its initiatives include supporting new technologies and development through subsidies for energy and climate measures in households and businesses. The purpose of the subsidies is to support companies through the final phase of technology development and increase the likelihood of a successful market integration[16]. For technology to gain economic support through Enova, several criteria have to be fulfilled, including contributing towards energy and emission reduction, that the technology is technically ready for market introduction, and being socially beneficial, but requiring subsidies in order to be feasible.

For this thesis, several Enova subsidies will be relevant. One measure that can qualify for an Enova subsidy is a cost-controlled energy storage system (smart system), consisting of four elements: an adapter, a control center, at least two controllable loads, as well as at least two energy storage solutions. See suggested possible controllable loads and energy storage types in Figure 2-3. When investing in this combined measure, a homeowner can get a subsidy for 35% of the investment cost, up to 10 000 NOK[17].

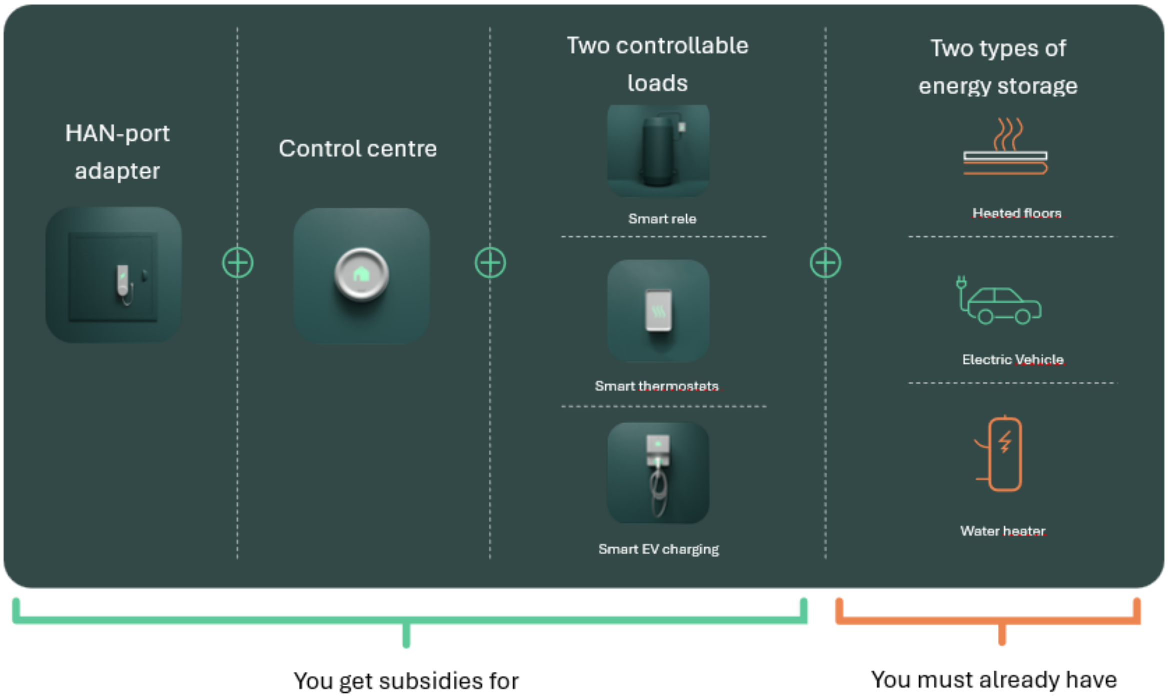


Figure 2-3: Translated overview of the Enova subsidy for a smart system[17].

Another subsidized energy reduction measure is investing in a smart water heater, which qualifies for a subsidy of 35% of the total cost, up to 4000 NOK[18]. Solar panels qualify for a subsidy of 7500 NOK, and an additional 1250 NOK/kWp installed power (until 20 kW is installed), resulting in a potential subsidy of 32 500 NOK[19]. Another measure that Enova gives subsidies for is installing balanced ventilation, however, to qualify, the installed system needs to have at least 80% heat recovery as an annual average, in addition to covering at least 50% of the BRA. The subsidy is 25% of the investment cost up to 5000 NOK[20].

Lastly, there is also a potential subsidy for the improvement of the building envelope, where the criteria for qualifying are that the walls, roof, windows, and doors, as a unit, are improved to a new energy class, with varying subsidies depending on the level of upgrades. For all subsidies within this measure, the subsidy is 25% of the total investment, with up to 100 000 NOK for reaching TEK10 standards, 125 000 NOK for a low-emission house standard, and 150 000 NOK for a passive house standard [21].

Note that, currently, there is no subsidy for the use of battery storage systems from Enova.

3. Case study

3.1. Energy Performance and Renovation Potential

Part 2 of this thesis will include an in-depth analysis of the Rørvollveien 17 case, where energy performance and the impact of implementing energy reduction measures on the energy grade will be examined. Key findings will be discussed and elaborated upon, and will lay the groundwork for the broader discussion in Part 3.

3.2. Methodology

This case study aims to evaluate various measures in a real case, focusing on two key aspects of interest:

i) To increase the energy grade
ii) Evaluate the payback time of the measures

The energy label is, as mentioned, based on normalized consumption values, while the economic evaluation is based on real consumption[7]. When investigating the impact of the measures on the actual consumption, it is essential to understand that measures such as smart control (shifting the time of use) of the heating tank will reduce the energy bill, while still consuming the same amount of annual energy in kWh.

NS3031 requires that the data set for annual energy consumption consists of separate values for exhaust, technical equipment, lighting, hot water use, and heating, in addition to the total annual energy consumption. Some of these values are available with tracked data, while others have been estimated, where the rationale behind the estimates will be elaborated later.

The first data set contains the actual energy consumption in Rørvollveien 17 from 2022. The second data set originates from the energy simulation completed in the program Simien and is simulated using normalized consumption values[22]. The methodology for compiling each data set will be further explained in the next section.

After compiling the main data sets, the estimated cost of the potential energy reduction measures will be calculated, followed by an evaluation and comparison of their economic feasibility and their energy reduction impact.

As mentioned, the two data sets that will be used are results from a normalized simulation and the actual energy consumption. The reason both are investigated is that dwellings are given their energy label based on the normalized energy consumption, however, it is known that the normalized values are designed to have a safety margin to guarantee that the estimation is not too low. For this reason, it is interesting to see how much this normalized consumption differs from the actual consumption.

3.2.1. Simulation: Simien using normalized values

To be able to create a simulation of Rørvollveien 17 in sufficient detail, it follows the floor plans, composition of walls, windows, doors, as well as renovation records. In addition, the program accounts for outside factors such as shading on the façade and windows due to surrounding buildings and nature, and is accounted for through the inputs of cardinal direction, as well as horizon angle for four sectors for each of the façade walls. In terms of other factors, it accounts for the natural flow of air and uses normalized consumption values for technical equipment, lights, and hot water consumption. As it was not possible to add the electric vehicle in the simulation program, it was added after the initial simulated normalized consumption dataset was compiled.

3.2.2. Tracked: actual consumption 2022

When compiling the data set for actual energy consumption in Rørvollveien 17, consumption data from 2022 is used. The documentation of the various consumption elements of the dwelling is gathered from the homeowner, where the electricity consumption data was obtained through the electricity supplier, and the hot water consumption and EV charging were specifically tracked utilizing a Shelly monitoring device[23]. The total energy consumption is intended to be divided into the specific energy use components of exhaust, technical equipment, lighting, hot water use, and heating. For this reason, instantaneous consumption for the base load, exhaust fans, fridge system, and lights was measured in the dwelling using the energy meter. Based on this measured energy consumption, annual energy consumption was estimated for the specific energy use components, which will be further explained and calculated in Chapter 3.3.3. Using the gathered data, the annual energy consumption with the specific energy use components is compiled, combining the total electricity use, hot water consumption, EV charging, and the measured loads.

3.2.3. Computer Programs Utilized

3.2.3.1. Python Programming: MILP

When investigating the energy reduction measures of installing solar panels, batteries, and utilizing smart systems to time shift flexible loads such as the water heater and electric vehicle charger, the hourly variations are important. The interactions between consumption, energy production, and hourly spot prices, as well as several other intricate factors, are dynamic and interrelated. To accurately represent the impact and economic feasibility of the energy reduction measures that have this interactive effect on hourly consumption, they have to be investigated utilizing hourly data. For this reason, data regarding these interacting measures for the same dwelling, Rørvollveien 17, from my previous bachelor's thesis is used.

In the bachelor’s thesis from 2022, a Python program was developed utilizing the mathematical modelling technique Mixed Integer Linear Programming (MILP). Where a cost function (electricity bill) is minimized by calculating the optimal control of the decision variables[24]. The decision variables are the charge and discharge power from the battery, the charge power to the EV, and the power to the heating tank.

However, since the spot prices varied significantly between 2022 and 2024, where 2022 was a year with historically high prices, and 2024 had unusually low prices, the Python code with the MILP model is utilized to generate updated results based on the 2024 spot prices for this master thesis.

Additionally, it is important to understand that different measures will influence each other, resulting in what is known as a ‘cannibalization effect’. This means that if the insulation in the exterior wall is improved, the energy demand for heating is reduced, thus lowering the potential for self-consumption of electricity supplied from the PV production and increasing the share exported to the grid. In this report, the main analysis is done by analyzing each measure separately. To make comparison easier, the compiled list of measures is presented by sorting them according to their cost of reduction. Two measurement bundles are analyzed comprehensively by estimating the new hourly energy consumption after measures, and then running the MILP analysis to calculate the result utilizing PV, battery, and smart control.

3.2.3.2. Simien

The Simulation program Simien was utilized to simulate the energy consumption in Rørvollveien 17 per the normalized consumption patterns in NS3031:2014. It is a tool widely used in Norway for energy calculations for both residential and commercial buildings. The program takes several factors, such as climate-specific data, the building envelope, technical systems, and use patterns, into account in the energy consumption estimation[25]. It simulates the delivered energy based on the input of data for the dwelling and divides the energy into specific energy use components. The program is used to simulate the energy consumption baseline, as well as the resulting energy reduction following the energy reduction measures.

3.2.3.3. Microsoft Excel

Microsoft Excel is used for data collection, energy consumption estimates, cost assessment of measures, and overall economic evaluation. In addition, it was utilized as a tool for sorting the results into graphs and tables for a coherent and clear presentation.

3.2.3.4. Flow of Energy Consumption

As the data and information collected is from various sources such as Simien, estimates, and measurements, a consistent way of presenting the data in a consistent format in line with the NS3031 is developed, and is self-made, to allow for easier comparison and recognition.

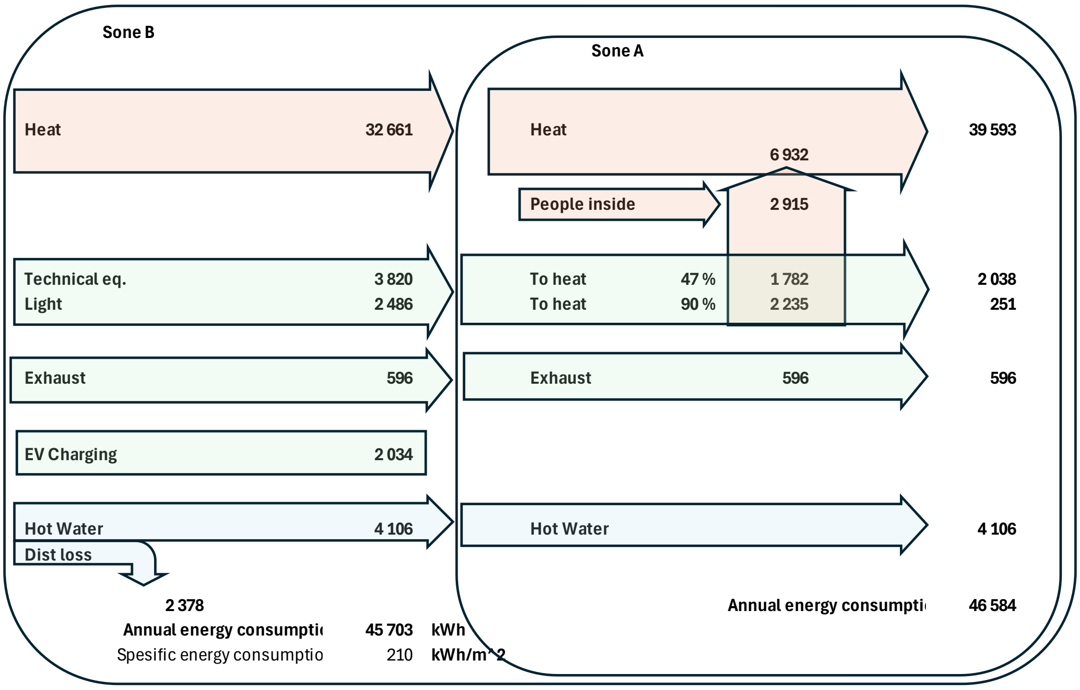


Figure 3-1: Example figure presenting the flow of energy need.

Figure 3-1 is therefore created to provide a more detailed and pedagogical overview. Since some of the relevant information is embedded within the simulation program, a form of 'reverse engineering' has been used, for example, the 47% factor determining how much of the technical equipment is emitted as usable heat for the dwelling. Additionally, the figure will also illustrate the differences and connections between the old and new NS3031, highlighting where the specific changes have an impact on the calculation result.

3.3. Energy consumption: Rørvollveien 17

Rørvollveien 17 is a 218 m^2 dwelling located in Drammen, Norway. It was built in 1963 with one floor and an unheated basement. In 1983, both an extension and an addition were done, with added rooms on the original floor and an additional second floor. In recent years, most windows have been replaced, as well as additional insulation in some outer walls. See details of the floor plan in Appendix 7.1.

Figure 3-2: The case study house Rørvollveien 17 viewed from southeast.

3.3.1. Simulation Model of Rørvollveien 17

In the Simien simulation program, the building envelope and heating system are modelled comprehensively. To ensure an accurate representation, the floor plans of the dwelling were reviewed, the homeowner was interviewed, and on-site measurements were taken to verify key building characteristics.

After establishing the baseline model of the dwelling, the various energy consumption elements of hot water consumption, lighting, technical equipment, and people are added, where the normalized value from NS3031:2014 is set for each one.

There was a trial-and-error period in the implementation of the dwelling into the simulation, in terms of learning the program, as well as late in the simulation process, it was necessary to split the dwelling into three, instead of two zones. The first floor was initially established as one temperature zone, while the second floor was the second temperature zone. However, as it was found that the flooring on the first floor had one half consisting of a significant amount of concrete while the other did not, it was necessary to create them separately, then connect the zones to each other. Therefore, the three zones are the first floor, section a, which is named 1st floor living room, and first floor section b, named 1st floor entrance, and finally the second floor.

When accounting for the heat pump, it is placed on the second floor in the simulation, even though it is placed on the first floor. As seen in the floor plans in Appendix 7.1, where the staircase is placed between the first and second floor, there is a room that has no flooring on the second floor and is marked with 'åpent opp' in the floor plan. This opening between the floors results in a ceiling height of 3,59 m, and an opening of 11,9 m^2. When running an annual energy simulation, placing the heat pump on the first floor caused a significant error in the program, as it would lead to a heating deficiency of 2184 hours on the second floor, and therefore, the simulation would not run. The available heating power on the first floor is significantly larger than on the second, 73,3% of the floor area is equipped with electric heating cables, in addition to a fireplace in the living room, two integrated panel heaters, one in the bedroom, and the other in the hall, which also has a heat pump. On the second floor, the bathroom, which is only 8% of the floor area, is the only room with electric heating cables. In addition, there is one integrated panel heater in each of the two bedrooms and one freestanding panel heater.

For this reason, considering that the heat pump is placed on the first floor, but in the spot where there is no divide between the first and second floor, most of the heat produced from the heat pump will rise and go directly to the second floor. Considering this, as well as the heating capacities of the floors, it is reasonable to move it to the second floor in the simulation. Even with this distribution of the heating capacities, the simulation still gives a mild error, as there are some hours in the year where the heating needs are still not covered, and the temperature will drop below the temperature setpoint. However, compared to the previous error, with a deficiency of 2184 hours on the 2nd floor and 6,8 hours on the 1st floor entrance, the mild error with a deficiency for 20,5 hours on the 2nd floor and 6,5 hours on the 1st floor entrance is not significant enough to invalidate the simulation.

3.3.2. Normalized Consumption Result

3.3.2.1. Normalized Energy Consumption NS3031:2014

When calculating the normalized energy use, the BRA is multiplied by the normalized values for the lighting, technical equipment, and hot water. The standard consumption values have previously been established in Part 1, Table 2-2 in Section 2.3.1. The resulting energy use for each category using a BRA of 218 m^2 is presented in Table 3-1. This is done to be able to investigate the methodology behind the normalization values later, in Section 3.4.2.

Table 3-1: Rørvollveien 17's normalized yearly energy consumption for lighting, technical equipment, and hot water.

	Lighting		Technical equipment		Hot water	
	kWh/(m^2)	kWh	kWh/(m^2)	kWh	kWh/(m^2)	kWh
Single-family home of 218 m^2	11,4	**2485**	17,5	**3815**	29,8	**6496**

3.3.2.2. Simulated Energy Distribution

The resulting annual energy consumption distribution for normalized consumption is presented in Figure 3-3.

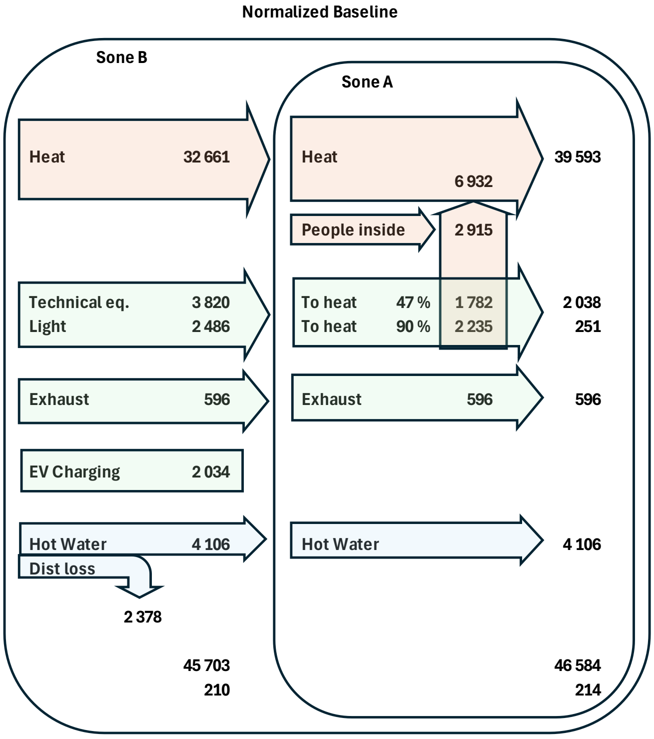


Figure 3-3: Flow of normalized energy consumption divided into calculation zones.

The energy consumption in calculation zone B is 45 703 kWh, which equates to a specific delivered energy of 210 kWh/m^2. The flow of energy in zone B is divided into the energy going directly to heat, the electricity used for technical equipment, light, as well as hot water, including distribution loss. The consumption values for lights, technical equipment, and the total hot water use are input through Simien, where the use of normalized values is applied, and is essentially identical to the values in Table 3-1. It is important to note that not all the electricity used for technical equipment and lights is used to power the appliances or lights, instead, a large portion is transmitted as heat, as can be seen in Figure 3-3 within zone A. Through the simulation, it is found that the percentage of the energy utilized for technical equipment that goes to heat is 47%, and 90% for the lights. In addition to the heat from these loads, there is an additional heat source from people inside the dwelling, which is simulated to be 2915 kWh annually. It is important to note that the energy consumed by the small exhaust system and EV charging is not included in the Simien simulation, as these could not be accurately simulated in the current version. Instead, the actual measured energy use for these components is used, as excluding them fully would skew the results. The explanation for the energy consumption of these components will be further elaborated in Section 3.5.

3.3.3. Actual consumption

To compile the actual energy consumption data, some specific energy use components were found using the measured instantaneous energy use of Rørvollveien 17, while some were estimated based on the appliances and use patterns. To measure the instantaneous energy use, the dwelling's energy meter was used. This was executed by disconnecting or turning off all loads in the dwelling, followed by turning on and off various equipment to measure the size of the different loads.

In some cases, where the specific use pattern in Rørvollveien 17 is clear, that is what is used to make an estimate. However, in cases where it is hard to pinpoint the specific use pattern, an average is used to make an informed estimation.

3.3.3.1. Instantaneous consumption

When utilizing the energy meter, the baseload, which in this case only includes appliances on standby, measured at 27W. The exhaust fans in the bathroom and kitchen were measured at 64W and 170W, respectively. The integrated fridge comprising two 150L fridges and one 80L freezer had an instantaneous power draw of 182W. And lastly, when all the lights were on, they alone measured 403W.

Table 3-2: Measured instantaneous power draw.

	Exhaust fan bath.	Exhaust fan kitc.	Baseload	Fridge sys.	Lights
Power draw [W]	64	170	27	182	403

3.3.3.2. Exhaust

The only fans in the household are the exhaust fans in the bathroom and kitchen. Following the use patterns known based on the houseowner, the bathroom fan is on close to 100% of the time, while the kitchen fan is used approximately 30 minutes every day. This results in an annual energy use of 565 kWh and 31 kWh, respectively, which results in an annual exhaust energy consumption of 596 kWh.

3.3.3.3. Technical Equipment

For the technical equipment, there are several appliances that need to be accounted for, including the previously measured baseload, the fridge and freezers, dishwasher, washing machine, dryer, oven, TV, charging of phones, and other small power draws. When calculating the annual energy use of the appliances, the brand, model, and approximate age are used to either find the exact annual power drawn under normal conditions, or a similar model and make, that can be used to estimate a realistic number.

For instance, for the ASKO DFI8557XXL dishwasher, which is approximately 5 years old, the data sheet could not be found. Therefore, the ASKO DFI8557MMXXL, which is the same product line, but a newer generation released around 2021, is the closest model available and will be used for the energy use estimate. Based on its data sheet, the energy used in Auto mode with cold water intake is 0,9-1,4 kWh per cycle, while the Eco mode uses 0,65 kWh per cycle. Assuming that the dishwasher is used once a day, five days a week, the energy use would range between 234- 364 kWh per year using the Auto program[26]. Considering that the programs used in the household are normally a mix between Auto and Eco, the lower end of the range is used, and the annual consumption from the newer dishwasher is set to 250 kWh. Additionally, to account for efficiency improvements between the models, a 9% lower efficiency is assumed, therefore, the annual consumption from the dishwasher is set to 272 kWh.

This methodology is used for all the mentioned appliances, except for the freezer, where the daily power drawn under normal conditions was available on the data sticker, showing 0,65 kWh/day, combined with a 3% age-related efficiency loss, resulting in an annual energy consumption of 308 kWh/year.

With this methodology, the appliances' energy use is shown in Table 3-3. This results in a total annual energy use of 2998 kWh for technical equipment. See the attached Excel sheet for further details.

Table 3-3: Annual energy consumption for technical equipment.

	Baseload	Fridges	Freezer	Washing m.	Dryer	Dishwasher	Oven	Stovetop	TV	Other.
Consumption [kWh/year]	236	640	308	160	270	272	328	365	16	400

3.3.3.4. Lights

The annual energy use from lighting is calculated using Section 3.3.3.1's measured instantaneous energy consumption of 403W, where all the lights in the dwelling are on. The methodology of calculating the annual energy use for lighting is instantaneous energy consumption, multiplied by the time of use, and a factor accounting for the possibility of dimming several of the lights in the house.

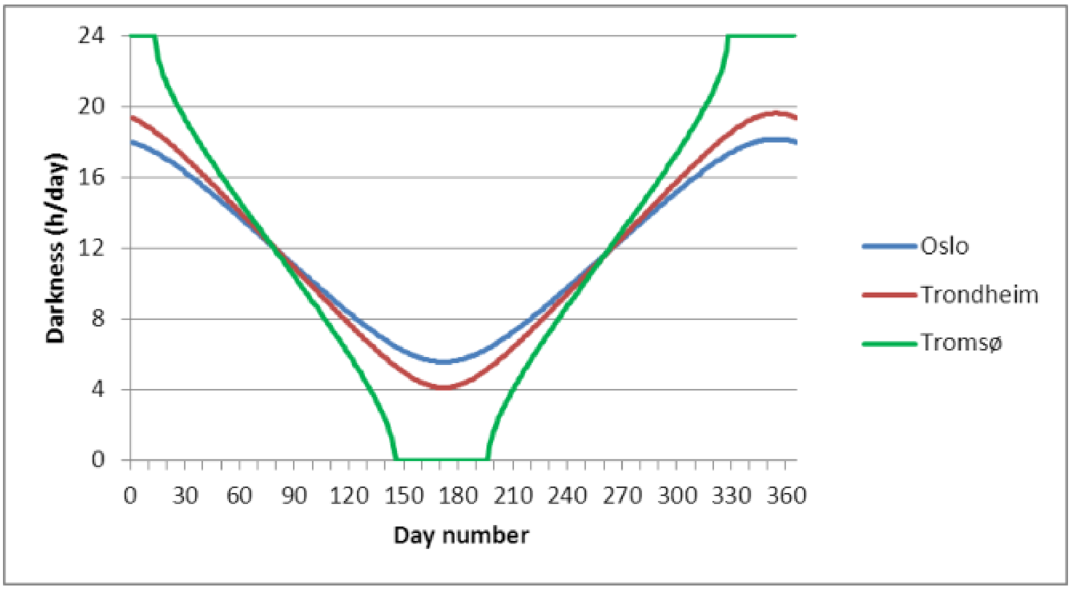


Figure 3-4: Hours of darkness as a function of the day number for three different Norwegian locations[18].

Using Figure 3-4 and the accompanying study done by SINTEF, a reasonable estimate of the average time a household in the Oslo area has its lights on is 3,5-5 hours a day[27]. This guideline accounts for the hours of darkness minus six hours for nighttime, as well as variations due to seasonal changes.

In the estimate of energy use in Rørvollveien 17, a daily use of 5,5 hours is used to have a margin of error. Combining this with a 10% reduction in total energy need due to dimming, the result is 725 kWh/year due to lights.

3.3.3.5. Hot water

Hot water consumption is found using tracked data from the household, which was done for a previous bachelor's thesis. The tracking is done using a smart device called Shelly EM, which can be used to control and monitor the heating tank's energy use for the day, week, month, or year[28]. The device can be used to track power output, daily usage, both hour by hour, and momentarily, as well as being used to set preset values and control the use of the heating tank.

The data from the 2022 tracking showed that the household uses 4560 kWh/year[23].

3.3.3.6. Heat pump

When estimating the energy use of the heating pump, it is based on the dwelling's model, the Mitsubishi MSZ-FH35VE. The model's energy use is based on its COP of 4, power input of 0,8 kW when heating[29], and the estimated time of use. The heat pump is only in use 6 months of the year, and in these months, it is in use about 60% of the time, which results in 2678 hours of use. The model's annual electrical use is therefore 2142 kWh, with 6428 kWh of thermal energy supplied, which in total is 8570 kWh/year of heat emitted from the heat pump.

3.3.3.7. Electricity used to heat directly

To find the electricity use that goes directly to heat, the total electrical energy use was used. It was found through the electricity meter data stored with the energy supplier. The data showed an annual consumption of 31 323 kWh in 2022. The already established electricity use for exhaust, technical equipment, lights, and hot water adds up to 8880 kWh/year, while the electricity consumed by the heat pump is 2142 kWh/year, and the electricity used for EV charging is 2034 kWh. Therefore, the electricity used for purposes other than direct heat is 13 056 kWh/year, resulting in 18 267 kWh of electricity going directly to heat annually.

3.3.3.8. Fireplace

When calculating the thermal energy supplied through the fireplace, the amount of firewood the dwelling buys seasonally is used. The dwelling usually goes through 1250 liters of birchwood each winter. This type of tree contains 2,586 kWh/L[30], and when utilizing an efficiency of 80% in the fireplace, the resulting heat supplied through the fireplace is 2586 kWh annually[30], [31].

3.3.3.9. Resulting Distribution of Energy Need

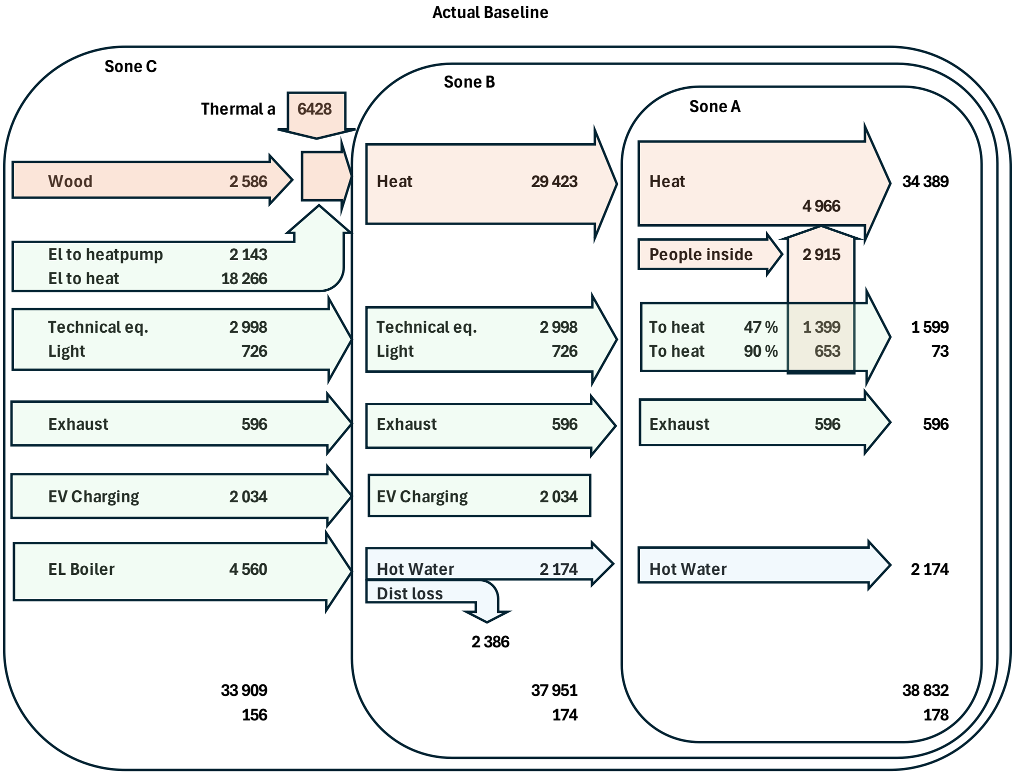


Figure 3-5: Flow of actual energy consumption divided into calculation zones.

Figure 3-5 visualizes the flow of the actual energy consumption, limited to calculation zone C. The sum containing the heat flowing into calculation zone A contains the heat going directly to electricity of 18 266 kWh, the heat emitted from the heat pump, of 8570 kWh, and the heat emitted from the fireplace, which results in 29 423 kWh of heat. In addition to the already calculated heat sources, a significant share of the electricity supplying the technical equipment and lights is transmitted as heat, which can be seen within zone A. The simulated percentages for the transmission to heat from Section 3.3.2.2 will be utilized, as this percentage is not consumption dependent, and will likely be the same as the normalized profile. In a similar manner, the people inside the dwelling emit heat as well, and the normalized value of 2915 kWh annually is utilized. In this case, the normalized value is used, as the actual use pattern is difficult to estimate, as there is no data to base it on.

With this distribution, the annual energy consumption is 37 951 kWh, which results in a specific delivered energy of 174 kWh/m^2 for zone B.

3.3.4. Completed data sets

The completed data sets for the actual energy consumption and the simulated normalized consumption are compiled in Table 3-4. This annual energy calculation is done according to the consumption value used to calculate the energy labeling according to the current legislation, which is in calculation zone B.

Table 3-4: Data sets for annual energy use

	Actual Consumption	Normalized Simulation
Exhaust [kWh]	596	596*
Technical equipment [kWh]	2998	3820
Lighting [kWh]	726	2486
Hot water Use [kWh]	4560	6484*
EV charging	2034	2034
El. Dir. To Heating [kWh]	29 423	32 661
Total [kWh]	37 951	43 073
Specific energy consumption [kWh/m^2]	174	210

*Values based on actual consumption are utilized to complete the normalized simulation data set.

The actual energy consumption in Rørvollveien 17 results in a corresponding energy grade of D, while the normalized energy consumption results in an E, and is illustrated in Figure 3-6.

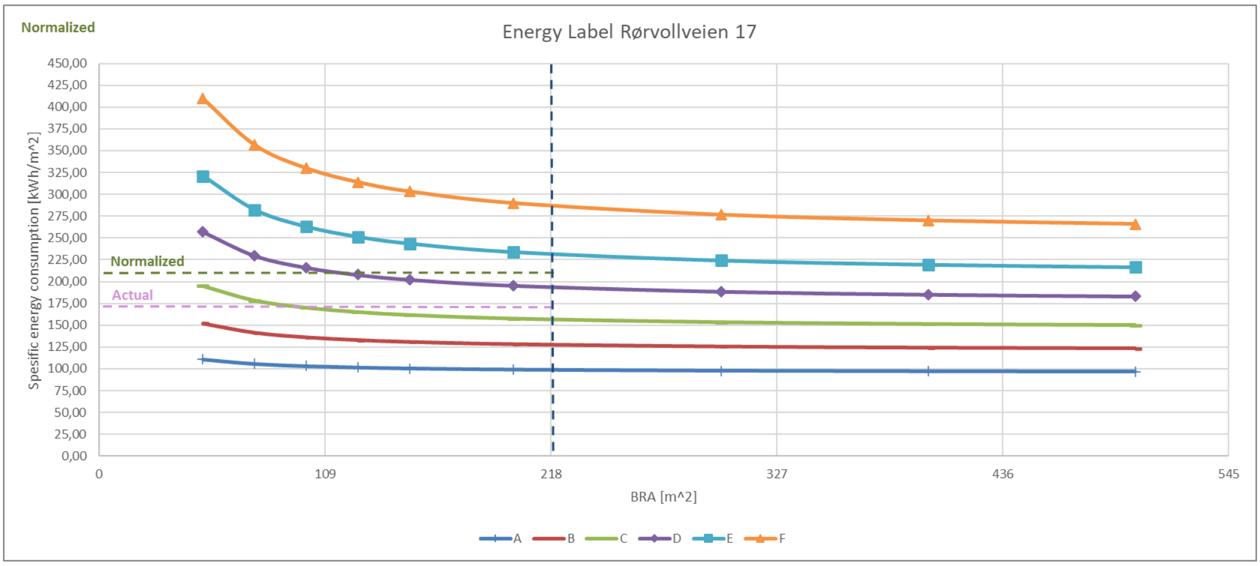


Figure 3-6: Corresponding energy grade according to the Specific energy consumption for the actual and normalized energy consumption.

3.4. Discussion of the discrepancy in the data sets

This section will include a discussion and evaluation of the discrepancy between the two completed data sets. It will consist of the values for technical equipment, lighting, and hot water use, as well as the electricity going directly to heating. As the values for exhaust and EV charging are identical, these will not be discussed.

3.4.1. Technical Equipment, Lighting, and Hot Water

When comparing the annual consumption for lights, technical equipment, and hot water for the actual consumption and the normalized simulation in Section 3.3.2.1, there is a significant difference between some of the values. For this reason, the method of calculating the normalized values and their discrepancies from the actual values will be discussed.

Currently, the program used to calculate the normalized simulation values is in line with the 2014 version of NS3031. The new NS3031:2025 version was just released, and the simulation program has not been modified yet. For this reason, it is interesting to see if the 2025 normalized values are different from the 2014 values, and if so, how much.

A key difference in the 2025 values is that they are introduced as a daily consumption pattern but are compiled into an annual value for comparison. Table 3-5 shows the normalized energy consumption for a dwelling with 218 m^2 of BRA from both versions.

Table 3-5: Showcasing the change in the annual normalized values from 2014 to 2025.

	Lighting		Technical equipment		Hot water	
Single-family home of 218 m^2	kWh/(m^2)	kWh	kWh/(m^2)	kWh	kWh/(m^2)	kWh
NS3031:2014	11,4	**2485**	17,5	**3815**	29,8	**6496**
NS3031:2025	11,4	**2486**	17,53	**3823**	25,06	**5464**

The annual values for lighting and technical equipment are practically identical, while the hot water is reduced by 16 %. As the new 2025 version will be utilized when the new energy labeling system comes into effect on January 1st, 2026, it is particularly relevant to investigate how this version compares to the actual consumption, as it will soon become the official normalized standard. Therefore, NS3031:2025 will be used in the comparison and discussion.

In both NS3031 versions, the normalized values for electricity consumption for the use of lights, technical equipment, and hot water are based on the gross floor area (BRA) of the dwelling. Figure 3-1 illustrates how consumption increases based on BRA, based on the 2025 version.

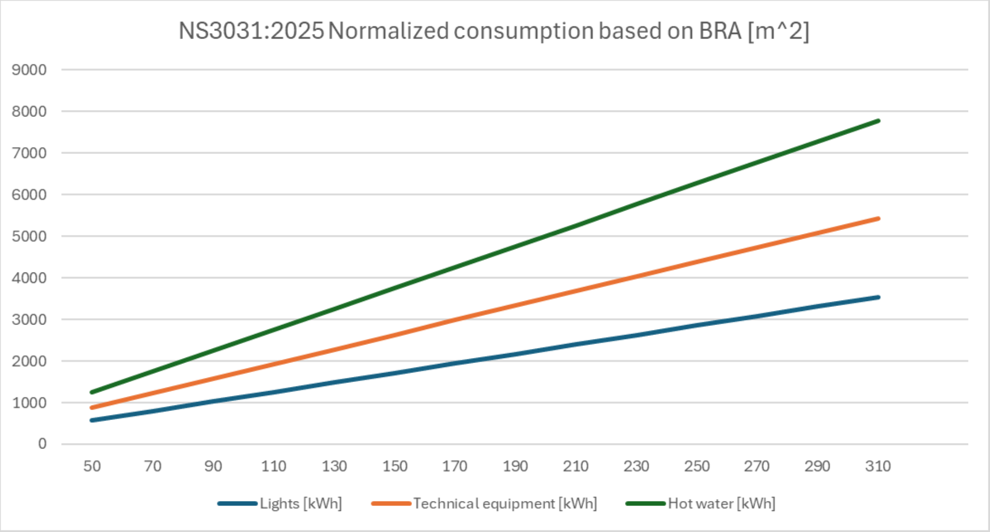


Figure 3-1: Normalized values for consumption based on BRA from NS3031:2025.

3.4.1.1. Lights

As previously mentioned, the recently published NS3031:2025 is an hour-by-hour daily profile, resulting in the same yearly consumption as in NS3031:2014 of 2485 kWh/year. Considering the development in energy efficiency for lights over the last 16 years, having the same energy consumption standard for lighting seems unreasonable.

Until 2010, incandescent lighting was common with a 60W bulb giving 800 lumens. From around 2005, fluorescent lights and halogen lights gained ground as a more efficient alternative, using around 30% less energy (42 W/800 lumens), as well as lasting up to 15 times longer.

They were commonly used until 2015, and were quickly replaced by LED lights, as in 2013, there was a rapid development of LED lights that significantly reduced their cost, quickly increasing their popularity. The 2014 LED lights were 80% more efficient, while the modern 2023 LED lights are around 95% more efficient than the incandescent lights, as well as having a 25 times longer lifespan[32], [33]. Comparatively, to replace a 60W incandescent bulb (800 lumens) with a LED light, a 2014 LED would require 11,4 W/ 800 lumens, while a 2023 LED would require 6,7 W/800 lumens, which means that it gives the same amount of brightness. This means that the energy consumption of LED bulbs decreased by 40-50% between 2014 and 2023.

For the case of Rørvollveien 17, the energy consumption estimate from lights was 726 kWh annually, compared to the normalization of 2485 kWh. Since we know that the house has modern LED lights with 6,7 W/800 Lumen, we can calculate the needed wattage to supply 800 Lumen corresponding to the NS3031 annual consumption from lighting. This can be calculated by dividing 2485 kWh by 726 kWh, and multiplying by the modern LED light's wattage of 6,7 W/800 lumens. This results in a light bulb technology that corresponds to 23 W/800 lumens needed to reach an annual use of 2485 kWh in Rørvollveien 17 in 2025. Technology-wise, this equals somewhere between the 2010s fluorescent lights and halogen lights (42 W/800 lumens) and 2014's LED (11,4 W/800 lumens). Based on this assumption, the NS3031:2014's 2485 kWh is fitting if the normalization values were based on 2010-2014 technology. But it is also reasonable to say that these normalizations should have been updated in the new NS3031:2025. The 2014 normalized value was justifiable, as it aligned with the state-of-the-art technology at that time. However, currently it no longer reflects the norm, as state-of-the-art technology can achieve the same, with only 726 kWh. This reinforces that the figures were not updated in the latest version of NS3031. For this reason, it could be reasonable to suggest that the 2025 standard was changed to correspond with the technology between the LED from 2014 and 2025, which would result in a use of 900 kWh annually.

3.4.1.2. Technical Equipment

When considering technical equipment, the normalized consumption results in an annual energy consumption of 3823 kWh. This is moderately higher compared to the estimated consumption of 2998 kWh at Rørvollveien 17. However, it is still within a reasonable ballpark, as the Rørvollveien 17 estimate is specific to this household's use pattern, which could be lower than the average.

That said, a difference of 21,6 % in consumption from technical equipment is still noteworthy. A possible reason for this difference is that the normalized value is based on the BRA of the dwelling, which might not necessarily be an accurate way of establishing the energy use of technical equipment. When comparing two dwellings, one 240 m^2, on the higher end of a common single-family home, and one 180 m^2, an average single-family home, both housing a family of four, they would require the same technical equipment. It would be necessary and likely that they both have a fridge, freezer, dishwasher, washing machine, dryer, TV, and some appliances, regardless of the size of the house. When comparing the technical equipment consumption in Rørvollveien 17, of 2998 kWh, to the 240 m^2 4200 kWh, and the 180 m^2 3156 kWh, this hypothesis seems likely.

As seen in Figure 3-1, the technical equipment need is a function that linearly increases with the BRA of the house. In most cases, the increase in technical equipment will not be as drastic as this normalization, as the need is not dependent on the square meters of the house. It could be argued that having a larger house implies greater economic means, and therefore more TVs, fridges, freezers, etc. However, a suggestion to limit the proportional increase between consumption and size, as the need for technical equipment does not necessarily scale linearly with floor area.

3.4.1.3. Hot water

When investigating the annual hot water use in Rørvollveien 17 of 4560 kWh compared to the normalized value of 5464 kWh, the normalization is a 16,6 % increase. Like the technical equipment and the lighting, the hot water use is also a consumption profile based on the useful floor area of the house. In reality, the amount of hot water used in a house is likely more directly linked to how many people live in the house. However, the correlation between the floor area of a house and the people living there would, in most cases, be significant.

At the time the data was collected, four people were living in Rørvollveien 17. The house has four bedrooms, with one currently being used as an office. For this reason, even though four people lived there, the house is fit to house five people. With an additional person living in the house, the hot water consumption would likely approach the NS3031 normalization value. Thus, it seems like a justifiable deviation between the actual consumption and the normalization.

It is worth mentioning that, similar to the technical equipment, a dwelling of 180 m^2 housing the same family would likely have the same hot water use regardless of having a decreased floor area. So, an alternative solution for the normalization is to have it be based on the number of people the dwelling is designed to house. A small house with a small share of common areas and a bigger share of bedrooms would likely have the same hot water use as a bigger house with large common areas and few bedrooms.

3.4.1.4. Normalized Profile vs Self-Consumption of PV

The reason for investigating the normalized profiles in this level of detail is that the distribution and the accuracy can significantly influence the results, particularly when estimating how much of PV production can be utilized for self-consumption. This is a key factor in determining the energy grade improvement associated with implementing solar panels. Inaccurate profiles can falsely increase self-consumption estimates, as the base loads from technical equipment, lights, and hot water consumption are generally larger in the normalization than in reality. This leads to a misleading representation of actual performance. For this reason, it is essential that NS3031:2025 is updated to include more realistic load profiles.

Furthermore, when evaluating energy grades in relation to solar panels, it is unclear whether the panels should be modeled based on Oslo's solar conditions or the dwelling's actual location. For this reason, to get as accurate data as possible, solar irradiation data from the location of the case studies are utilized.

3.4.2. Electricity going directly to heat

When evaluating the annual electricity directly used for electricity, the actual consumption is 29 423 kWh, while the normalized consumption results in 32 661 kWh. The difference in annual space heating between the actual and normalized consumption is 3238 kWh. This is likely due to two main reasons: i) some smart control of the heating cables is implemented in the bathrooms, living room, kitchen, and laundry room. ii) The temperature setpoint in some of the rooms not used daily is lowered manually.

The lowered heating need from using a smart home is a result of lowering electric heating loads, for instance, at night. This measure will result in an energy reduction of 2129 kWh in Rørvollveien 17 (see Section 3.5.1). Therefore, the reduction needing to be accounted for is now 1109 kWh. In the simulation, the whole house has a set point of 22 degrees Celsius, in reality, there are two rooms that, for most of the time, are unheated. Most of the time, the bedroom on the first floor as well as the office on the second floor have the door closed, and no heat consistently. For these reasons, the reduction in 3238 kWh from the simulated heating need is consistent with the known use.

3.5. Energy reduction measures

This chapter will include an economic analysis of each measure, followed by a comparison of the feasibility of the measures. The cost estimate is calculated based on the materials, equipment, technology, and installation work necessary to implement each measure, and therefore, the cost and resulting profitability vary heavily depending on the measure.

In this chapter, the calculated energy reduction caused by each measure is calculated a little differently, depending on the measure. The energy reduction caused by the re-insulation measures of supplementary insulation of the walls and roof, and changing windows and doors, is completed in the Simien simulation.

Three of the suggested measures, decentralized balanced ventilation, a smart system with heating cables, and improving airtightness, were not possible to simulate in Simien. Therefore, the estimation for energy savings in the energy evaluation of the dwelling by Effy will be used[34]. To verify that Effy's estimates are accurate, the simulated energy savings from the measures that were possible to simulate are compared. When comparing the energy savings from the simulation and Effy's estimation, the accuracy is 94% on average between the windows, doors, walls, and roof, with Effy's estimation being slightly higher in all cases. However, they are similar enough to use the Effy estimation to investigate the implementation of the suggested measures of a decentralized balanced ventilation system with heat recovery, a smart system with heating loads and water heater, as well as improving the building envelope's airtightness.

For the last two measures, solar panels and a hybrid system, consisting of PV panels, a battery system, and time shifting of the flexible loads, the water heater and EV charger, data and cost estimates from the previous bachelor's thesis are utilized. The Python file from the thesis is modified to utilize 2024 spot prices and gives an output showing the resulting yearly cost, savings, export and import needed with the measures.

3.5.1. Individual Measures

3.5.1.1. Windows

Currently, the windows on the first floor are already at a U-value of 1-1,2 W/m^{2}K, as most of them were changed five years ago, while all but one of the upstairs windows are from the 80s with a U-value of 2,2W/m^{2}K. For this reason, the four windows and two glass veranda doors are replaced by windows with a U-value of 0,8 W/m^{2}K. As the lifetime of modern windows is around 40 years, it is necessary to replace the windows on the second floor as they are being used past their technical lifetime, in addition to needing to improve the U-value to reduce heat loss.

Table 3-6: Cost of elements needed to install new windows[35], [36], [37], [38], [39].

Measure, Windows									
Product	**Amount**	**Size**	**U-verdi**	**Price**	**Utforing No.**	**Karmlist No.**	**Hour**	**Total**	
Window (top swing)	1	125x140cm	0,8	8104	4	1,33	3,5	kr	8 104
Window (fixed)	2	160x110cm	0,8	4231	3	1,33	3,5	kr	8 462
Window (top swing)	1	125x110cm	0,8	7222	2	1,33	3,5	kr	7 222
Glass door	2	90x200cm	0,8	11974	2	1,33	3,5	kr	23 948
Casing (Utforing)	11	18x120x2400mm		369				kr	4 059
Casing (Karmlist)	6	12x58x4400mm		199				kr	1 194
Installation	14	hours		750				kr	10 500
Total								**kr**	**63 489**

The total cost of replacing four windows, two glass veranda doors, the materials needed for installation, and the installation work is 63 489 NOK, with details of the materials presented in Table 3-6. The measure can potentially qualify for an Enova subsidy if it is a part of a larger renovation project, where the roof, walls, windows, and doors are all upgraded to at least TEK10 standards. In that case, 25% of the investment will be subsidized, reducing the investment cost of replacing the windows to 47 617 NOK. Using the Simien energy simulation, the annual energy reduction is estimated to be 1962 kWh.

3.5.1.2. Doors

The case for replacing the exterior doors is similar to the windows, the technical lifetime of exterior doors is 40 years, and as the door was installed in 1983, and has a U-value of around 2,8 W/m^{2}K, they are past their technical lifetime.

The measure of replacing the two doors includes the doors, side panel, materials, and installation, and has a total cost of 26 921 NOK. See Table 3-7 for the materials needed. Like the measure of replacement of windows, the replacement of the doors can qualify for a 25 % subsidy, reducing the investment cost to 20 191 NOK. The replacement of the doors will lead to a 532-kWh reduction in energy consumption.

Table 3-7: Cost of elements needed to install new doors[37], [38], [39], [40], [41], [42].

Measure, Doors									
Product	**Amount**	**Size**	**U-verdi**	**Price**	**Utforing No.**	**Karmlist No.**	**Hour**	**Total**	
Door main	1	90x210cm	0,8	7115	3	1,33	3,5	kr	7 115
Side panel	1	30x210cm	0,8	3894	0	0	3,5	kr	3 894
Door laundry room	1	90x210cm	0,8	5595	2	1,33	3,5	kr	5 595
Casing (Utforing)	5	18x120x2400mm		369				kr	1 845
Casing (Karmlist)	3	12x58x4400mm		199				kr	597
Installation	10,5	hours		750				kr	7 875
Total								**kr**	**26 921**

3.5.1.3. Roof Insulation

The measure of supplementary insulation of the roof is preferably carried out in combination with the refurbishment of the roof, as this reduces the associated costs. The lifetime of a roof is approximately 40-50 years, and as it was last refurbished in 1983, when the second floor was added, the roof is nearing its technical lifetime. As the refurbishment is necessary maintenance of the dwelling, and would need to be replaced regardless, it is not accounted for in terms of the insulation costs.

Table 3-8: Cost of elements needed to re-insulate the roof[39], [43], [44].

Measure, Roof				
Product	**Metres or area**	**Size**	**Price**	**Total**
Wood planks	324	48x98mm	27,45	kr 8 894
Wood planks	326	48x98mm	27,45	kr 8 949
Insulation, 34	149	100mm	78,07	kr 11 632
Installation	30	hours	750	kr 22 500
Total				**kr 51 975**

When it comes to the supplementary insulation of the roof, the materials needed are battens and insulation. The cost, including installation work, is estimated to be 51 975 NOK, see Table 3-8. This measure can also qualify for the 25 % subsidy, which reduces the total investment cost of supplementary insulation of the roof to 38 981 NOK. The measure has a significant annual energy reduction of 2899 kWh.

3.5.1.4. Wall Insulation

The case for the supplementary insulation of the walls is the same as the roof, as the cladding's lifetime is 50 years, and was installed in the 80s, the façade cladding needs to be refurbished soon. As the refurbishment is necessary maintenance of the dwelling, and the removal and re-fitting of the exterior is required to complete the measure, it is not accounted for in terms of the insulation costs.

Table 3-9: Cost of elements needed to re-insulate the walls[39], [43], [44], [45].

Measure, Walls				
Product	**Metres or area**	**Size**	**Price/meter**	**Total**
Wood planks	450	48x98mm	27,45	kr 12 353
Insulation, 34	172	100mm	78,07	kr 13 428
Wind barrier (Vindsperre)	1	3x50m	1079	kr 1 079
Wind barrier (Vindsperre)	1	1,5x50m	636	kr 636
Installation	30	hours	750	kr 22 500
Total				**kr 49 996**

The total cost of materials for battening the walls, which includes battens, insulation, a wind barrier membrane, and installation work, is 49 996 NOK, and is elaborated in Table 3-9. As this measure is eligible for the 25 % subsidy, the resulting cost is 37 497 NOK. This measure also has a significant annual reduction, with 3011 kWh.

3.5.1.5. Decentralized Balanced Ventilation

The main principle for a decentralized balanced ventilation system is the same as other mechanical ventilation heat recovery units, it supplies fresh air and extracts stale air from the room. However, in the decentralized heat recovery ventilation, there is no ductwork and other necessary elements connected to a centralized unit, as the entire unit is in the air duct[46]. The expected lifetime of the unit is around 20 years, with some electrical components possibly needing service or replacement within the lifetime[47].

Table 3-10: Cost of elements needed to install a decentralized balanced ventilation system [48].

Measure, Decentralized balanced ventilation system					
Product	**Amount**	**Size**	**Price**	**Total**	
Vent	3	LUNOS e^2 60	11 400	kr	34 200
Installation	9	hours	750	kr	6 750
Total				**kr**	**40 950**

The installation of a decentralized balanced ventilation system with heat recovery is estimated to cost 40 950 NOK, see detailed breakdown in Table 3-10. As the measure qualifies for the Enova subsidy for balanced ventilation, of 5000 NOK, the investment cost is reduced to 35 950 NOK. The measure has an annual energy reduction of 1662 kWh.

3.5.1.6. Smart System with Heating Cables

The idea of utilizing the heating cables in combination with a smart system that controls the loads is reducing the temperature, and thus the heating load, when leaving the house for work on weekdays or while sleeping. The technical lifetime of the components needed is around 50 years for the heating cables, which were installed five years ago, and approximately 15 years for the smart control system[48], [49].

Table 3-11: Cost of elements needed to install smart system with heating cables[50], [51].

Measure, Smart System Heating Cables					
Product	**Amount**	**Model**	**Price**	**Total**	
Elko thermostat (heating cables)	5	wifi plus/rs ph	1198	kr	5 990
Smarthub Control center	1	Tibber pulse HAN	1999	kr	1 999
Installation	2,5	hours	750	kr	1 875
Total				**kr**	**9 864**

The technological devices needed to transform the existing system into a controllable smart system for the heating cables, as well as the installation, will have a total investment cost of 9864 NOK, see Table 3-11. Enova has an incentive of 35% of the total investment cost for a smart system that includes a control center, controllers, and at least two controllable loads. For this reason, this measure will be incentivized by 3452 NOK and will have a total energy cost of 6412 NOK. The energy savings are 2129 kWh per year, stemming from decreasing the temperature of the heating loads.

3.5.1.7. Improving Airtightness

The measure of improving the airtightness in the building envelope is completed through supplementary isolation using expanding foam and improving the moisture barrier in locations with high thermal bridges. These thermal bridges are identified using a thermal camera in a thermal imaging inspection of the house. Areas especially vulnerable to these are around windows, doors, floor-wall junctions, and areas where plumbing or electrical cables go through the walls[52]. Using closed-cell foam insulation, the lifetime of this measure will be between 30-50 years.

Table 3-12: Cost of elements needed to improve the envelope's airtightness [53].

Measure, Improving Airtightness				
Product	**Amount**	**Type**	**Price**	**Total**
Isolation Material	5	Fugeskum bostik	179	kr 895
Installation	10	hours	750	kr 7 500
Total				**kr 8 395**

The cost of improving the building envelope’s airtightness is estimated to be 8393 NOK, which includes materials and installation work, see Table 3-12 for details. The reduction in annual energy consumption is 513 kWh.

3.5.1.8. Solar Panels

With the use of solar panels, the dwelling can be supplied with electricity from a separate power source from the energy grid, providing a system that is not fully dependent on the grid. The use of PV panels significantly reduces energy imports, while in many cases producing excess energy that can be exported to the grid. The technical lifetime of the solar panels is between 25-30 years, as their performance naturally declines over their lifetime. However, after its technical lifetime is up, they can still be efficient in producing energy, just at a reduced capacity[53].

Table 3-13: Cost of elements needed to install 20,9 kWp of solar panels[23].

Measure, Solar panels				
Product	**Amount**	**Model**	**Price**	**Total**
PV panels	81	550E-E Solcellekraft	4 429	kr 358 753
Total				**kr 358 753**

The cost of the installation of solar panels, with 20,9 kWp of installed power, is presented in Table 3-13, and results in an investment cost of 358 753 NOK. However, as Enova has a subsidy for the installation of solar panels, which results in 27 700 NOK, the total investment cost is reduced to 331 053 NOK.

Table 3-14: MILP analysis of 20,9 kWp of solar panels.

Systems	Baseline	Solar
Installed PV	0	20,9
ToU Heating tank	0	0
ToU EV charging	0	0
Bat. Power	0	0
Bat. Capacity	0	0
Yearly cost	31 427	18 801
Import	31 323	23 016
Red. in import	N/A	8 307
Export	N/A	15 719
PV production	N/A	24 026
cycles	N/A	N/A
Cost, incl. Instal	N/A	358 753
Savings	N/A	12 626
Payback time	N/A	28,4

A MIPL model simulation is used to evaluate the solar system's energy reduction when implemented with the existing dwelling. The result of the MILP analysis of 20,9 kWp solar panels shows a reduction of 8307 kWh in imports, and exports 15 719 kWh of generated electricity.

3.5.1.9. Hybrid System

When utilizing a hybrid system, consisting of solar panels, a battery, and flexible loads (heating tank, and EV charging), to reduce energy use and energy cost, the optimal use of a hybrid system is where each component in the system is utilized to its full potential. The benefit of the components together is that solar panels provide energy production efficiently, the battery storage provides a way of utilizing the energy as well as a storage medium, while the flexible loads give the possibility to store excess energy and provide flexibility to make it possible to regulate the Time of Use[23]. The lifetime of the components in the system differs, as the lifetime of the water heater is approximately 20 years, the solar panels 25 years, while a battery's lifespan is estimated to last between 10 to 15 years, or 4000 cycles[54], [55], [56].

Table 3-15: Cost of elements needed for a hybrid system[54] .

Measure, Hybrid System				
Product	**Amount**	**Model**	**Price**	**Total**
Shelly (water heater)	1	PRO 1 PM	849	kr 849
Shelly (EV)	1	PRO 1 PM	849	kr 849
Fast charger	1	EV	16 151	kr 16 151
Smarthub Control center	1	Tibber pulse HAN	1999	kr 1 999
Installation	3	hours	750	kr 2 250
PV panels	81	550E-E Solcellekraft	4 429	kr 358 753
Battery	1	Pixii Home, 10kW,20kWh	95 470	kr 95 470
Installation	3	hours	750	kr 2 250
Total				**kr 478 571**

A hybrid system consisting of 20,9 kWp solar panels, a 1,9 kW water heater, a 7,4 EV charger, and a battery with 10 kW continuous output capacity and 20 kWh capacity has a total investment cost of 478 571 NOK, see Table 3-15 for a complete breakdown. The system is eligible for two Enova subsidies, one for PV panels and one for a smart system. The subsidy is 35 434 NOK, reducing the cost to a total of 443 137 NOK.

Table 3-16: MILP analysis of the hybrid system.

Systems	Baseline	Hyb. System
Installed PV	0	20,9
ToU Heating tank	0	1,9
ToU EV charging	0	7,4
Bat. Power	0	10
Bat. Capacity	0	20
Yearly cost	31 427	11 970
Import	31 323	17 622
Red. in import	N/A	13 701
Export	N/A	10 325
PV production	N/A	24 026
cycles	N/A	553
Cost, incl. Instal	N/A	478 571
Savings	N/A	19 457
Payback time	N/A	24,6

To evaluate the hybrid system's energy reduction when implemented with the existing dwelling, it has been simulated in the MILP model. The results for a hybrid system, with 10 kW output and 20 kWh capacity, are an annual PV generation of 24 026 kWh, and utilizing the battery can reduce the energy needed in the dwelling by 13 701 kWh, through self-consumption, and exports 10 325 kWh.

3.5.2. Combining the Hybrid System and Envelope Measures

It is essential to note that when the building envelope measures are implemented, the annual heating need is reduced due to additional insulation and airtightness in the building envelope. Therefore, the potential reduction made possible using solar production and the hybrid system is affected. Later, in Section 3.7, the results of utilizing a hybrid system after implementing the other building renovation measures will be discussed. The hybrid system investigated is the one with 10 kW output and 20 kWh capacity, as this is the most feasible system configuration for this case.

To find the simulated results after the building renovation measures, a new consumption case has to be established. To make this consumption case, the data for energy consumption in Rørvollveien 17 was modified to account for the reduction in energy need. The modification in the energy consumption data was established by assigning an estimated profile for the heat reduction, as the reduction in energy use will not be linear throughout the year. The insulation measures will have the majority of their impact during the winter and colder months. For this reason, each month is assigned a heat profile value, which ranks the intensity of heating needs, where January and February are assigned 1, November and December 0,9, March and October 0,8, beginning of April 0,4, then from April 16th to September 15th the value is 0, while the rest of September is 0,4.

The hourly energy reduction is then established by having a factor multiplied by the heating profile value hour-by-hour, to match the yearly reduction from Simien. The new energy consumption case is then established by subtracting the hourly energy reduction from the actual hourly consumption data. Using this consumption case, the MILP analysis is run to evaluate the results utilizing the hybrid system after implementing all the measures, and after only the economic measures.

Table 3-17: MILP analysis of the hybrid system after implementing measures.

tot sys.	Baseline	All measures	Economic Measures
Installed PV	0	20,9	20,9
ToU Heating tank	0	1,9	1,9
ToU EV charging	0	7,4	7,4
Bat. Power	0	10	10
Bat. Capacity	0	20	20
Yearly cost	31 427	1 773	3 508
Import	31 323	6 607	8 352
Red. in import	N/A	11 990	12 439
Export	N/A	12 036	11 587
PV production	N/A	24 026	24 026
cycles	N/A	443	443
Cost, incl. Instal	N/A	478 571	478 571
Savings	N/A	17 478	15 743
Payback time	N/A	27,4	30,4

3.5.3. Summary of the Individual Measures

The summary of the individual energy reduction measures' cost after Enova subsidies and energy reduction is presented in Table 3-18.

Table 3-18: Cost and energy reduction of the measures.

Measures				
Measures	**Reduction e.use [kWh/year]**	**Cost [kr]**	**Enova subsidy [kr]**	**Investment cost [kr]**
Windows	1973	kr 63 489	kr 15 872,25	kr 47 617
Doors	532	kr 26 921	kr 6 730,25	kr 20 191
Roof insulation	2918	kr 51 975	kr 12 993,73	kr 38 981
Wall insulation	2999	kr 49 996	kr 12 498,89	kr 37 497
Balanced ventilation	1662	kr 40 950	kr 5 000,00	kr 35 950
Smart system Heating Cables	2129	kr 9 864	kr 3 452,40	kr 6 412
Airtightness	513	kr 8 395	kr -	kr 8 395
Solar	8307	kr 358 753	kr 27 700,00	kr 331 053
Hybrid system	13 701	kr 478 571	kr 35 434,30	kr 443 137

When evaluating the feasibility of the measures with the goal of improving the dwelling's energy grade as much as possible, the focus, as previously mentioned, should be on measures that reduce consumption significantly, at the lowest possible cost. Therefore, the cost per kilowatt hour of reduced energy is depicted in Table 3-19, where the measures are sorted in ascending order according to the cost of reduction, and the investment cost accounts for the Enova subsidies.

Historically, in Norway, the average spot prices have stayed relatively stable, however, in the previous decade, the prices have had large fluctuations both yearly, seasonally, and daily. In this period, 2022 had the highest spot prices, while 2024 had unusually low prices.

For an economic evaluation, the payback times are calculated using the average energy price in 2022 and 2024, including the capacity component, energy component, and fees, which result in a total energy price of 2,83 NOK/kWh and 0,817 NOK/kWh, respectively. The estimated cost savings from the measures are found by multiplying the reduction in energy use by the average energy price. This is utilized to calculate a simplified version of payback time by dividing the cost savings from the measures by the investment cost and is used for all measures except solar and hybrid systems, where the detailed results from the MILP analysis is used. In the following section, the lower spot prices from 2024 will be the basis for the discussion, unless stated otherwise.

Table 3-19: Energy reduction measures sorted according to [NOK/kWh].

Measures						
Measures	Reduction e.use [kWh/year]	Investment cost [kr]	Cost of Reduction [kr/kWh]	2024 Payback time [years]	2022 Payback time [years]	Lifetime [years]
Smart system Heating Cables	2 129	6 412	3	3,7	1,1	15
Wall insulation	2 999	37 497	13	15,3	4,4	45
Roof insulation	2 918	38 981	13	16,4	4,7	50
Airtightness	513	8 395	16	20,0	5,8	40
Balanced ventilation	1 662	35 950	22	26,5	7,6	20
Windows	1 973	47 617	24	29,5	8,5	40
Hybrid system	13 701	470 837	34	24,6	6,8	20
Doors	532	20 191	38	46,5	13,4	40
Solar	8 307	331 053	40	28,4	6,4	25

3.6. Economic Evaluation

The first category of measures is the measures with the lowest cost of reduction, where they have a significant margin between the estimated payback time and the technical lifetime, even when using 2024 spot prices. These measures include **Smart system heating cables**, **Wall insulation**, **Roof insulation**, and **Airtightness**. The smart system utilizing heating cables is the most cost-effective of the measures, as it has significant energy reduction without high investment cost or comprehensive installation work, in addition to having a substantial subsidy from Enova. The re-insulation measures significantly reduce heat loss from the building envelope and are measures commonly recommended for a reason. However, as mentioned earlier, these measures are typically carried out in combination with changing the exterior of both the walls and roof, which is typically seen as necessary maintenance. If re-insulation and maintenance are done separately, the total cost will increase significantly, which results in reducing the cost-effectiveness of the energy efficiency measures. The final energy reduction measure that has a good margin of profitability is improving the airtightness, as it is a simple measure to complete, as well as not complicated installation work.

Secondly, there is a middle category of measures that has a good margin of profitability, even using the 2024 prices, where the payback time is around half the measure's lifetime, which includes replacing the **Windows** on the second floor.

The third category, which consists of the measure of replacing the two **Doors** and **Balanced ventilation**, is not very cost-effective when using 2024 prices, does not break even, and for that reason is not recommended unless it is needed to reach a desired energy grade.

The fourth category, which is made up of the measures **Hybrid system** and **Solar** panels, where the cost of reduction is high, and the payback time is longer than the technical lifetime when using 2024 spot prices. However, when using the 2022 spot prices, it results in a very good payback time. It is also interesting to see how the hybrid system can provide huge benefits in terms of reducing the imported energy, which can be essential when trying to improve the energy grade.

It is also essential to mention that the PV system size of 20,9 kWp is a large system. In this evaluation, various sizes of systems have been investigated, however, only the largest system size is presented in this section, as it was the best fit for this case. In Part 3, however, various PV system sizes will be discussed further.

3.7. Improving energy grade up to an A

As the overarching goal of the EPBD is to have a zero-emission building stock, it is interesting to investigate if, and how, the dwelling needs to be upgraded to obtain an energy grade A.

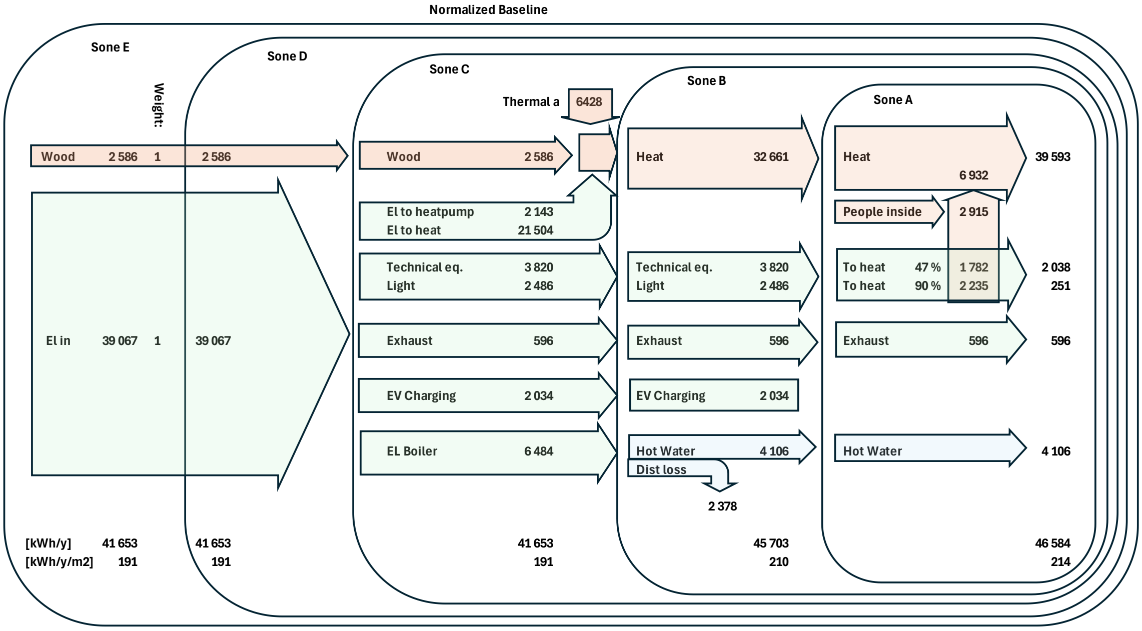


Figure 3-2: The normalized baseline's flow of energy and the corresponding specific energy consumption in the various calculation zones.

Currently, utilizing the normalized consumption values, the dwelling results in an E, with 210 kWh/m^2, as seen in Figure 3-2. This energy grade is calculated utilizing the current method, which only extends to calculation zone B. However, as the methodology will be extended to include calculation zone E from January 1st, 2026, it is particularly relevant to investigate this case in calculation zone E. The updated method accounts for thermal energy produced by the already installed heat pumps, which improves the dwelling's energy grade. When utilizing the normalized consumption data in calculation zone E, the specific energy consumption is 191 kWh/m^2, which is still an energy grade E.

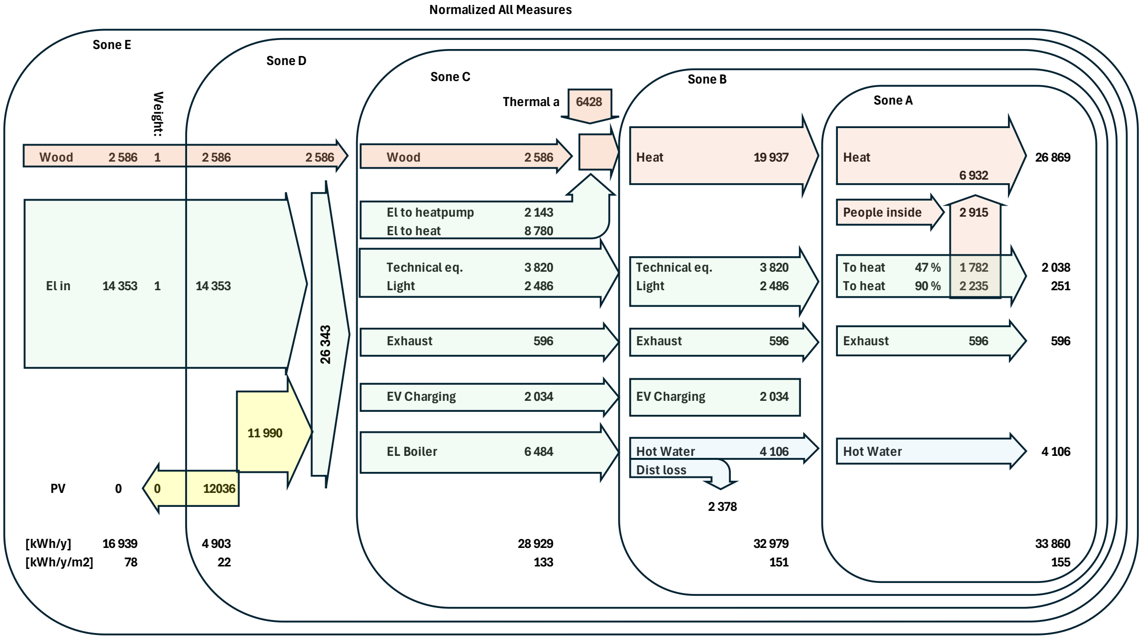


Figure 3-3: The normalized case with all measures' flow of energy and the corresponding specific energy consumption in the various calculation zones.

When comparing Figures 3-2 and 3-3, it can be observed that implementing all the re-insulation and building measures will reduce the **Heat** consumption in zone B by 12 726 kWh, to 19 937 kWh. These measures reduce the specific energy consumption from 210 kWh/m^2 to 151 kWh/m^2 in calculation zone B. The heat pump further reduces it to 133 kWh/m^2 in Sone C. When accounting for the hybrid system, the specific energy consumption in zone E will be 78 kWh/m^2, which is an energy grade A.

To simplify this change in energy grade, the building-specific energy consumption was initially 210 kWh/m^2 and ends up at 78 kWh/m^2. This change is due to a reduction in specific energy consumption caused by: i) Building measures of 59 kWh/m^2, ii) Heat pump of 29 kWh/m^2, iii) Hybrid system of 55 kWh/m^2, and an increase by the iv) Distribution loss from hot water of 11 kWh/m^2. Without the hybrid system, the dwelling will result in 133 kWh/m^2 and a grade C, and it is obvious that some sort of PV/Hybrid system is a key to reaching the goal of grade A for this case.

The current lower threshold of energy grade A, for a 218 m^2 dwelling, is 97 kWh/m^2. With the new energy labeling system, the thresholds for the energy grades will likely be modified, and in this case, it is likely that all the measures might be necessary. However, the specific energy consumption of 78 kWh/m^2 is well below the lower threshold. For this reason, it is interesting to see if removing some of the least feasible measures will still result in an A.

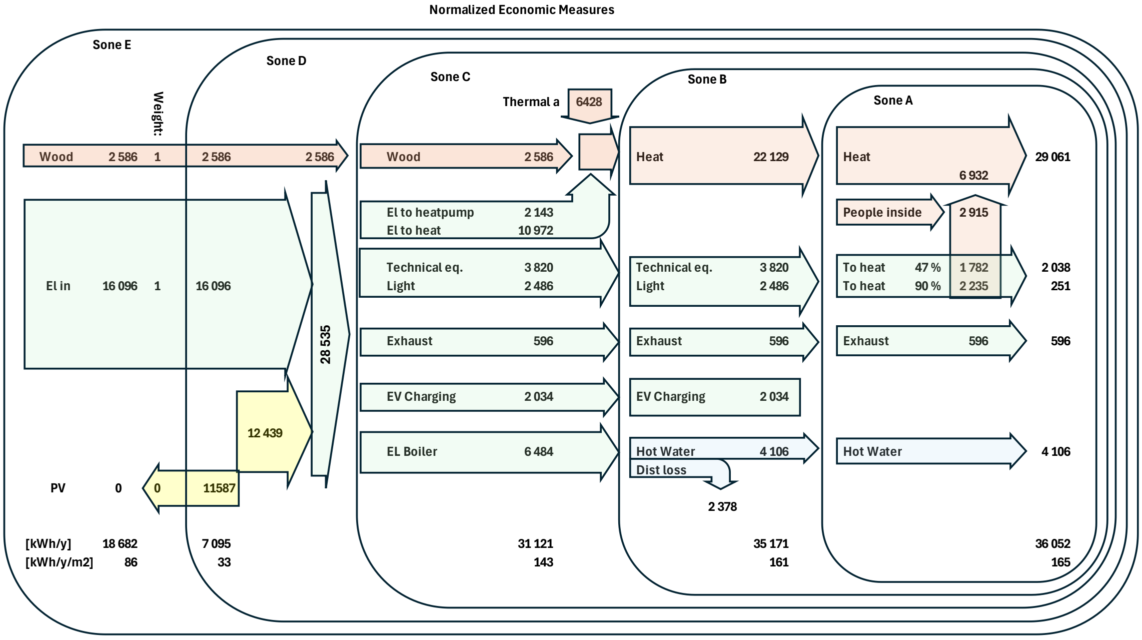


Figure 3-4: The normalized case with all economic measures' flow of energy and the corresponding specific energy consumption in the various calculation zones.

Replacing doors and installing decentralized balanced ventilation are two energy reduction measures that are evaluated to be somewhat unfeasible using the 2024 spot prices. For this reason, a simulation consisting of economically feasible re-insulation and building measures (all except doors and balanced ventilation), and a hybrid system is simulated. The specific energy consumption of the economically feasible measures alone is 143 kWh/m^2, which also results in an energy grade of C, in calculation zone C, as can be seen in Figure 3-4. In a case without PV/Hybrid system, the specific energy consumption remains at 143 kWh/m^2 even when calculating for zone E. However, when utilizing the hybrid system, the resulting specific energy consumption will be 86 kWh/m^2, which is an energy grade A.

To get an understanding of where the various system configurations fall within the energy grades thresholds, Figure 3-5 displays where the discussed measure configurations fall on the scale.

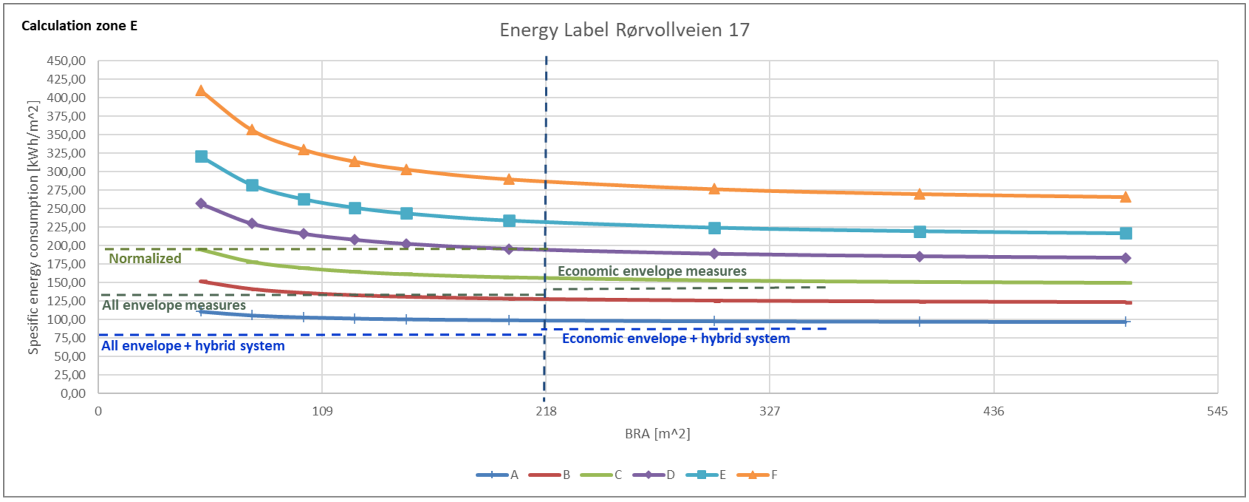


Figure 3-5: Corresponding energy grade according to the Specific energy consumption for the envelope and hybrid system configurations.

3.8. Timeline of the implementation of the measures

It is recommended to complete the improvements in increments when comprehensively renovating a dwelling. Therefore, it is important to properly plan what measures to prioritize first and which ones to combine. When planning what measures to prioritize, the potential energy reduction, as well as the years left of the technical lifetime of the current building components, is especially important.

When evaluating which measures would be beneficial to implement simultaneously, the goal is to make the renovation process more efficient, either by reducing the amount of work required or making it less complicated. Two obvious renovation bundles that should be carried out together are the roof-related measures and the façade-related measures. Other measures, such as the smart system with heating cables and the hybrid system without the solar panels, are singular measures that can be implemented alone without any effect on the installation or cost of any other measures.

The measures that are recommended to combine in terms of the roof-related upgrades are supplementary insulation and solar panels in combination with re-fitting the roof cladding. Since the re-fitting of the roof on top of the insulation is required for the supplementary insulation, it is therefore advised to combine the maintenance of the roof cladding with the roof insulation measure. Similarly, the installation of the solar panels before the other measures are completed will result in needing to have them removed and reinstalled to be able to execute the renovations. To maximize the roofing and panel lifespan, the most efficient way to implement these measures is to evaluate how many years the roof has left and plan for the installation of the insulation and solar panels accordingly. If the roof is nearing the end of its lifetime, it will make the measures more practical and cost-effective, as they can be completed in conjunction with the necessary maintenance of the roof.

The second renovation package is the wall-related upgrades, and includes the supplementary insulation of the walls, replacing windows, doors, installing decentralized balanced ventilation, as well as improving the airtightness in combination with the refurbishment of the exterior cladding. When completing the supplementary insulation of the wall, the exterior cladding must be removed to access the inner wall and then reinstalled afterwards. For this reason, the logic behind the combination of measures is the same as for the roof. Similarly, the windows must be removed and reset after the supplementary insulation is added, as the wall thickness increases by a few centimeters, and they must be flush to the exterior. For this reason, combining the measures of supplementary insulation, window replacement, and door replacement is strongly suggested. In addition, the installation of a decentralized balanced ventilation and improving the airtightness are also preferable to include in this renovation package, as they are more efficiently completed when there is access to the inner wall, and the work can be coordinated with the insulation process.

In the case of Rørvollveien 17, the roof was installed 42 years ago, in 1983, as previously mentioned. Considering the technical lifetime of 40-50 years, the roof should be refitted within 8 years, preferably earlier, as it has already passed the lower threshold. For this reason, the roof in Rørvollveien 17 has good prerequisites for completing the roof-related upgrades as a package. The measures have a combined energy reduction of 11 225 kWh, and could be carried out anytime between now and the next five years, depending on the condition and potential timeline for the other renovation packages and singular measures. When it comes to the second renovation package, the measures of replacing the doors and decentralized balanced ventilation are exempt as they are not economically feasible measures in this case. Therefore, the combined energy reduction for the wall-related upgrades is 5485 kWh. The case for the walls is similar to the roof, as the last re-cladding was in the 1980s, and with a technical lifetime of 50 years, it should be replaced between now and the next five years.

3.9. Conclusion

To summarize, the renovation of the dwelling is intended to be completed gradually over a span of 25 years, as the overarching goal is a zero-emission building stock by 2050. From the analysis completed in Chapter 3, it is shown that the majority of measures are needed to be able to reach an energy grade A, and it will not be possible to achieve without implementing the hybrid system. The energy grade in Rørvollveien 17 is, through the energy reduction measures, improved from an energy grade E to an A, with an initial consumption of 210 kWh/m^2 and reduced to 78 kWh/m^2 through improvements. This change is due to a reduction in specific energy consumption caused by i) Building measures of 59 kWh/m^2, ii) Heat pump of 29 kWh/m^2, and iii) Hybrid system of 55 kWh/m^2.

When evaluating the economic feasibility of the hybrid system, it is heavily affected by the extreme cases of spot prices, however, the results indicate a profitable long-term investment. When it comes to the implementation of the insulation and building measures, it is essential to install them in the suggested packages, otherwise, the cost of installation work will significantly increase, and make the measures unfeasible. As the current roof has reached the end of its lifetime, it is suggested to prioritize the roof-related upgrades, as a deteriorating roof can cause leaks and problematic damage to the building envelope. The hybrid system is preferable to implement at the same time or slightly after the roof measures, as this will cause maximized utilization of the solar panels. The exterior wall's lifetime is also nearing its limit, however, the consequence and potential damage from slightly delaying the wall measures in favor of the roof is acceptable. Therefore, the suggestion is to implement the wall-related upgrades within the next couple of years. The final measure of a smart system utilizing heating cables can be implemented anytime, however, as it is the best energy reduction measure in terms of cost of reduction, it would be preferable to implement it immediately.

4. Implications for the Norwegian Building Stock

At the beginning of this thesis, the initial assumption was that the EPBD would trigger chaos and large forced renovations for homeowners. However, throughout the in-depth analysis in Part 1, the deep dive into the EPBD and the Norwegian energy labeling system showed that this is not the case. The new EU directive, as well as the updated NS3031:2025, offers significant flexibility. This flexibility is a result of the extension of the calculation zone for the energy grade, which now includes the heat pump, as well as imported and exported electricity from on-site generation. This makes renewable building renovation measures more attractive, as they now contribute more significantly to improving the energy grading in a way that was not possible with the previous system.

The results in Part 2 show that the dwelling in Rørvollveien must have a heat pump, implement a significant share of the energy reduction measures, and utilize a hybrid system to be able to reach the energy grade A, where the threshold is below 97 kWh/m^2. Part 3 aims to investigate how, and to what extent, these results apply to the broader Norwegian building stock. This evaluation is going to include a rough evaluation of energy reduction measures and a solar system in another dwelling, Jongsåsveien 31A, and how the results of the two cases compare.

Additionally, since Part 2 shows that local PV production is essential to be able to reach an energy grade A, Part 3 will explore how the performance of PV panels will differ in various parts of Norway, with a focus on Drammen and Tromsø. Finally, the current status of the Norwegian building stock will be discussed, along with how the results of parts 1 and 2 can be applied in practice.

4.1. Transferability of Results: Case Study - Jongsåsveien 31A

To investigate how the results from part 2 apply to other dwellings, and if they seem accurate, Jongsåsveien 31A will be given a preliminary assessment. Jongsåsveien 31A is a three-story dwelling built in 1991, in Sandvika, Norway, and has an area of 247 m^2.

Figure 4-1: Picture of the facade of Jongsåsveien 31A taken by the homeowner.

The energy consumption and estimated energy reduction caused by the energy reduction measures are, for this case, extracted from the energy assessment of the dwelling completed by the company Effy[57]. The dwelling's energy report stated that the specific energy consumption is currently 268 kWh/m^2 and an energy grade E, while the specific energy consumption and grade after implementing all the suggested building energy reduction measures is 118 kWh/m^2 and a B. Considering that the dwelling was built in 1991, and compared to the detailed analysis of Rørvollveien 17 built in 1963/83, it is likely that a specific energy consumption of 268 kWh/m^2 is a typing error, especially as this consumption does not correspond to an energy grade E.

Table 4-1 The energy reduction caused by the measures suggested by Effy[65].

Measures	
Measures	**Reduction e.use [kWh/year]**
Windows	3331
Doors	1170
Roof insulation	804
Wall insulation	2529
Balanced ventilation	1430
Airtightness	1014
Total	**10278**

However, the total energy reduction from the building measures and resulting energy grade seems correct when compared to Rørvollveien 17's data. For this reason, the normalized consumption is calculated based on the specific energy consumption of 118 kWh/m^2 and the combined energy reduction of all the measures of 10 278 kWh. To make the results comparable to part 2, the same model for the flow of energy is utilized.

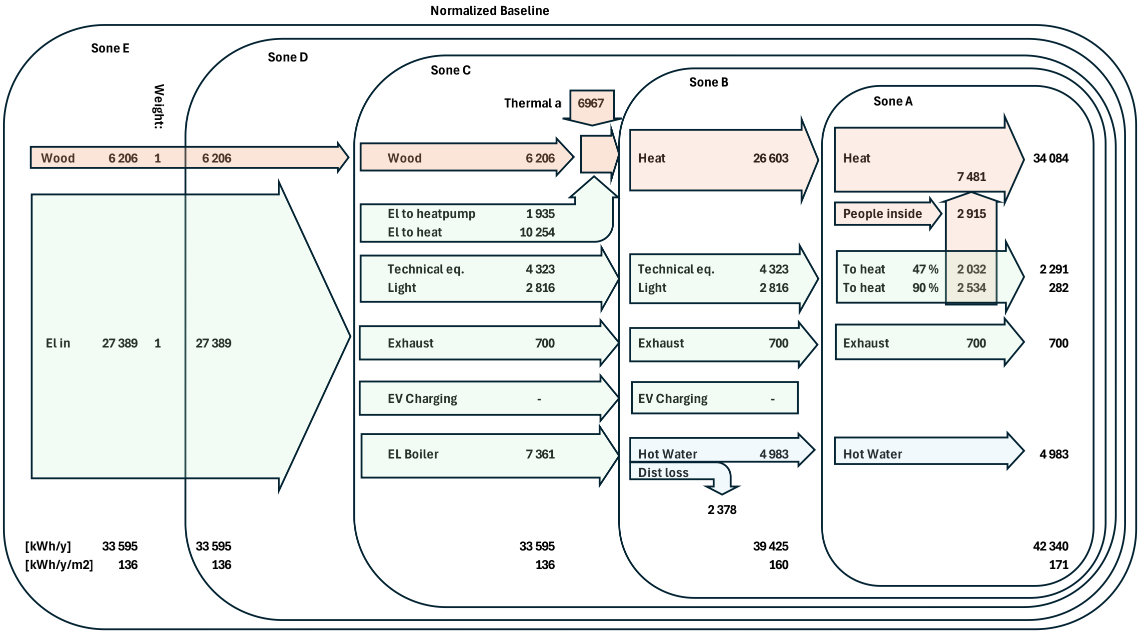


Figure 4-2: The normalized baseline's flow of energy and the corresponding specific energy consumption in the various calculation zones.

To make the results comparable, some estimates had to be made. For energy consumption with wood as the energy source, the house owner informed that he usually goes through 6000 liters of wood annually, which results in supplying 6206 kWh of heat. The house owner also relayed the information regarding their new heat pump purchased in 2020, which is a Mitsubishi Iguru 6600, with a COP of 4,6 and power of 1,02 kW[58]. The heat pump is only in use 6 months of the year, and in these months, it is in use about 42,5% of the time, which results in 1897 hours of use. The model's annual electrical use is therefore 1935 kWh, with 6967 kWh of thermal energy supplied, which in total is 8902 kWh/year of heat emitted from the heat pump. As there was no available data for the exhaust consumption, the exhaust consumption in Rørvollveien 17 is used as a baseline, and scaled up to match the larger BRA in Jongsåsveien. The consumption values for technical equipment, lights, and hot water are calculated according to the BRA and the NS3031:2014 normalized values. The same percentages for the transmission to heat from Section 3.3.2.2 will be utilized for the technical equipment and lights, as well as the heat emitted from people within the dwelling. In this case, these previously simulated values are used, as the actual values are difficult to estimate without a detailed simulation for this case specifically and will likely be approximately the same.

Using this compiled energy consumption, the actual baseline, depicted in Figure 4-2, for the dwelling before any energy reduction measures will correspond to 136 kWh/m^2, which is an energy grade C. This result is calculated based on calculation zone E, which gives credit to the newly installed highly efficient air-to-air heat pump. When utilizing calculation zone B, which does not include the heat pump, and will be the method used until Jan 1^{st,} 2026, the energy grade is a D and has a specific energy consumption is 160 kWh/m^2.

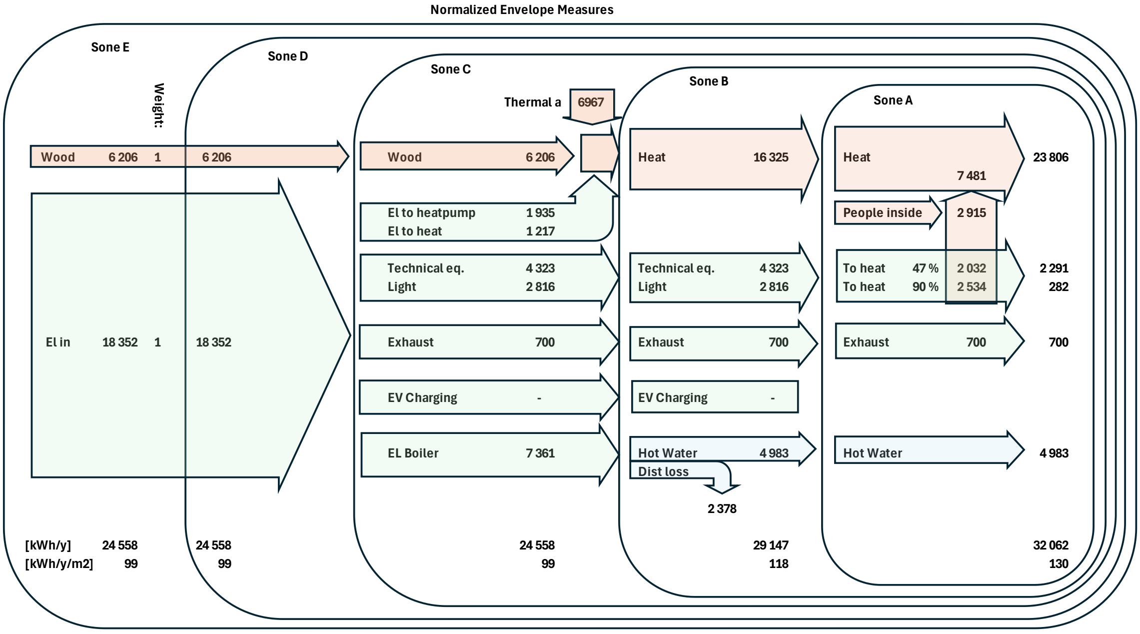


Figure 4-3: The flow of energy and the corresponding specific energy consumption after implementing the envelope energy reduction measures in the various calculation zones.

In Figure 4-3, all measures in Table 4-1 are implemented. The specific energy consumption in calculation zone E is 99 kWh/m^{2,} and on the threshold of an A. As can be seen later in this section, in Figure 4-4, this specific energy consumption is on the threshold between an A and a B, and for that reason, it would be interesting to investigate the effect of installing solar panels.

The data regarding the solar panels and system is gathered using the solar calculation on solkart.no, where the dwelling's address is entered. The tool estimates how many kWp can be installed on the roof and provides the expected energy generation based on local solar irradiation data. The roof of this dwelling faces east and west, as opposed to the optimal direction of south. When investigating the results after the implementation of the solar system, which includes 10,9 kWp of installed panels facing east, and 3,65 kWp facing west, it results in a total of 14,6 kWp of installed power, and an annual production is 12 670 kWh.

To determine self-consumption in detail, a MILP analysis is needed, but since hourly data was not available, an estimate has to be made. When evaluating the potential for self-consumption, the east and west-facing roofs are actually beneficial, as the solar production better aligns with the dwelling's energy consumption pattern. This increases self-consumption, since peak production occurs in the late morning and evening. If the panels faced south, the peak of production would be midday, when energy consumption is low, resulting in a larger share of exported energy. However, based on the Rørvollveien case, which has a south-facing roof and a hybrid smart system, where 57% is self-consumption, it is assumed that Jongsåsveien will have an even larger initial share of self-consumption due to facing east and west. This should result in significant self-consumption even without the use of a battery. Therefore, 50% self-consumption is used as an estimate.

In this calculation of energy reduction, the cannibalization effect is not accounted for, as it is a rough estimate without a detailed simulation. This effect will somewhat reduce the energy reduction possible when combining all of the energy reduction measures, which will lower the efficiency of the measures. Additionally, in contrast to the Rørvollveien case, the use of an EV is not included in the energy consumption.

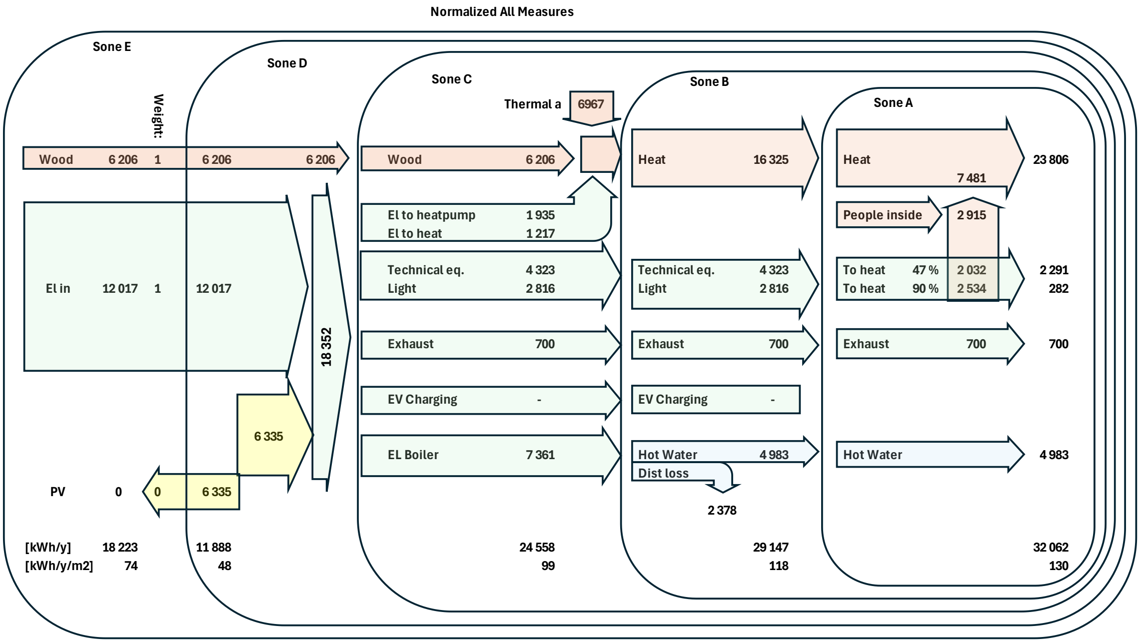


Figure 4-4: The flow of energy and the corresponding specific energy consumption after implementing the envelope energy reduction measures with PV production in the various calculation zones.

The resulting specific energy consumption after implementing all envelope measures and solar panels of 14,6 kWp is 74 kWh/m^2, which further reduces the energy grade to an A, with a significant margin.

To get an understanding of where the various system configurations fall within the energy grades thresholds, Figure 4-5 displays where the discussed measure configurations fall on the scale.

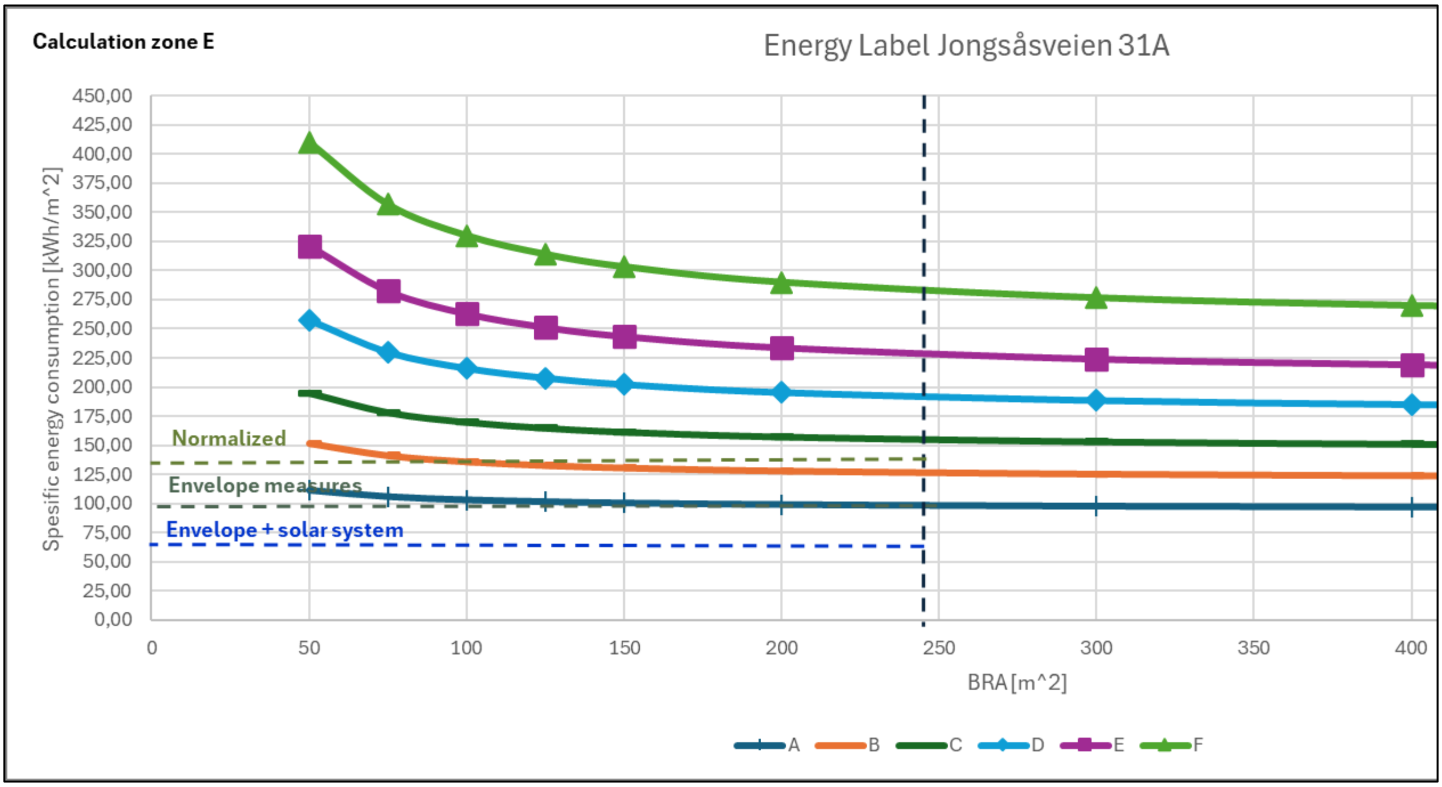


Figure 4-5: Corresponding energy grade according to the Specific energy consumption for the envelope and hybrid system configurations.

4.1.1. Discussion of Applicability

The energy grade in Jongsåsveien is, through the energy reduction measures, improved from an energy grade C to an A, with initially 136 kWh/m^2 and improved to 74 kWh/m^2. This change is due to a reduction in specific energy consumption caused by 1) Building measures of 42 kWh/m^2, 2) Heat pump of 28 kWh/m^2, and 3) PV system of 25 kWh/m^2.

This comparison highlights that the implementation of solar panels, despite being installed on a relatively small roof area with suboptimal orientation, can contribute significantly to energy reduction. They may even be a more attractive option, due to being simple and less disruptive to install. While the baseline in this case was already a B, the comparison between the building measures and the solar panels suggests that solar panels can give a substantial contribution, where the result is a grade A with a significant margin. From a national perspective, it can be beneficial to further incentivize the implementation of PV panels in dwellings like Jongsåsveien 31A, which already have a good energy grade and have good solar prerequisites, as it will contribute significantly to reaching the goal of a zero-emission building stock.

The inspection of Jongsåsveien is to investigate the theoretical results of energy reduction measures and PV panels, an economic evaluation has not been completed for this case.

4.2. How Does Changing Location Affect PV Self-Consumption

To assess how the same dwelling would perform in different parts of the country, the Rørvollveien case was simulated using solar irradiation data for Trondheim and Tromsø, both located further north than Drammen, with Trondheim roughly halfway up the country, and Tromsø far in the north. These cities likely experience significantly different solar paths. Tromsø in particular is an interesting case, with minimal solar exposure during wintertime, and the phenomenon of midnight sun in the summer, where the sun does not set between the middle of May to the end of July[59].

Using the same consumption data, the simulations aim to compare these locations in terms of the percentage and amount of PV production used for self-consumption. As the most significant difference in results appeared between Drammen and Tromsø, these will be the focus when comparing results. Each location is investigated with three system sizes of solar panels, 20,9 kWp, 10,45 kWp, and 5,23 kWp, and three battery system configurations: i) no battery or flexible loads, ii) medium battery (3,3 kW, 10 kWh) and flexible loads, iii) large battery (10 kW, 20 kWh) and flexible loads.

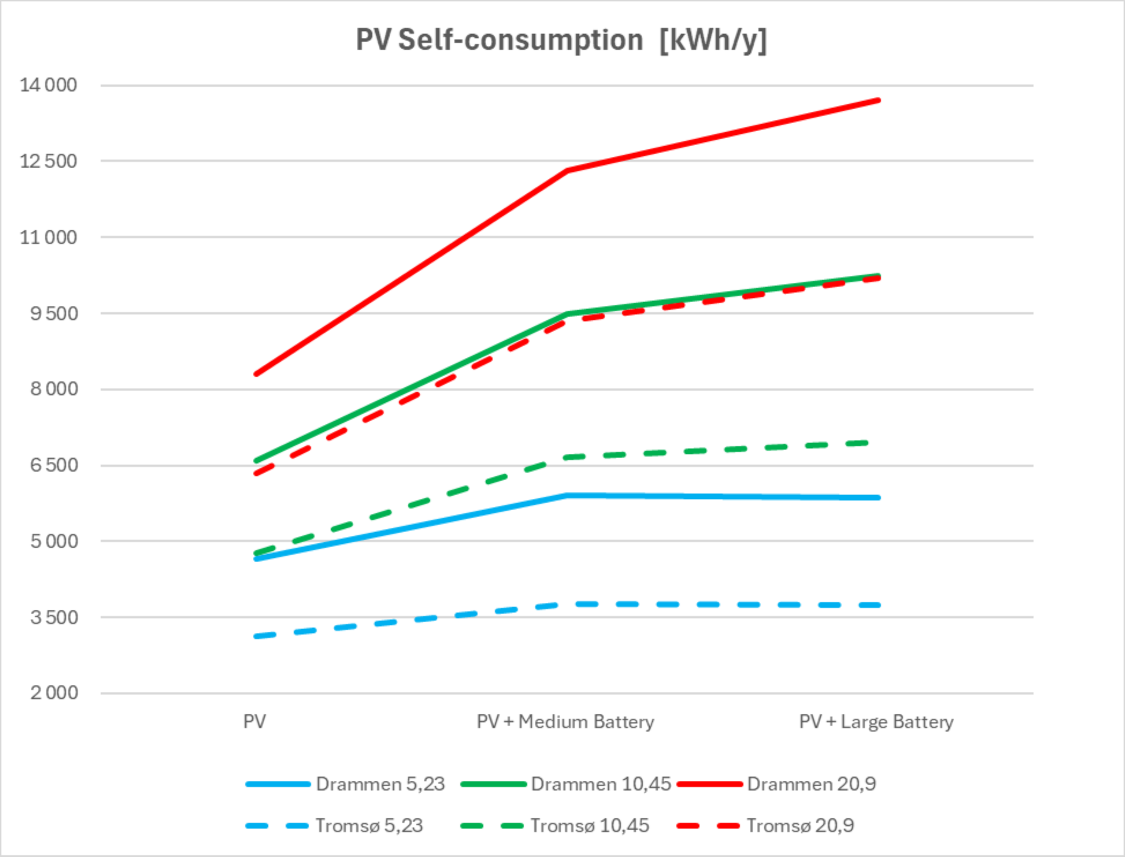


Figure 4-6: PV self-consumption with various system configurations and locations.

The results in Figure 4-6 illustrate the PV production that is utilized for self-consumption across the various system configurations in Rørvollveien and in Tromsø. It is evident that solar irradiation in Drammen is significantly higher than in Tromsø, where a system consisting of half the installed capacity generates approximately the same electricity. For most of the two smaller PV systems, the effect of upgrading from a medium to a large battery system appears to plateau. However, for the largest PV system in Drammen, the amount of self-consumption still increases significantly between the medium and large battery systems.

This implies that if the goal of the installation is to improve the energy grade, dwellings located in the South (Drammen) can achieve this by investing in a very large battery, which significantly increases their self-consumption. Note that while this method is effective in terms of energy grading, it may not be economically feasible.

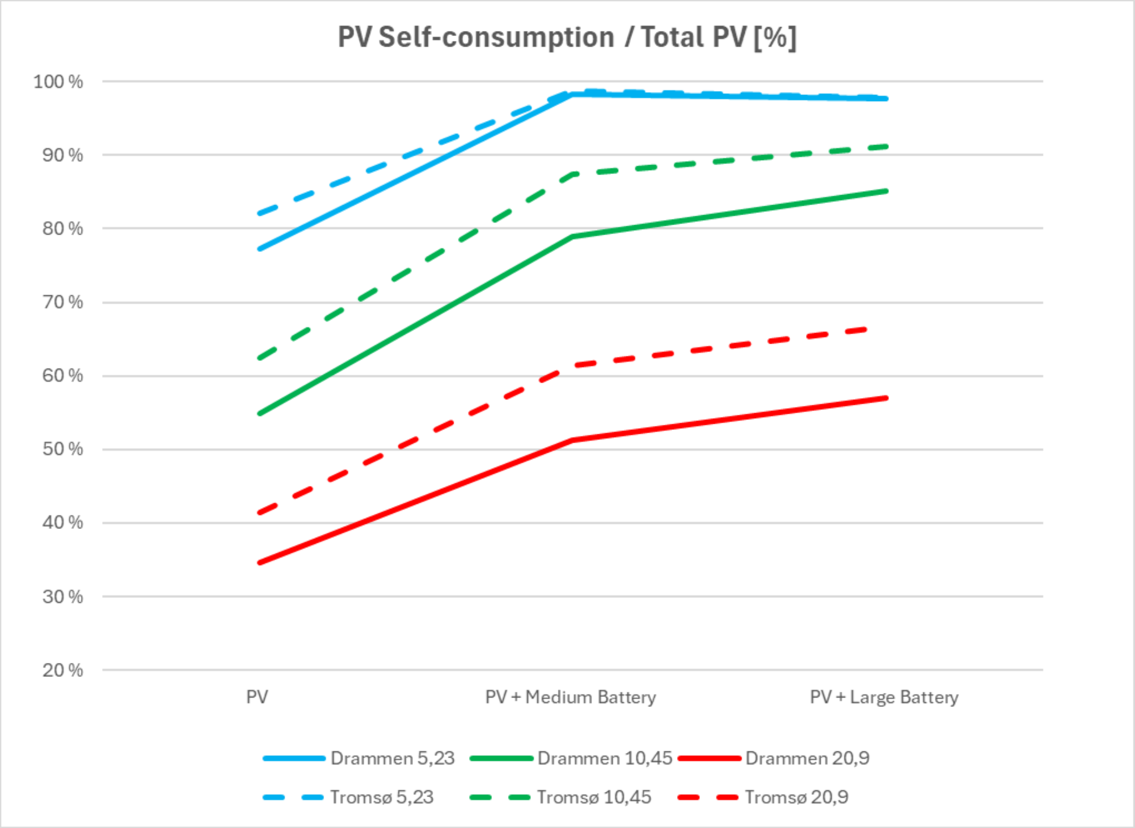


Figure 4-7: PV self-consumption in percent with various system configurations and locations.

The first figure illustrates the expected result, that the conditions for PV panels are better in the south of Norway as opposed to the north. However, when analyzing Figure 4-7, the potential for self-consumption compared to the generated electricity, an interesting effect of the midnight sun was found. In northern regions, the compatibility between the consumption profile and the PV production profile in the summer months is surprisingly strong, resulting in high compatibility and efficient self-consumption. This effect is especially noticeable in the largest PV system size.

When evaluating self-consumption, it is important to understand that the first solar panel installed will have nearly 100% of its PV generation used for self-consumption. However, as more panels are added, the percentage going to self-consumption decreases. Which makes the benefit of a battery system increase when increasing number of panels increases, as it helps store and makes it possible to access generated electricity.

4.3. Broader implications for the National Building Stock

4.3.1. The Current State of the Norwegian Building Stock

In Norway, there are approximately 2 750 000 residential buildings, as of 2024[60]. According to data from Enova, around 1 440 000 residential buildings have registered energy certificates, meaning that 47,6% of the building stock is in unknown condition.

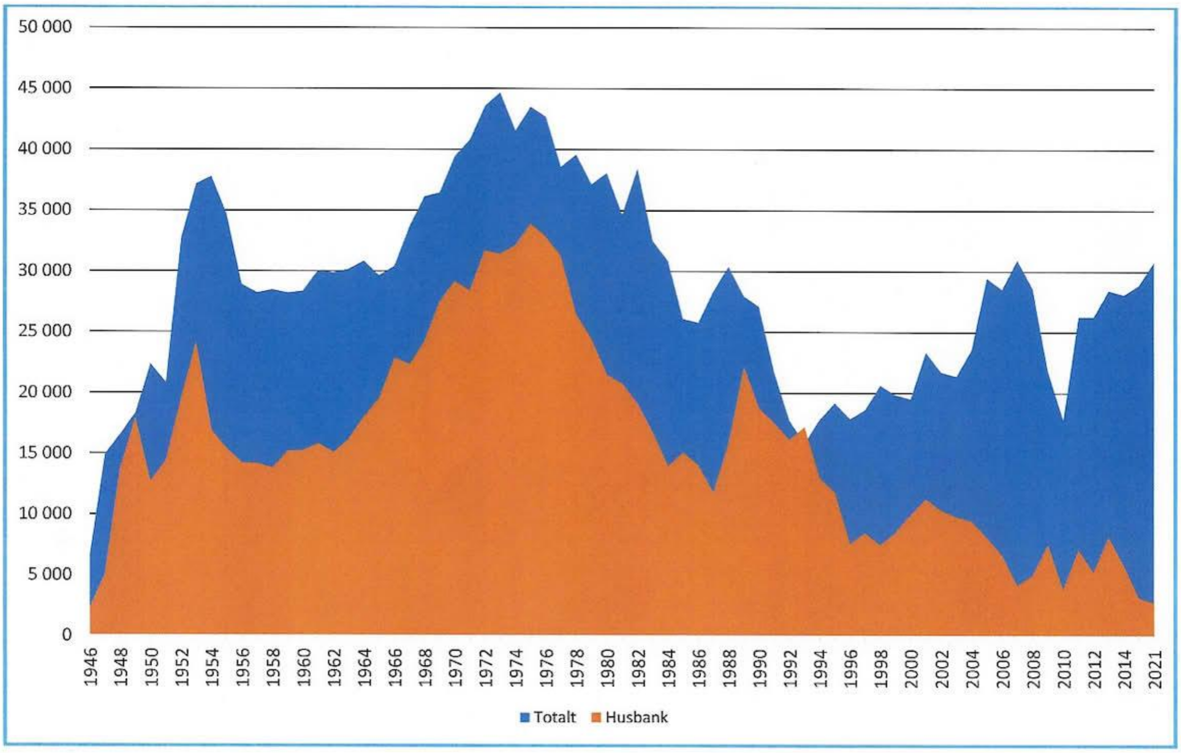
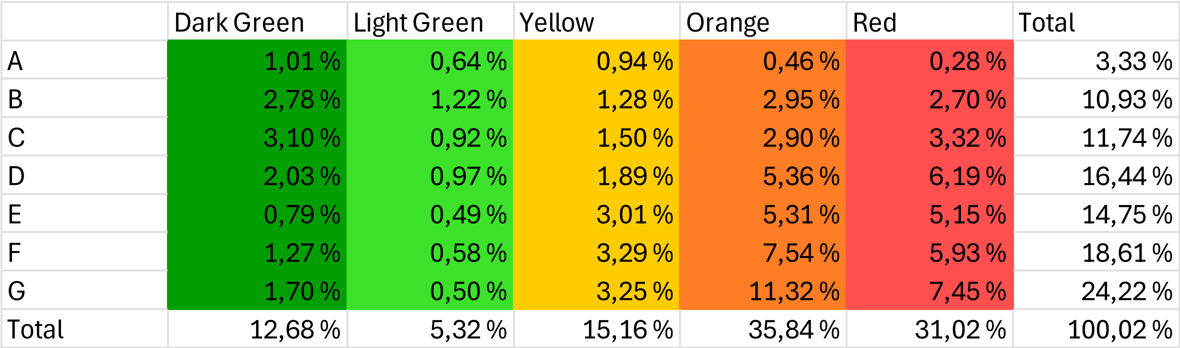


Figure 4-2: The building of dwellings in Norway from 1946 to 2021, including Husbanken's share[60].

According to Enova's data, Table 4-2 presents the distribution of energy grades for the registered dwellings.

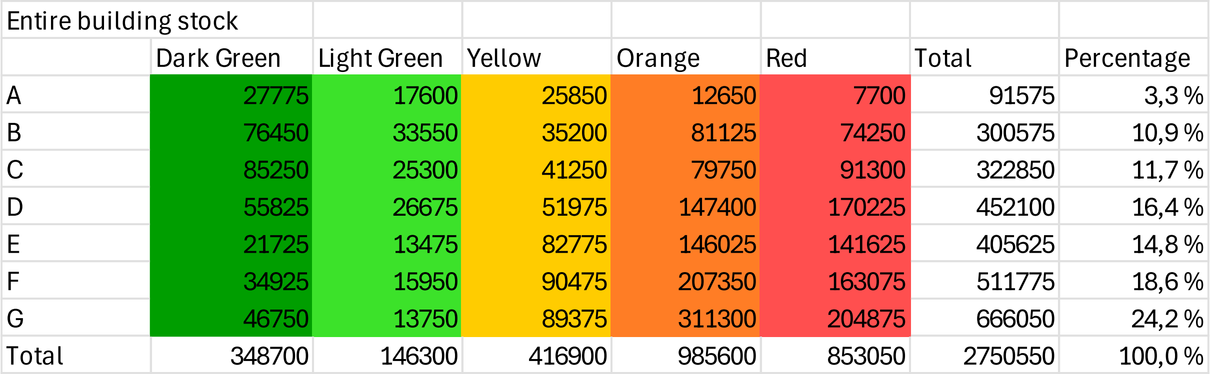
Table 4-2: Distribution of share energy and heating ratings[61].



	Dark Green	Light Green	Yellow	Orange	Red	Total
A	1,01 %	0,64 %	0,94 %	0,46 %	0,28 %	3,33 %
B	2,78 %	1,22 %	1,28 %	2,95 %	2,70 %	10,93 %
C	3,10 %	0,92 %	1,50 %	2,90 %	3,32 %	11,74 %
D	2,03 %	0,97 %	1,89 %	5,36 %	6,19 %	16,44 %
E	0,79 %	0,49 %	3,01 %	5,31 %	5,15 %	14,75 %
F	1,27 %	0,58 %	3,29 %	7,54 %	5,93 %	18,61 %
G	1,70 %	0,50 %	3,25 %	11,32 %	7,45 %	24,22 %
Total	12,68 %	5,32 %	15,16 %	35,84 %	31,02 %	100,02 %

As 47,6% of the Norwegian building stock is in unknown condition, it is essential to have an estimate of the building stock's condition and distribution among the energy ratings. It is crucial as the state of the building stock, combined with the energy labeling system, will shape the method and plan of reaching the goal on a national level. When estimating the distribution of the state of the dwellings without a registered energy certificate, it is assumed that they have the same distribution as the currently registered dwellings.

Table 4-3: Estimated number of dwellings within each energy and heating rating.



Entire building stock							
	Dark Green	Light Green	Yellow	Orange	Red	Total	Percentage
A	27775	17600	25850	12650	7700	91575	3,3 %
B	76450	33550	35200	81125	74250	300575	10,9 %
C	85250	25300	41250	79750	91300	322850	11,7 %
D	55825	26675	51975	147400	170225	452100	16,4 %
E	21725	13475	82775	146025	141625	405625	14,8 %
F	34925	15950	90475	207350	163075	511775	18,6 %
G	46750	13750	89375	311300	204875	666050	24,2 %
Total	348700	146300	416900	985600	853050	2750550	100,0 %

This results in a distribution of the number of dwellings in each energy and heating rating, as seen in Table 4-3. For this thesis, the focus is on the energy grade improvements possible in older dwellings. The EPBD states that 55% of the total reduction must come from renovating the 43% worst-performing buildings, primarily energy grade F and G, and parts of E. While it remains important to implement energy reduction measures in dwellings with a higher energy grade, the directive stresses that to get a significant impact toward zero-emission, the largest impact will come from relatively simple measures that result in large energy reductions in lower-performing dwellings. In contrast, comprehensive and costly measures that are implemented in well-performing dwellings, the impact will often only result in marginal improvements in performance.

4.3.2. The goal of a zero-emission building stock

The EPBD's overarching goal is to achieve a zero-emission building stock by 2050. This does not specifically imply that each building should be zero-emission, but rather that the building stock as a whole should be zero-emission.

A significant portion of the current building stock in Norway was built before 1984. These dwellings are typically assigned an energy grade E or lower, due to the lower building standards at that time. To reach an energy grade A, these dwellings, like Rørvollveien, need significant improvements in the building envelope in addition to installing solar panels. These measures are cost-intensive and will not be feasible for all dwellings. Furthermore, as mentioned, the feasibility of implementing the re-insulation packages for walls and roofs (and PV panels) depends on the current condition and age of the elements and will influence when they should be implemented. Therefore, the responsibility of reaching a zero-emission building stock cannot be solely on the older and worst-performing dwellings, however, they remain a key factor in the solution.

For this reason, a more balanced approach can be done, newer buildings can contribute by both meeting zero-emission standards and providing a surplus through solar energy or other renewable sources. At the same time, older buildings can focus on implementing the most cost-effective measures that improve their energy efficiency, potentially including solar panels. Through this approach, energy consumption is balanced and reaches net zero without forcing older dwellings to bear the burden.

4.3.3. Possible solutions for bad PV conditions

Through this thesis, the results suggest that PV panels are a key element in the transition towards a zero-emission building stock. However, PV panels will not be feasible for many dwellings due to suboptimal solar irradiation, roof size, shape, cardinal direction, or condition and age. An interesting idea to make it possible for these homeowners to invest in PV production, is the development of a privately developed solar park (or wind turbine park), where individuals can purchase a share of the installed panels, making it possible to own and produce PV electricity without being dependent on good installation conditions or opting to install panels on a roof with suboptimal conditions.

Similarly, another interesting suggestion is the concept of neighbor sharing. The same idea is applied, but allows dwellings with poor solar condition prerequisites to purchase a share of the PV panels installed on a neighbor’s roof. In such cases, the neighbor’s conditions are optimal, and they have space for more panels, but choose not to maximize the number of panels on the roof, as this results in excess PV production, which does not reduce their specific energy consumption, as it will not be self-consumed.

Note that for these suggestions to affect the specific energy consumption and grade of the dwelling purchasing the solar panel share, the energy labeling system would need to be modified.

4.4. Sources of Error

4.4.1. Cannibalization Effect

A source of error is that the cannibalization effect between the various building energy reduction measures is not accounted for. This effect is previously mentioned and can be briefly explained as a negative impact on the potential for energy reduction for measures implemented after another measure is implemented. This effect is, however, accounted for between the building energy reduction measures as a package and the hybrid system, but not between the various building measures.

4.4.2. Variation in Spot Prices

In this thesis, the spot prices from 2022 and 2024 are used. Historically, these years are two extremes, where 2022 was the highest it has ever been, and 2024 was unusually low. For this reason, it is assumed that the spot prices within the measures' technical lifetimes will likely fluctuate between these values. When evaluating the various measures’ feasibility, both extremes are weighed in terms of risk and reward.

Spot prices are very volatile and dependent on the global energy market and are difficult to predict. for this reason, the extremes of 2022 and 2024 serve as a realistic approximation of the likely span of spot prices in the future decades. In the final result and recommendation, the spot price is assumed to fall between the two extremes.

4.4.3. Effy Estimates

In this thesis, the company Effy was used to complete an energy evaluation of the dwellings in Rørvollveien and Jongsåsveien. This energy evaluation was used to gather information regarding the energy reduction caused by a decentralized balanced ventilation system with heat recovery, a smart system with heating loads and water heater, as well as improving the building envelope’s airtightness. For Jongsåsveien, the Effy energy reduction estimates were utilized for all the suggested measures. Additionally, the evaluation of the current energy grade and the resulting energy grade after implementing the measures is used. Utilizing this data can be a potential source of error, as there may be errors in the information they have as inputs or errors in their calculation and assumptions.

4.4.4. MILP Perfect Forecast

The model is based on historical data, with other words it is calculated with perfect forecast. It is a simplification, where everything is optimized, if one were to use the system, it would have a slightly lower result.

5. Conclusion

Based on the analyses and results, several key conclusions can be drawn regarding the various measures. When comparing the use of PV and hybrid systems, the traditional measures of wall and roof re-insulation are more economically feasible measures. However, when investigating the remaining energy reduction measures, with marginal economic feasibility in the worst-case spot prices, PV and the hybrid system emerge as the measures with the largest contribution in reducing energy consumption. It is worth noting that the results calculated for the hybrid system do not include any Enova subsidies, as, currently, there is no subsidy offered. For this reason, as the impact and importance of utilizing the battery system with PV production to efficiently improve the energy grade in dwellings is significant, the possibility of subsidizing residential battery systems should be evaluated by Enova.

Furthermore, the use of PV and batteries will be especially beneficial for older and poorly performing dwellings, such as Rørvollveien, where it is not possible to reach a high energy grade (A and B) through envelope energy reduction measures. Additionally, it is also a fitting and highly beneficial measure for dwellings, such as Jongsåsveien, where the dwelling already has a moderate energy grade, but can easily be improved to an A through the use of PV, in addition to utilizing the measure as an efficient way of contributing to the zero-emission building stock aim.

5.1. Further work

Suggestions for further work include developing a new NS3031 normalization profile for technical equipment, lights, and hot water consumption that is more closely matched with the average consumption. Additionally, some energy reduction measures that were not evaluated in this thesis, but from the results, it would be interesting to further investigate, are the measures of recycling greywater, as the energy loss from the use of hot water is significant, a clean-burning wood stove, as well as a heat pump. In the thesis, both cases evaluated already had a clean-burning wood stove and heat pump installed, and therefore, these measures fell outside the scope of the thesis. However, for dwellings where these are not implemented, they would likely be especially important and impactful for the worst-performing dwellings.

6. Reference list

[1] "Energy Performance of Buildings Directive." Accessed: Feb. 10, 2025. [Online]. Available: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

[2] "Norway," Ember. Accessed: May 19, 2025. [Online]. Available: https://ember-energy.org/countries-and-regions/norway

[3] P.-W. A. Frp stortingsrepresentant kommunalkomiteen, og Marius Arion Nilsen, stortingsrepresentant og fraksjonsleder, energi-og miljøkomiteen, "Boligeiere – nå må dere våkne!," Nordnorsk debatt. Accessed: May 19, 2025. [Online]. Available: https://www.nordnorskdebatt.no/5-124-350518

[4] O. Sylte, "Ikke EU-tvang mot huseiere om energieffektivisering," Energinytt24. Accessed: May 19, 2025. [Online]. Available: https://energinytt24.no/2024/02/eus-energieffektiviseringsdirektiv-epbd-tvinger-ikke-huseiere-til-noen-ting/

[5] M. Blaker, "Gir EUs nye krav deg en millionregning - eller er det uproblematisk?," Nettavisen. Accessed: May 19, 2025. [Online]. Available: https://www.nettavisen.no/5-95-2255714

[6] "Energy Labelling of Housing and Buildings - NVE." Accessed: Feb. 15, 2025. [Online]. Available: https://www.nve.no/energy-consumption-and-efficiency/energy-labelling-of-housing-and-buildings/

[7] "Beregning av energikarakteren," Enova. Accessed: Feb. 15, 2025. [Online]. Available: https://www.enova.no/energimerking/om-energimerkeordningen/om-energiattesten/beregning-av-energikarakteren/

[8] "Heat from Renewable Energy Sources".

[9] "Beregning av oppvarmingskarakteren," Enova. Accessed: Feb. 15, 2025. [Online]. Available: https://www.enova.no/energimerking/om-energimerkeordningen/om-energiattesten/beregning-av-oppvarmingskarakteren/

[10] "Karakterskalaen," Enova. Accessed: May 09, 2025. [Online]. Available: https://www.enova.no/energimerking/om-energimerkeordningen/om-energiattesten/karakterskalaen/

[11] "Beregning av bygningers energi- og effektbehov – NS 3031." Accessed: May 04, 2025. [Online]. Available: https://standard.no/fagomrader/energi-og-klima-i-bygg/bygningsenergi/beregning-av-bygningers-energi--og-effektbehov/

[12] "NS 3031:2014 Beregning av bygningers energiytelse er trukket tilbake, men vises fortsatt til i byggteknisk forskrift." Accessed: May 12, 2025. [Online]. Available: https://standard.no/fagomrader/energi-og-klima-i-bygg/bygningsenergi/ns-3031-beregning-av-bygningers-energiytelse-er-trukket-tilbake-men-vises-fortsatt-til-i-byggteknisk-forskrift/

[13] "NS 3031:2014 | Viewer." Accessed: May 07, 2025. [Online]. Available: https://lese.standard.no/product/2534497/nb?langUI=nb

[14] "NS 3031:2025 | Viewer." Accessed: May 12, 2025. [Online]. Available: https://lese.standard.no/product/2603481/nb#_STS_1_1_id-6364f3f9-091d-4969-aa62-e8d45b7bcde9

[15] Energidepartementet, "Ny energimerkeordning: Premierer avlasting av kraftsystemet og energieffektivisering i eksisterende bygg," Regjeringen.no. Accessed: May 12, 2025. [Online]. Available: https://www.regjeringen.no/no/aktuelt/ny-energimerkeordning-premierer-

avlasting-av-kraftsystemet-og-energieffektivisering-i-eksisterende-bygg/id3095038/
[16] "Om Enova – Vi bidrar til ny energi- og klimateknologier," Enova. Accessed: May 22, 2025. [Online]. Available: https://www.enova.no/om-enova/
[17] "Pris- og effektstyrt energilagringssystem | Søk om støtte," Enova. Accessed: May 22, 2025. [Online]. Available: https://www.enova.no/privat/alle-energitiltak/pris--og-effektstyrt-energilagringssystem-for-boliger/
[18] "Smart varmtvannsbereder | Søk om støtte," Enova. Accessed: May 22, 2025. [Online]. Available: https://www.enova.no/privat/alle-energitiltak/smart-varmtvannsbereder/
[19] "Solcelleanlegg | Energitiltak | Solenergi," Enova. Accessed: Jan. 25, 2023. [Online]. Available: https://www.enova.no/privat/alle-energitiltak/solenergi/solcelleanlegg/
[20] "Balansert ventilasjon | Oppgradere huset," Enova. Accessed: May 28, 2025. [Online]. Available: https://www.enova.no/privat/alle-energitiltak/oppgradere-huset/balansert-ventilasjon/
[21] "Oppgradering av bygningskroppen – Oppgradere huset," Enova. Accessed: May 28, 2025. [Online]. Available: https://www.enova.no/privat/alle-energitiltak/oppgradere-huset/oppgradering-av-bygningskroppen-/
[22] AdminSim, "Simien gjør energiberegning tilgjengelig og effektiv." Accessed: Jun. 12, 2025. [Online]. Available: https://simien.no/
[23] S. Gjerde, S. Jensen, and M. Meland, "Energy Cost Reduction in Residential Buildings Using Solar PV Panels, Battery Storage, and Time-Shifting of Flexible Loads," 2023.
[24] "Mixed Integer Linear Programing - an overview | ScienceDirect Topics." Accessed: May 18, 2023. [Online]. Available: https://www.sciencedirect.com/topics/engineering/mixed-integer-linear-programing
[25] AdminSim, "Om oss | Simien." Accessed: May 23, 2025. [Online]. Available: https://simien.no/om-simien/
[26] anis, "ASKO DFI8557MMXXL Built In Dishwasher User Manual," Manuals+. Accessed: May 02, 2025. [Online]. Available: https://manuals.plus/asko/dfi8557mmxxl-built-in-dishwasher-manual
[27] E. Rosenberg, "Electricity end-use consumption focusing on lighting in Norwegian households".
[28] "Shelly EM + 120A Clamp," Shelly Cloud. Accessed: May 05, 2023. [Online]. Available: https://www.shelly.cloud/en/products/shop/em-120a
[29] "MSZ-FH35VE : Deluxe FH35 High Wall Heat Pump // Mitsubishi Electric." Accessed: May 01, 2025. [Online]. Available: https://www.mitsubishi-electric.co.nz/product/nlaproduct.aspx?item=69115B
[30] N. F. Delebekk, "Så dyr må strømmen være for at vedfyring skal lønne seg." Accessed: May 04, 2025. [Online]. Available: https://www.faktisk.no/artikkel/sa-dyr-ma-strommen-vaere-for-at-vedfyring-skal-lonne-seg/113053
[31] "Aduro 1.4 | Peisovn med hevet brennkammer." Accessed: Jun. 07, 2025. [Online]. Available: https://www.aduro.no/aduro-peisovner/peisovner/aduro-1-4-hoy-vedovn-med-hevet-brennkammer/
[32] "Milestones in the Development of Halogen Light Bulbs," Svetila.com. Accessed: May 08, 2025. [Online]. Available: https://www.svetila.com/en/content/102-milestones-in-the-development-of-halogen-light-bulbs

[33] J. Energy, “Types of Light Bulbs: A Buying Guide,” Just Energy. Accessed: May 08, 2025. [Online]. Available: https://justenergy.com/blog/types-of-light-bulbs-buying-guide/

[34] S. Fjeld, “Energirapport Rørvollveien 17,” Effy, Energirapport, Nov. 2025.

[35] “Toppsving vindu - 1 rute - Kjøp online her!” Accessed: May 14, 2025. [Online]. Available: https://www.sparevinduer.no/toppsving-vindu/1-rute-sv/

[36] “Balkongdør - 1 fylling 1 rute - Kjøp online her!” Accessed: May 14, 2025. [Online]. Available: https://www.sparevinduer.no/1-fylling-1-rute-fk159cm/

[37] “Utforing 18x120x2400mm hvit,” Byggmax. Accessed: May 14, 2025. [Online]. Available: https://www.byggmax.no/utforing-18x120x2400mm-hvit-p086718120

[38] “Karmlist 12x58x4400mm hvit,” Byggmax. Accessed: May 14, 2025. [Online]. Available: https://www.byggmax.no/karmlist-12x58x4400mm-hvit-p086712059

[39] snille tips, “Pris på vindusbytte: Hva koster det å bytte vinduer i 2025?,” Signumvindu.no. Accessed: May 10, 2025. [Online]. Available: https://signumvindu.no/pris-pa-vindusbytte-hva-koster-det-a-bytte-vinduer-i-2025/

[40] “På lager! Facadedør med 1 fyldning og 1 rude - Sparvinduer.” [Online]. Available: https://www.sparevinduer.no/ytterdoerer/ytterdoer-nordkapp/

[41] “Sidefelt - 1 rute - Kjøp online her!” Accessed: May 14, 2025. [Online]. Available: https://www.sparevinduer.no/sidefelt/1-rute-sp/

[42] “Ytterdør Torsvik Hvit 100x210 Høyre,” Vinduer og Dører – Stort Utvalg, Beste Pris | Vindu Butikken. Accessed: May 10, 2025. [Online]. Available: https://vindubutikken.no/produkt/ytterdorer-ny/ytterdor/ytterdor-torsvik-hvit-1/ytterdor-torsvik-hvit-100x210-hoyre

[43] “48x98 Konstruksjonsvirke C24,” Byggmax. Accessed: May 14, 2025. [Online]. Available: https://www.byggmax.no/48x98-konstruksjonsvirke-c24-p08148098

[44] “Isolasjon Glava 34 Proff Plate,” Byggmax. Accessed: May 14, 2025. [Online]. Available: https://www.byggmax.no/isolasjon-glava-34-proff-plate

[45] “Vindsperre Tolago 1,5x50 m - 26926 - Bygghjemme.no.” Accessed: May 14, 2025. [Online]. Available: https://www.bygghjemme.no/hus-och-bygg/tak/takpapp/underlagspapp/vindsperre-tolago/p-1855153-1855155

[46] “Everything You Need to Know About Ductless HRUs | Alnor.” Accessed: May 27, 2025. [Online]. Available: https://www.ventilation-alnor.co.uk/index/support/alnor-knowledge-base/heat-recovery/mvhr-guide.html

[47] “Ventilation with heat recovery | Zehnder Group Sales International.” Accessed: May 29, 2025. [Online]. Available: https://www.international.zehnder-systems.com/en/comfortable-indoor-ventilation/ventilation-with-heat-recovery?utm_source=chatgpt.com

[48] “The Lifespan Of A Smart Home: | John Ross Smart Living.” Accessed: May 29, 2025. [Online]. Available: https://www.jrsmartliving.co.uk/the-lifespan-of-a-smart-home/

[49] F. H. Almeida/ScanStockPhoto, “Varmekabler: Kostbar oppvarming?,” Huseierne. Accessed: May 29, 2025. [Online]. Available: https://www.huseierne.no/hus-bolig/tema/oppvarming/varmekabler-kostbar-oppvarming-strompriser/

[50] “ELKO TERMOSTAT MED WIFI PLUS/RS PH ELKO.” Accessed: May 26, 2025. [Online]. Available: https://www.megaflis.no/elektro/smarthjem/elko-termostat-med-wifi-plusrs-ph-elko

[51] “Futurehome Smarthub II + Tibber Pulse HAN ⚡ Tibber Store.” Accessed: May 26, 2025. [Online]. Available: https://tibber.com/no/store/produkt/futurehome-smarthub-2-pulse-han

[52] “Expanding Foam Can Be Used as Insulation, Here’s How,” Mass Foam Systems. Accessed: May 27, 2025. [Online]. Available: https://www.massfoamsystems.co.uk/insulation-faqs/can-expanding-foam-be-used-as-insulation/

[53] “How Long Do Solar Panels Last? | EnergySage.” Accessed: May 29, 2025. [Online]. Available: https://www.energysage.com/solar/how-long-do-solar-panels-last/

[54] “David, “What’s the lifetime of a home battery?,” Electric Car Home Ltd. Accessed: May 29, 2025. [Online]. Available: https://electriccarhome.co.uk/battery-storage/whats-the-lifetime-of-a-home-battery/

[55] Q. Meng, H. Yin, M. R. Johannessen, and L. Berntzen, “Analysis of development of Norwegian household solar energy ecosystem,” *J. Phys. Conf. Ser.*, vol. 2552, no. 1, p. 012004, Jul. 2023, doi: 10.1088/1742-6596/2552/1/012004.

[56] “How Long Do Water Heaters Last? | A.O. Smith.” Accessed: May 29, 2025. [Online]. Available: https://www.hotwater.com/info-center/how-long-do-water-heaters-last.html

[57] J. Sekkenes, “Energirapport Jongåsveien 31A,” Effy, Energirapport, Jun. 2024.

[58] “Iguru 6600 | Luft-luft varmepumpe - Mitsubishi Electric.” Accessed: Jun. 10, 2025. [Online]. Available: https://mee.no/privat/produktkategori/luft-luft-varmepumper/iguru/iguru-6600/

[59] “Når er det midnattssol i Nord-Norge? – Nordfra.no.” Accessed: Jun. 08, 2025. [Online]. Available: https://www.nordfra.no/datoer-for-midnattssol-i-nord-norge/

[60] J.-D. Martens, “boligmassen i Norge,” *Store norske leksikon*. Dec. 27, 2024. Accessed: Feb. 13, 2025. [Online]. Available: https://snl.no/boligmassen_i_Norge

[61] “Statistikk | Enova Energimerking.” Accessed: Feb. 13, 2025. [Online]. Available: https://portal.ems.enova.no/statistikk/energikarakter

[62] *Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast) (Text with EEA relevance)*. 2024. Accessed: Feb. 10, 2025. [Online]. Available: http://data.europa.eu/eli/dir/2024/1275/oj/eng

[63] “Building Renovation Passports,” Irish Green Building Council. Accessed: Mar. 22, 2025. [Online]. Available: https://www.igbc.ie/policy-and-regulation/renovation-strategies/building-renovation-passports

7. Appendix

7.1. Rørvollveien 17

7.1.1. Floor Plans

Figure 7-1 depicts the floor plan and details for the first floor of Rørvollveien 17. Figure 7-2 depicts the second floor, while Figure 7-3 depicts the façade facing east.

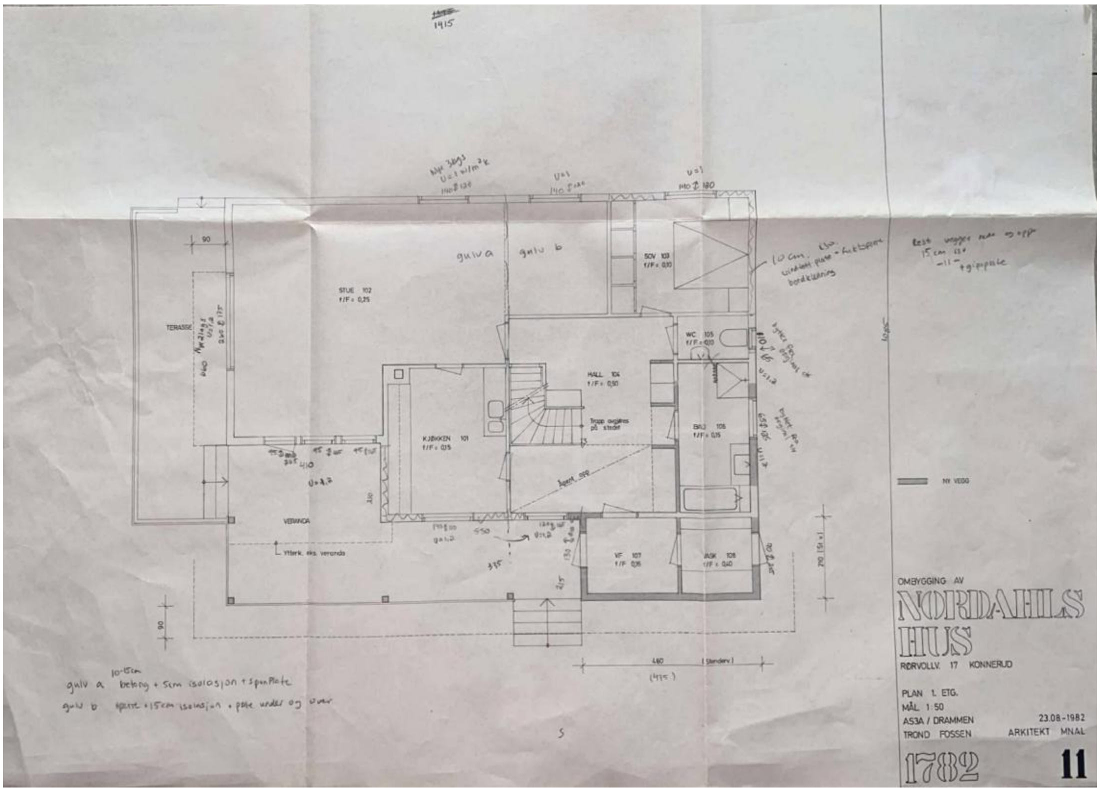


Figure 7-1: Floor Plan of the first floor in Rørvollveien 17.

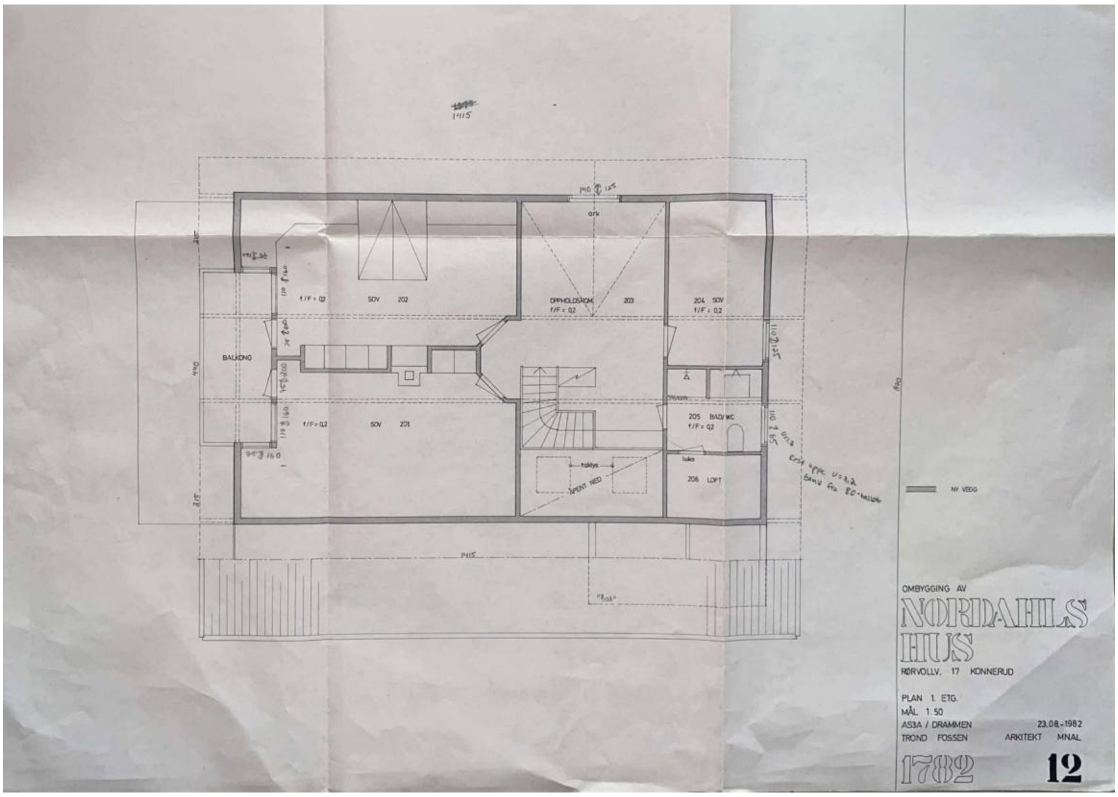


Figure 7-2: Floor Plan of the second floor in Rørvollveien 17.

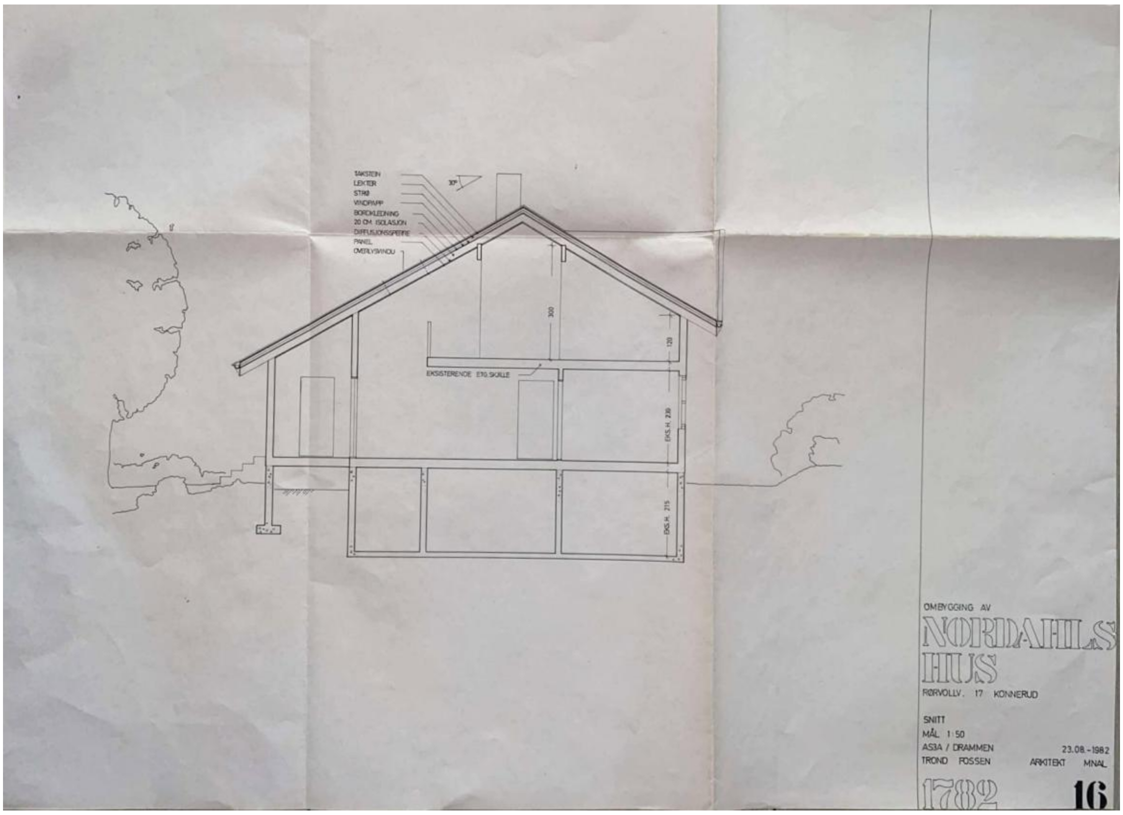
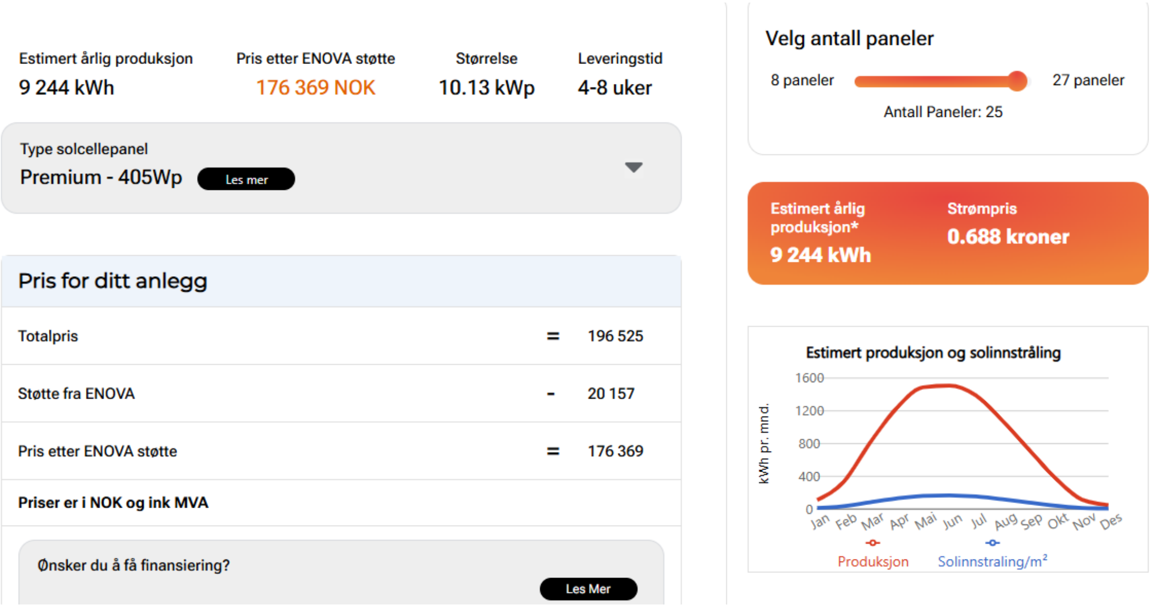


Figure 7-3: Façade facing east in Rørvollveien 17.

7.2. Jongsåsveien 31A

7.2.1. Solkart.no's PV Production Estimate



Estimert årlig produksjon	Pris etter ENOVA støtte	Størrelse	Leveringstid
9 244 kWh	176 369 NOK	10.13 kWp	4-8 uker

Type solcellepanel
Premium - 405Wp

Pris for ditt anlegg

Totalpris	=	196 525
Støtte fra ENOVA	-	20 157
Pris etter ENOVA støtte	=	176 369
Priser er i NOK og ink MVA		

Ønsker du å få finansiering?

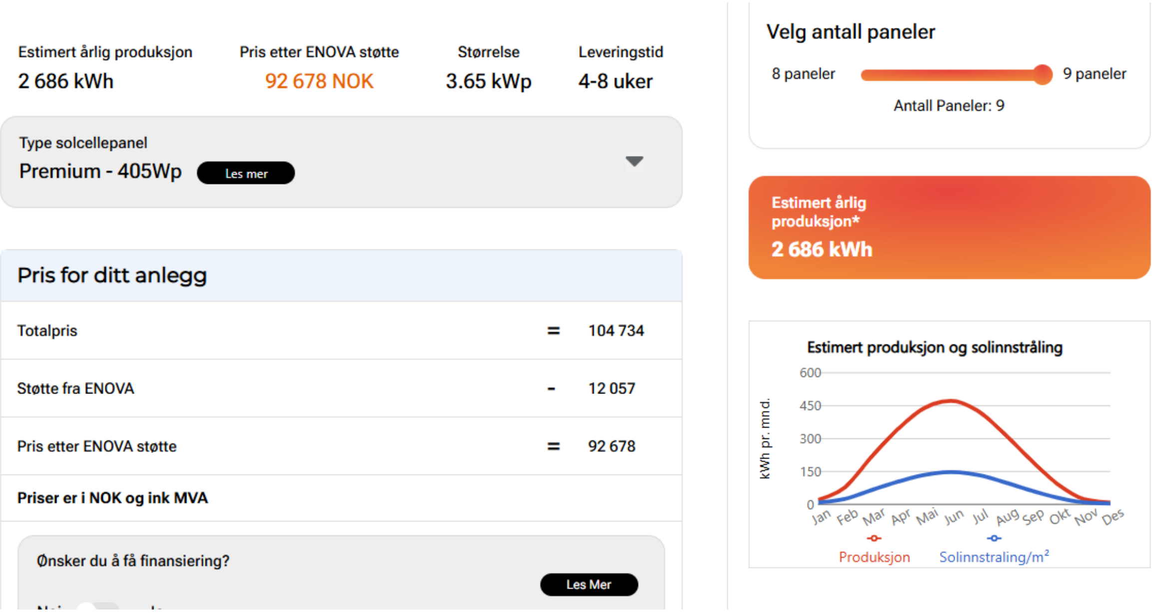
Velg antall paneler
8 paneler — 27 paneler
Antall Paneler: 25

Estimert årlig produksjon*
9 244 kWh

Strømpris
0.688 kroner

Estimert produksjon og solinnstråling

Figure 7-4: Solkart's estimate on the PV Production from the east-facing roof.



Estimert årlig produksjon	Pris etter ENOVA støtte	Størrelse	Leveringstid
2 686 kWh	92 678 NOK	3.65 kWp	4-8 uker

Type solcellepanel
Premium - 405Wp

Pris for ditt anlegg

Totalpris	=	104 734
Støtte fra ENOVA	-	12 057
Pris etter ENOVA støtte	=	92 678
Priser er i NOK og ink MVA		

Ønsker du å få finansiering?

Velg antall paneler
8 paneler — 9 paneler
Antall Paneler: 9

Estimert årlig produksjon*
2 686 kWh

Estimert produksjon og solinnstråling

Figure 7-5: Solkart's estimate on the PV Production from the west-facing roof.

7.3. Energy Performance of Buildings Directive (2024)

For this thesis, the focus is on the EPBD's impact, therefore, it is essential to have a rudimentary understanding of its content. It is important to note that the EPBD's composition and wording are very simplified and repetitive, as its purpose is to act as a guideline for how member states can implement the overarching idea of the directive, and in most cases, does not include specific instructions. Therefore, to give a fundamental understanding of the directive, this section will outline the EPBD's main ideas, where a zero-emission building will be defined, an excerpt from Article 9.2 will be showcased, and Articles 9 and 12 will be summarized.

The EPBD has 84 underlying sections, all have the collective goal to contribute to reaching the main aim, as well as 38 articles that further elaborate various aspects of the paragraphs. The key aspects are financing and support measures for renovation, energy poverty and social impact, the role of small and medium enterprises (SMEs) and local actors, energy performance certification, as well as building stock monitoring, and public sector leadership[62].

7.3.1. Article 2.2: Definition of zero-emission building

According to the definition of a zero-emission building in the directive, it "means a building with a very high energy performance, as determined in accordance with Annex I, requiring zero or a very low amount of energy, producing zero on-site carbon emissions from fossil fuels and producing zero or a very low amount of operational greenhouse gas emissions"[62].

Annex I is named the 'Common general framework for the calculation of the energy performance of buildings'. It is a general framework for what the energy performance calculation should include, and its main ideas, which do not give any further elaboration regarding the definition of a zero-emission building.

7.3.2. Article 9.2: Trajectories for Progressive Renovation, Residential Building Stock

In the directive, the elaboration of the energy performance standards in Article 9.2 states[62]:

> By 29 May 2026, each Member State shall establish a national trajectory for the progressive renovation of the residential building stock in line with the national roadmap and the 2030, 2040 and 2050 targets contained in the Member State's national building renovation plan and with the aim of transforming the national building stock into a zero-emission building stock by 2050. The national trajectory for the progressive renovation of the residential building stock shall be expressed as a decrease in the average primary energy use in kWh/(m^2.y) of the entire residential building stock over the period from 2020 to 2050, and shall identify the number of residential buildings and residential building units or floor area to be renovated annually, including the number or floor area of the 43 % worst-performing residential buildings and residential building units.
>
> Member States shall ensure that the average primary energy use in kWh/(m^2.y) of the entire residential building stock:
>
> (a) decreases by at least 16 % compared to 2020 by 2030;
>
> (b) decreases by at least 20-22 % compared to 2020 by 2035;
>
> (c) by 2040, and every 5 years thereafter, is equivalent to, or lower than the nationally determined value derived from a progressive decrease in the average primary energy use from 2030 to 2050, in line with the transformation of the residential building stock into a zero-emission building stock.
>
> Member States shall ensure that at least 55 % of the decrease in the average primary energy use referred to in the third subparagraph is achieved through the renovation of the 43 % worst-performing residential buildings. Member States may count the decrease in the average primary energy use achieved by the

> renovation of residential buildings affected by natural disasters such as earthquakes and floods towards the share achieved by means of the renovation of the 43 % worst-performing residential buildings.
>
> In their renovation efforts to achieve the required decrease in the average primary energy use of the entire residential building stock, Member States shall put in place measures such as minimum energy performance standards, technical assistance and financial support measures.
>
> In their renovation efforts, Member States shall not disproportionately exempt rental residential buildings or building units.
>
> Member States shall report in the national building renovation plans the methodology used and data gathered for estimating the values referred to in the second and third subparagraphs. As part of the assessment of national building renovation plans, the Commission shall monitor the achievement of the values referred to in the second and third subparagraphs, including the number of buildings and building units or floor area of the 43 % worst-performing residential buildings, and make recommendations where necessary. Those recommendations may include a more extensive use of minimum energy performance standards.
>
> The national trajectory for the progressive renovation of the residential building stock shall refer to data on the national residential building stock, based, as appropriate, on statistical sampling and energy performance certificates.
>
> If the average fossil share of energy use in residential buildings is lower than 15 %, Member States may adjust the levels laid down in the points (a) and (b) of the third subparagraph, to ensure that the average primary energy use in kWh/(m^2.y) of the entire residential building stock by 2030, and every five years thereafter, is equivalent to, or lower than a nationally determined value derived from a linear decrease in the average primary energy use from 2020 to 2050, in line with the transformation of the residential building stock into a zero-emission building stock.

To make Article 9.2 more concise, the directive intends for each Member state to establish a national plan to reach a zero-emission residential building stock by 2050, with trajectory targets for 2030, 2040, and 2050. The improvement in the residential building stock will be shown through a decrease in the average primary energy use (kWh/m^2 per year). The directive suggests specific energy reduction targets, with at least a 16% reduction by 2030 compared to 2020, at least 20-22% by 2035 compared to 2020, and further reductions every five years until 2050. Within this reduction, 55% of the total reduction must come from renovating the 43% worst performing buildings. As implementation measures, the minimum energy performance standard (MEPS), technical assistance, and financial support measures are suggested approaches. The article also stresses that rental residential buildings and building units shall not be disproportionately exempt from renovations. In addition, it allows member states to adjust the targets if their share of fossil energy use in residential buildings is below 15%[62].

7.3.3. Summary of other relevant articles

Article 7 aims to ensure that all new buildings are zero-emission and should apply to new buildings owned by public bodies from January 1st, 2028, and from January 1st, 2030, for all new buildings. In addition, they want to have the Global Warming Potential (GWP) disclosed in the energy certificates and should apply for new buildings with a useful floor area above 1000 m^2 from January 1st, 2028, and from January 1st, 2030, for all new buildings.

Article 12 introduces the Building Renovation Passport (BRP), a document that provides a long-term master plan for retrofits to improve the energy performance of a building. It ensures that a deep retrofit can be implemented wholistically, and in phases[63]. Depending on how the Member States want to implement it, the use of a BRP will either be voluntary or mandatory. It should be affordable, and Member States should consider providing financial support to vulnerable households wanting to renovate their buildings.

Other slightly relevant articles include article 8, which expands on existing buildings, and article 19, which elaborates on the energy performance certificates. However, they will not be further elaborated upon as they are very general and do not contain any specific regulations that should be implemented.

Annex V is a template for what the EU intends to be included in the energy performance certificates. On the first page, the following elements should be displayed: the energy class, the calculated annual primary energy use in [kWh/(m^2 .y)], the calculated annual final energy use in [kWh/(m^2 .y)], renewable energy produced on-site in percentage of energy use, operational greenhouse gas emissions, and the GWP, if possible. Additionally, the certificate should also display elements such as the calculated annual primary energy and the calculated annual final energy consumption in [kWh or MWh], renewable energy production, main energy carrier, and source of renewable energy source. Lastly, the calculated energy needs in [kWh/(m^2 .y)], whether the building can react to external signals and adjust energy consumption, and the contact information of the relevant one-stop shop for renovation advice.