Weighing the Importance of Energy Savings, CO_2 Emissions and Costs When Implementing Renewable Energy Technologies

Case: Nærøyfjorden UNESCO World Heritage Centre

Sylvi Brækken

Master's Thesis in Climate Change Management

Department of Environmental Sciences, Faculty of Engineering and Science

WESTERN NORWAY UNIVERSITY OF APPLIED SCIENCES

Sogndal

June, 2021

I confirm that the work is self-prepared and that references/source references to all sources used in the work are provided, cf. Regulation relating to academic studies and examinations at the Western Norway University of Applied Sciences (HVL), § 10.

Weighing the Importance of Energy Savings, CO_2 Emissions and Costs When Implementing Renewable Energy Technologies

Case: Nærøyfjorden UNESCO World Heritage Centre

Master's thesis in Climate Change Management

Author: Sylvi Brækken	Author sign. Sylvi Brækken
Thesis submitted: Spring 2021	Open thesis

Main supervisor: Marte Lange Vik, Western Norway University of Applied Sciences

Co-supervisor: Anders-Johan Almås, Western Norway Research Institute

Keywords: renewable energy technologies, solar panels, solar thermal collectors, heat pumps, fjord, sustainable development goals (SDGs), UNESCO World Heritage, renovation	Number of pages: 63 + Appendix: 52 Sogndal, 24.06.21

Preface

This master's thesis is conducted as part of the 2-year master's programme Climate Change Management at Western Norway University of Applied Sciences (HVL) in Sogndal. The work is conducted at Department of Environmental Sciences under supervision of associate professor Marte Lange Vik. The project's co-supervisor is the director of Western Norway Research Institute, Anders-Johan Almås. The project amounts to 30 ECTS.

I would like to thank Marte Lange Vik for good advice and consultation during the project work. I would like to thank Anders-Johan Almås for supervision concerning the technical aspects.

I would also like to thank Berit Johanne Skogvang and Halldór Þrastarson for collaboration on making the base models, as well as the chapter with our combined recommendation.

Also thanks to project leader of Nærøyfjorden UNESCO World Heritage Centre, Gøran Johansen, and the architects of the concept building from MAD architects.

Sogndal, 24 June 2021

Sylvi Brækken

Abstract

Buildings and construction of buildings account for around one third of the energy consumption in the world. A large investment in energy efficiency can reduce the energy use of Norwegian buildings by 39 TWh from 2020 to 2050. The energy saved through energy efficiency measures in buildings can be used in other sectors, such as the industry and transport sectors. In 2017, the building and construction sector contributed with 18% of Norwegian greenhouse gas emissions. It is important to reduce greenhouse gas emissions and energy use of buildings to contribute towards the sustainable development goals (SDGs) and a sustainable future.

This master's thesis looks into different combinations of renewable energy technologies that can be implemented in the renovation of Nærøyfjorden UNESCO World Heritage Centre. The thesis is part of a larger project that includes three master's theses, all looking at the World Heritage Centre but with different focus areas. The purpose of this thesis is to discuss how energy savings, CO_2 emissions and costs can be weighed against each other and to recommend a combination of energy technologies for the World Heritage Centre.

The evaluated combinations include one or several of the following energy technologies: water-to-water heat pump, air-to-water heat pump, evacuated tube collectors, flat plate collectors, standard solar panels and solar shingles. All combinations also include an electric boiler covering 10% of the heating demand. Energy simulations were conducted using SIMIEN; life cycle assessments (LCAs) were performed in One Click LCA, and costs were found through research and used in the net present value (NPV) method.

Finally, the combination with a water-to-water heat pump, flat plate collectors and standard solar panels was recommended. This combination resulted in the fourth highest energy savings and a slightly negative NPV, which was seen as acceptable. The difference in emissions between the combinations was minimal, and this was therefore not considered in the assessment.

Due to uncertainties regarding costs, the real profitability of the solutions could be different. Before deciding on a final combination for the UNESCO World Heritage Centre, professional consulting and inspection of the area and building are required.

Sammendrag

Bygninger og konstruksjon av bygninger står for rundt en tredjedel av energiforbruket i verden. En stor investering i energieffektivitet kan redusere energiforbruket i norske bygninger med 39 TWh fra 2020 til 2050. Energien som spares gjennom energieffektiviseringstiltak i bygninger kan brukes i andre sektorer, som industri- og transportsektorene. I 2017 bidro bygg- og anleggssektoren med 18 % av norske klimagassutslipp. Det er viktig å redusere klimagassutslipp og energiforbruk i bygninger for å bidra til FNs bærekraftsmål og en bærekraftig fremtid.

Denne masteroppgaven ser på forskjellige kombinasjoner av fornybare energiteknologier som kan implementeres i renoveringen av Nærøyfjorden UNESCO Verdensarvssenter. Oppgaven er en del av et større prosjekt som inkluderer tre masteroppgaver, der alle ser på verdensarvssenteret, men med forskjellige fokusområder. Hensikten med denne oppgaven er å diskutere hvordan energibesparelser, CO_2-utslipp og kostnader kan veies opp mot hverandre og å anbefale en kombinasjon av energiteknologier for verdensarvssenteret.

De evaluerte kombinasjonene inkluderer en eller flere av følgende energiteknologier: vann-til-vann-varmepumpe, luft-til-vann-varmepumpe, vakuumrørsolfangere, plane solfangere, standard solcellepaneler og solcelletakstein. Alle kombinasjoner inkluderer også en elektrokjel som dekker 10 % av varmebehovet. Energisimuleringer ble utført ved bruk av SIMIEN; livssyklusanalyser (LCA) ble utført i One Click LCA, og kostnader ble funnet og brukt i nåverdimetoden.

Til slutt ble kombinasjonen med en vann-til-vann-varmepumpe, plane solfangere og standard solcellepaneler anbefalt. Denne kombinasjonen resulterte i den fjerde høyeste energibesparelsen og en noe negativ nåverdi, som ble ansett som akseptabelt. Forskjellen i utslipp mellom kombinasjonene var minimal, og dette ble derfor ikke tatt med i vurderingen.

På grunn av usikkerhet rundt kostnader, kan den reelle lønnsomheten til løsningene være annerledes. Før en endelig kombinasjon blir valgt for verdensarvssenteret, er det nødvendig med profesjonell rådgivning og inspeksjon av området og bygningen.

Contents

Preface i

Abstract ii

Sammendrag iii

List of Figures vi

List of Tables vii

Nomenclature viii

1 Introduction **1**
1.1 Background . . . 1
1.2 Case Study . . . 2
1.3 UNESCO and Sustainability . . . 4
1.4 Purpose and Scope . . . 5
1.4.1 Case Specific Concerns . . . 6
1.4.2 Limitations . . . 6
1.5 Structure of the Thesis . . . 6

2 Environmental Concerns in Building Renovations **7**
2.1 Sustainability . . . 7
2.2 Technical Requirements, TEK17 . . . 9
2.3 Environmental Certification . . . 10

3 Renewable Energy Technologies **11**
3.1 Solar Panels . . . 11
3.2 Solar Thermal Collectors . . . 12
3.2.1 Dimensioning Solar Thermal Collector Systems . . . 13
3.2.2 Location and Application . . . 14
3.3 Heat Pumps . . . 14
3.3.1 Dimensioning Heat Pumps . . . 16
3.3.2 Location and Application . . . 17
3.3.3 Free Cooling . . . 17
3.4 Greenhouse Gas Emissions from Electricity . . . 17

4 Costs **18**
4.1 Future Electricity Prices . . . 18
4.2 Profitability Analysis . . . 18

5 Method **21**
5.1 SIMIEN . . . 21
5.1.1 Base Case - Concept Building With an Electric Boiler and Underfloor Heating . 22
5.1.2 Input Data for the Concept Building . . . 22
5.1.3 Solar Energy - Area and Angle of Roof . . . 25
5.1.4 Dimensioning Solar Thermal Collectors . . . 25
5.1.5 Solar Thermal Collectors - Input SIMIEN . . . 29
5.1.6 Heat Pumps . . . 30
5.1.7 Heat Pumps - Input SIMIEN . . . 30

5.1.8 Solar Panels - Input SIMIEN . . . 31
5.1.9 Different Combinations of Energy Technologies . . . 31
5.1.10 Methodological Reflections . . . 32
5.2 Life Cycle Assessment . . . 32
5.2.1 General Input . . . 32
5.2.2 Solar Panels . . . 33
5.2.3 Solar Thermal Collectors . . . 33
5.2.4 Heat Pumps . . . 34
5.2.5 Electric Boiler . . . 34
5.2.6 Methodological Reflections . . . 35
5.3 Costs . . . 35
5.3.1 Electricity Prices . . . 35
5.3.2 General Input . . . 36
5.3.3 Solar Panels . . . 36
5.3.4 Solar Thermal Collectors . . . 37
5.3.5 Heat Pumps . . . 37
5.3.6 Electric Boiler . . . 38
5.3.7 Methodological Reflections . . . 38

6 Results 40
6.1 Results from SIMIEN . . . 40
6.1.1 Base Case: Electric Boiler and Underfloor Heating . . . 40
6.1.2 Different Combinations of Energy Technologies . . . 40
6.2 Results from One Click LCA . . . 43
6.2.1 Emissions Related to Electricity . . . 47
6.3 Results from the Profitability Analysis . . . 48
6.4 Combined Results . . . 50

7 Discussion 52
7.1 Weighing Saved Energy, Emissions and Costs . . . 52
7.2 Comparing the Combinations . . . 52
7.3 Sustainable Development Goals . . . 54

8 Conclusion 56

9 The Full Concept Recommendation 57
9.1 Study Conducted by Berit . . . 57
9.2 Study Conducted by Halldór . . . 57
9.3 Study Conducted by Sylvi . . . 57
9.4 Implementation into the Project . . . 58

References 59

A SIMIEN Input Data for Concept Building I

B Technical Data Sheet - Solar Shingles V

C Results from SIMIEN VI

D Results from One Click LCA XVI

E Results from the Profitability Analysis XVII

List of Figures

1 Existing building and concept building . . . 2
2 Concept building showing roof, windows and orientation . . . 3
3 Location of case building and World Heritage Centre in Geiranger . . . 3
4 Concept - local resources and World Heritage values . . . 5
5 Sustainable development goals . . . 7
6 Sustainable development goals 7, 9 and 12 . . . 8
7 Solar panel working principle . . . 11
8 Solar thermal collector working principle . . . 12
9 Heat pump working principle . . . 15
10 Different seawater heat pump systems . . . 16
11 Energy coverage vs. power coverage, example . . . 16
12 Future predicted electricity prices . . . 18
13 Example of a net present value calculation . . . 19
14 Methods flow chart . . . 21
15 Terrain profile . . . 25
16 Load duration curve heating and cooling . . . 26
17 Load duration curve heating . . . 26
18 Load duration curve heating with energy coverage marked . . . 27
19 Solar radiation for the south east roof . . . 28
20 Costs for air-to-water heat pumps . . . 38
21 Total emissions for all combinations, including the base case . . . 43
22 Emissions related to combinations 1-2 . . . 44
23 Emissions related to combinations 3-6 . . . 45
24 Emissions related to combinations 7-10 . . . 46
25 Emissions related to combinations 11-18 . . . 47
26 Emissions for all combinations, with an emission factor of 17 g CO_2e/kWh . . . 47

List of Tables

1 Sustainable development goals mentioned in the pilot project . . . 4
2 Solar radiation for different angles and orientations . . . 14
3 SIMIEN: Efficiencies and COP for the electric boiler . . . 22
4 Input SIMIEN - information about the building . . . 23
5 Input SIMIEN - doors on north east wall . . . 23
6 Input SIMIEN - north east walls and windows . . . 24
7 Power needed to cover a certain percentage of the heating demand . . . 27
8 Area of evacuated tube collectors . . . 29
9 SIMIEN: Efficiencies and COP for the evacuated tube collector . . . 30
10 SIMIEN: Efficiencies and COP for the flat plate collector . . . 30
11 SIMIEN: Efficiencies and COP for the water-to-water heat pump . . . 30
12 SIMIEN: Efficiencies and COP for the air-to-water heat pump . . . 30
13 Net delivered energy for the base case . . . 40
14 Net delivered energy and energy saved for combinations 1-2 . . . 41
15 Net delivered energy and energy saved for combinations 3-6 . . . 41
16 Net delivered energy and energy saved for combinations 7-10 . . . 42
17 Net delivered energy and energy saved for combinations 11-18 . . . 42
18 Initial investment cost and net present value of combinations 1-2 . . . 48
19 Initial investment cost and net present value of combinations 3-6 . . . 48
20 Initial investment cost and net present value of combinations 7-10 . . . 49
21 Initial investment cost and net present value of combinations 11-18 . . . 50
22 Combined results . . . 51

Nomenclature

Abbreviations	
CO_2e	CO_2 equivalent
COP	coefficient of performance
DHW	domestic hot water
DOT	design outdoor temperature
EPD	environmental product declaration
GWP	global warming potential
IIC	initial investment cost
NE	north east
NPC	net present cost
NPV	net present value
NW	north west
O&M	operation and maintenance
R&D	research and development
SCOP	seasonal coefficient of performance
SDG	sustainable development goal
SE	south east
STC	standard test conditions
SW	south west
UNESCO	United Nations Educational, Scientific and Cultural Organization

Symbols		Unit
C_{rep}	replacement cost	NOK
f_d	discount factor	-
i	real discount rate	-
L	lifetime	years
N	number of years	years
R_{rep}	replacement cost duration	years
S	residual value	NOK

Subscripts	
comp	component
proj	project
rem	remaining

1 Introduction

1.1 Background

Climate change is a pressing and possibly irreversible threat to the planet and all its inhabitants. Ambitious mitigation is essential to limit global warming to 1.5 °C while achieving sustainable development [1, pp. 51, 79]. Mitigation is the aim to limit human sources of climate change and their cumulative effects, particularly emission of greenhouse gases and other pollutants which impacts the world's energy balance [2, p. 114]. Adapting to the anticipated changes will become more and more difficult and expensive, and action must be taken sooner rather than later. We need increased investments and innovation in energy efficiency and renewable energy technologies to reduce greenhouse gas emissions in the transport, industry and building sectors [3].

Buildings contribute with about 40% of CO_2 emissions globally [4]. In Norway, 80% of the energy consumed in buildings is covered by electricity, and most of this electricity is produced from renewable sources. This results in low emissions during the lifetime of Norwegian buildings [5, p. 7]. However, even though the energy consumption of buildings is almost free of fossil fuels, the building and construction sector contributed with 18% of Norwegian greenhouse gases in 2017. These numbers include emissions from production of building materials, emissions from import of goods and services, emissions from building sites and energy use in buildings [6].

Buildings and construction of buildings also account for around one third of the energy consumption in the world [4]. A large investment in energy efficiency can reduce the energy use of Norwegian buildings by 39 TWh from 2020 to 2050. This is a reduction of more than 55%, even though the building stock might increase with 25% due to an increased population [7]. The energy saved through energy efficiency measures in buildings can be used in other sectors, for example in electrification of the transport sector. Electrifying the transport sector will significantly reduce CO_2 emissions, but it will also massively increase the need for electricity. The industry and transport sectors in mainland Norway might need 23 TWh more electrical energy in 2040 than in 2018 [5, p. 7]. Focusing on energy efficiency in buildings can relieve substantial amounts of energy, preventing the need to produce this energy from new power plants and avoiding a large expansion of the electric power system [7].

To reduce the energy use of Norwegian buildings we need to focus on existing buildings. It is important to maintain and renovate existing buildings instead of only building new constructions, as it results in less waste generation and in most cases also reduced energy use and pollution [8, p. 1]. One way to reduce the electric energy delivered to a building is to implement a renewable energy technology, such as heat pumps, solar thermal collectors or solar panels. These energy technologies can be implemented in both new buildings and in renovation projects.

1.2 Case Study

The case study of this thesis is an old concrete building which is to be renovated and turned into a UNESCO World Heritage Centre.

14 July 2005, UNESCO officially gave the area of Nærøyfjorden status as World Heritage as part of the West Norwegian Fjords [9]. UNESCO gives cultural and natural sites of "outstanding universal value" status as World Heritage, and by earning this status, sites gain international recognition [10]. The World Heritage Council for the West Norwegian Fjords decided that the area should consist of two World Heritage Centres, as the area stretches over large geographical distances [11, p. 7]. The West Norwegian Fjords consist of Geirangerfjorden and Nærøyfjorden, where the northern part, Geirangerfjorden already has a centre [12]. The southern part, Nærøyfjorden, does not have a World Heritage Centre and it was decided to build this centre in Aurlandsvangen in Aurland Municipality.

A pilot project has been conducted where a concept for the World Heritage Centre has been designed. Figure 1 shows the old building on the left and the concept building on the right. The old concrete building was built in 1954 [13]. The building has been used for multiple purposes over the years, and this will continue as the World Heritage Centre will have rooms that can be used for a multitude of events and purposes. Today the building is owned by Aurland Kjøle- og Fruktlager, which is a cooperative with local farmers and other inhabitants of Aurland. The building now includes storage, a small store and a small office area [11].

Figure 1: The case building is in the middle of the figure, showing half of the existing building on the left and half of the concept building on the right [11, p. 1].

The World Heritage Centre will include a store, as well as sales of local products on the ground floor. Aurland Kjøle- og Fruktlager will also have a storage area on this floor. The first floor will include a café and a presentation and display of the World Heritage values. The second floor will have a large room that could be used for a multitude of purposes. The third floor will have office spaces for the Norwegian Environment Agency (SNO), the conservation manager of the area and Aurland Fjellstyre, as well as the Nærøyfjorden World Heritage staff [11, p. 15-17].

Multiconsult has conducted a technical assessment of the building and found that the existing construction is more than good enough to be renovated instead of torn down. This can benefit both the environment, climate and the economic aspect [11, p. 9]. The project leader of Nærøyfjorden World Heritage Centre has a goal of achieving an environmentally friendly building and to get a BREEAM certification or a similar certification [14].

Nærøyfjorden World Heritage Centre has planned to use different energy technologies, such as solar thermal energy and using the fjord as a heat source in heat pumps [11, p. 4]. Solar panels are also mentioned as a possible addition [11, p. 9]. A drawing of the concept building is shown in figure 2. Here one can see that solar thermal collectors and solar panels can be placed either on the north west (NW) side or the south east (SE) side of the roof.

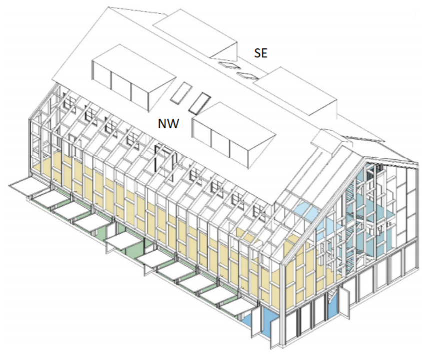


Figure 2: Concept building showing the roof, windows and orientation of the building [11, p. 14].

Figure 3 shows the case building and its proximity to the fjord on the left. Utilising the fjord as a heat source in heat pumps is therefore an option. On the right is a map showing the location of the World Heritage Centre in Geiranger in the north and the planned World Heritage Centre in Aurlandsvangen in the south.

Figure 3: The location of the case building is on the left [15]. On the right is a map showing the location of the World Heritage Centre in Geiranger with a blue dot and the planned World Heritage Centre in Aurlandsvangen with a red dot [16].

1.3 UNESCO and Sustainability

The main goal of the United Nations Educational, Scientific and Cultural Organization (UNESCO) is to contribute to world peace and security by promoting cooperation through culture, science and education [17]. UNESCO played an important role in developing the United Nations' sustainable development goals (SDGs) in 2015. The SDGs should be used as a basis in all municipal and county level planning in the coming years, and is therefore a natural part of the pilot project of the UNESCO World Heritage Centre in Aurland [11, p. 4].

In the pilot project, they have stated that the project will have an impact on several of the SDGs, see table 1. Some of the goals mentioned are more relevant for this thesis than others, for example goals related to sustainable consumption, energy and innovation. The goals concerning health and education are not as relevant.

Table 1: List of SDGs mentioned in the pilot project.

3	Good Health and Well-Being
4	Quality Education
7	Affordable and Clean Energy
9	Industry, Innovation and Infrastructure
11	Sustainable Cities and Communities
12	Responsible Consumption and Production
14	Life Below Water
15	Life on Land
17	Partnerships

The pilot project states that the project particularly hits goal 12, as they plan to use the existing building, instead of tearing it down and building new [11, p. 4]. They have also planned to use energy solutions such as solar thermal energy and using the fjord as a heat source in heat pumps, natural ventilation, and a mixture of low and high technological solutions to create a practical and user-friendly centre in Aurland. This will, according to the pilot project, have an impact on goals 7, 9 and 11 [11, pp. 4-5].

The project wishes to achieve a new way of thinking when it comes to World Heritage Centres. They want to connect existing local resources with a clear representation of the World Heritage values. The existing cooperative has been an important part of the circular process with cultural landscape, grazing animals, processing, dissemination and end product since the 1950s. Connecting the World Heritage values and the existing cooperative will lead to a holistic concept, which is managed and anchored locally, see figure 4 [11, p. 8]. The World Heritage Centre is to be partly owned by the existing cooperative. The basement will include a store selling local food and storage for the cooperative. This will gather local farmers and strengthen the community. The existing cooperative in the building will work as a driving force for local farmers, local crafts and small scale production and sale. This will, according to the pilot project, have an impact on goals 3, 4, 9, 14, 15 and 17 [11, p. 5].

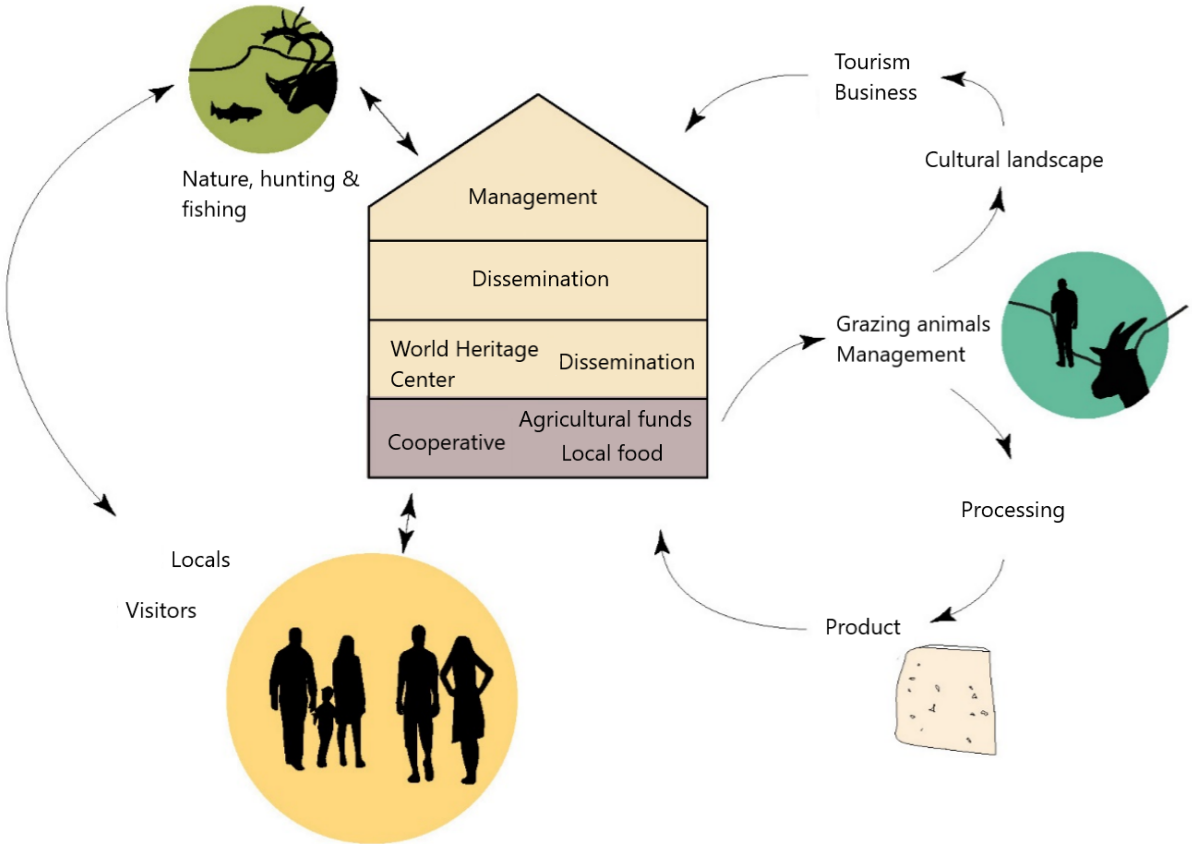


Figure 4: Concept - local resources connected with dissemination of the World Heritage values [11, p. 8], translated to English by author.

The SDGs considered most relevant for this thesis and the UNESCO World Heritage project, goals 7, 9 and 12, will be explored further in section 2.1.

1.4 Purpose and Scope

This master's thesis looks into different combinations of renewable energy technologies that can be implemented in the renovation of the World Heritage Centre in Aurland. Renewable energy technologies include systems that produce electricity or heat, both of which reduce the electric energy needed from the grid. The combinations will be assessed based on their energy savings, costs and greenhouse gas emissions.

Research question:

- How does weighing of energy savings, CO_2 emissions and costs impact the choice of renewable energy technologies in the case of Nærøyfjorden UNESCO World Heritage Centre?

The purpose of this thesis is to discuss the importance of the three aspects and to recommend a combination of renewable energy technologies for Nærøyfjorden World Heritage Centre.

1.4.1 Case Specific Concerns

The fact that the case study is a renovation project does impact the project in its entirety, but does not impact the choices of energy technologies. The different energy technologies can be implemented in both renovation projects, in new buildings, and in existing buildings not being renovated.

Nærøyfjorden World Heritage Centre wants to utilise heat from the fjord and the sun. This is taken into account when deciding which energy technologies to include in the thesis. Two types of solar thermal collectors will be investigated, flat plate collectors and evacuated tube collectors. A water-to-water heat pump utilising the fjord as a heat source, an air-to-water heat pump, standard solar panels, and solar shingles will also be investigated.

1.4.2 Limitations

This master's thesis does not cover and consider every aspect of energy efficiency of the World Heritage Centre, only the aspect of energy production. The thesis is part of a larger project that includes three master's theses, all using the UNESCO World Heritage Centre but with different focus areas.

One of the other theses is looking at energy efficiency in the building structure. The building parts considered are roof, walls, windows, doors and slab on ground. The second is looking at energy sources for heating, ventilation and air conditioning systems (HVAC), and relevant control methods for building management systems and HVAC. The group collaborated on making the base models in SIMIEN, see chapter 5, as well as a full concept recommendation, see chapter 9.

Small wind turbines are not included in the thesis. This is due to the annual average wind speed in the area being below 5 m/s [18, p. 39], which according to Hosseinalizadeh et al. (2017) creates appropriate conditions for cost-effective use [19, p. 69]. There are also several other energy technologies available that could have been included. This could have led to different results and recommendations. Examples of technologies that could have been investigated are solar panels with the ability to follow the sun, and photovoltaic cells integrated into glass. Using other types of heat pumps or multiple smaller heat pumps to achieve a higher coefficient of performance (COP) could also be investigated.

1.5 Structure of the Thesis

Chapter 2 contains theory about sustainability, technical requirements and environmental certifications. This is followed by chapter 3, which contains theory concerning energy technologies. Chapter 4 contains theory about costs, electricity prices and profitability analysis. The methods used in the thesis are presented in chapter 5, followed by the results in chapter 6. A discussion leading to a recommended solution is presented in chapter 7, followed by a conclusion in chapter 8. Chapter 9 contains the full concept recommendation, combining the conclusions from all three master's theses written on Nærøyfjorden World Heritage Centre.

2 Environmental Concerns in Building Renovations

This chapter contains theory about sustainability and the SDGs most relevant for this thesis, section 2.1, as well as theory on technical requirements, section 2.2, and environmental certifications for buildings, section 2.3. The SDGs and TEK17 are baselines that the UNESCO World Heritage project and this thesis aim to follow. Many building projects also strive to obtain environmental certifications.

2.1 Sustainability

The concept of sustainable development was first introduced in the report Our Common Future, also known as the Brundtland Report in 1987 [20]. Sustainable development was here defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [21, para. 1].

Sustainable development is traditionally divided into three parts: environmental, economic and social sustainability [22]. When considering sustainability in the building sector, the concept may be limited to include materials, production of materials and the related costs. This means that only the environmental and economic aspects of sustainability are considered. In 2015, the United Nations developed 17 sustainable development goals (SDGs). The goals are seen as the world's common plan to eradicate poverty, fight inequality, and limit climate change by 2030 [20]. Figure 5 shows the 17 goals from an economic, social and environmental view. This figure suggests that economies and societies are incorporated parts of the biosphere [22].

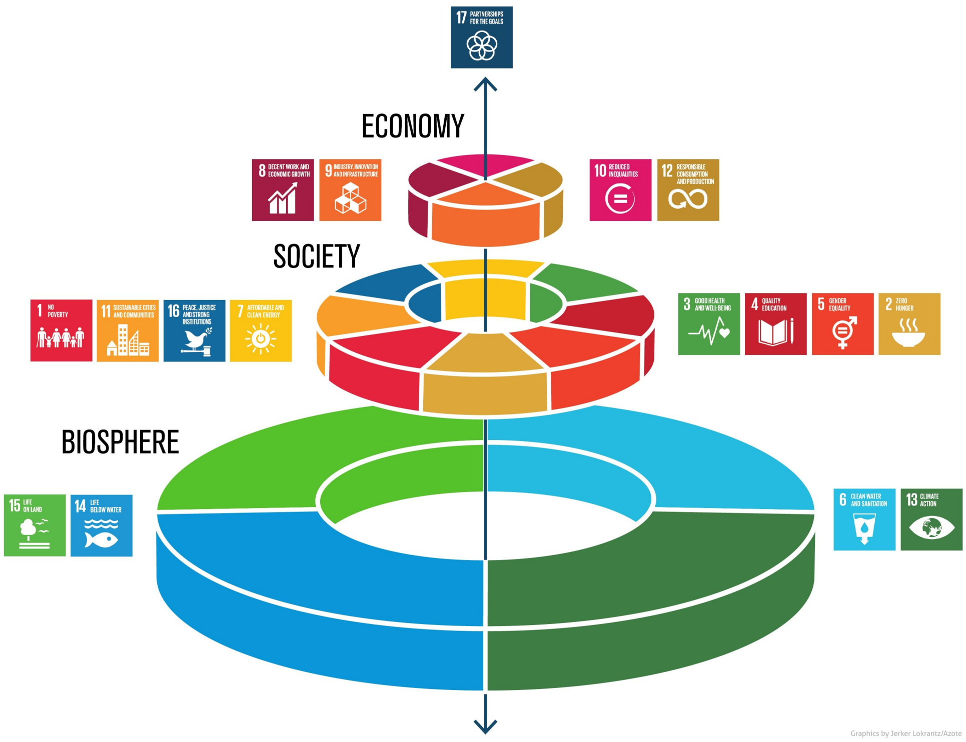


Figure 5: SDGs from an economic, social and environmental view [22].

As the case building is to be transformed into a World Heritage Centre, it is important to consider how this project contributes to the SDGs. The goals considered most important for this thesis and the World Heritage project are shown in figure 6. Goals 7 and 9 are seen as the two most important goals for this thesis as they concern energy and innovative solutions. Goal 12 is seen as one of the most important goals for the UNESCO World Heritage project as it concerns sustainable consumption, and reusing the building structure will save a lot of materials. Each goal has several smaller targets, of which the most relevant ones are included here.

Figure 6: The most important SDGs for this thesis: goals 7, 9, and 12 [23].

Goal 7: Affordable and Clean Energy

The goal is to secure access to reliable, affordable and sustainable energy [24]. Energy production and consumption are the number one reason for climate change, contributing with around 60% of global greenhouse gas emissions. By focusing on and investing in renewable energy sources, this project works towards target 7.2: "By 2030, increase substantially the share of renewable energy in the global energy mix" [24]. The indicator for this target is the renewable energy share in the total final energy consumption. By reducing the amount of electric energy needed from the grid, this energy can be used in e.g. electrification of the transport sector. On a larger scale, this could massively decrease the share of fossil energy and increase the share of renewable energy in the global energy consumption.

Goal 9: Industry, Innovation and Infrastructure

The goal is to advocate sustainable industrialisation, facilitate innovation and build robust infrastructure [24]. Innovation and technological advancements are central to finding durable solutions to economic and environmental difficulties. Increasing energy and resource efficiency is important, requiring investment in research and development (R&D). By building a sustainable and sturdy building, and supporting innovation and renewable technologies, this project will contribute to goal 9 and target 9.1: "Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all" [24].

By including the small-scale businesses within the cooperative, the World Heritage Centre contributes towards target 9.3: "Increase the access of small-scale industrial and other enterprises, in particular in developing countries, to financial services, including affordable credit, and their integration into value chains and markets" [24].

Goal 12: Responsible Consumption and Production

The goal is to enable sustainable consumption patterns and production methods [24]. Consumption and production are driving forces of the global economy. However, this practice relies on the natural environment and its resources. If we are not conscious of our production and consumption, it can have destructive impacts on the world. During the last century, the world has experienced economic and social improvements. This growth has unfortunately led to degradation of the environment and the natural system – a system we depend on for food, development and ultimately for our survival [24].

This goal is about striving to do more and better with less. It is also about raising resource efficiency, advocating sustainable lifestyles and about decoupling economic growth and environmental degradation [24]. The World Heritage project contributes to this goal by focusing on using the existing building instead of tearing it down and building new. By reusing the existing building, it contributes towards target 12.5: "By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse" [24].

The World Heritage Centre in Aurland will also communicate the values of the area and the importance of conservation. This will also contribute towards target 12.8: "By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature" [24].

2.2 Technical Requirements, TEK17

Today, new buildings must be built with the technical requirements for construction works, TEK17 [25]. For remodelling of buildings, the requirements are not as straight forward. According to the Planning and Building Act §31-2, measures on existing buildings are to be carried out in accordance with provisions and requirements given by the law [26]. This means, in principle, that the same requirements apply for remodelling as for new buildings. The preparatory work for the law states that the requirements only apply when "relevant". As a general rule, the requirements apply only to the parts of the building that are being remodelled [8, p. 5]. The municipality can also grant permission for remodelling or renovation even when it is not possible to reach the current requirements, if the remodelling is justifiable and necessary to ensure appropriate use [26].

TEK17 gives a minimum of properties a building must have to legally be built in Norway, and it is only a baseline [25]. Future requirements will likely be stricter as technology advances. Some may want to go beyond the minimum requirements to achieve more energy efficient buildings. Reaching the requirements of a passive, net-zero or plus house standard might be expensive. It is therefore important to find the best solutions when it comes to energy savings, greenhouse gas emissions and costs.

2.3 Environmental Certification

An environmental certification is an affirmation that a product, project or company conforms to one or several climate or environmental requirements. Environmental assessments are a prerequisite for environmental certifications and have become popular in the recent years along with an increased focus and interest in the climate and environment. In Norway, environmental assessments are voluntary. Companies might want to conduct such assessments to meet the requirements of a tender, achieve their own environmental goals, to signalise interest and commitment towards the climate and environment, or to be ahead of future requirements [6].

Environmental assessments can combat the negative impacts from the building sector. The building sector in Norway contributed with 18% of Norway's greenhouse gas emissions in 2017 and produces 25% of all waste in Norway [6].

BREEAM (Building Research Establishment Environmental Assessment Method) is an international environmental assessment method used in the building and construction sector. BREEAM-NOR is the Norwegian version and is the most popular tool in Norway. BREEAM is based on the three main principles for sustainable development: environmental, social and economic sustainability, with the main focus being the environmental aspect. Projects are normally assessed based on a life cycle assessment (LCA), and the certification is based on different categories. BREEAM-NOR uses nine categories, including materials, energy, transport, land use and ecology, as well as health and indoor environment [27]. Each category has topics with criteria and a point system to evaluate if a project or company has achieved a certain level of sustainable development within the topic. Some criteria are seen as mandatory depending on the level of certification one wishes to achieve [6].

There are five levels of BREEAM-NOR certification: Pass, Good, Very good, Excellent and Outstanding. When a building is built using BREEAM-NOR certification, it shows that the project has qualities beyond TEK17's minimum requirements and that the project considers and cares about societal values. To reach a high level of certification, one needs to implement measures from all the nine categories. One of the categories is energy, and by adding renewable energy technologies to a building one could achieve a higher level of certification [27].

3 Renewable Energy Technologies

This chapter contains theory about renewable energy technologies, which are systems that produce electricity or heat from a renewable source [28, p. 14]. Implementing such technologies reduces the delivered energy from the electricity grid. The renewable energy technologies investigated are solar panels, section 3.1, solar thermal collectors, section 3.2, and heat pumps, section 3.3. The following sections contain descriptions of how these technologies work, how to dimension the size of the systems, and information on location and application. The chapter also includes a section on CO_2 equivalents (CO_2e) and emissions from electricity, section 3.4.

3.1 Solar Panels

Solar energy can be utilised in several ways, and solar panels that generate electricity and solar thermal collectors that heat water are two of the most common ones.

Solar panels consist of several photovoltaic cells connected to each other. The photovoltaic cells consist of two layers of a semiconducting material, where silicon is often used. The bottom layer is commonly doped with boron which only has three electrons in the outer shell, while silicon has four. This results in an excess of holes and a p-layer (positive). The top layer is commonly doped with phosphorous which has five electrons in the outer shell. This results in an excess of electrons and an n-layer (negative). The difference in charge between the two layers creates an electric field and is called the pn-junction [29].

Figure 7 shows the typical structure of a photovoltaic cell and an equivalent circuit diagram. When photons hit the upper layer of the solar panel, the n-layer, they can knock electrons free. If a photon hits an electron in the depletion zone within the pn-junction, the electron will travel to the n-layer, and the hole travels to the p-layer [30, p. 237]. If one connects an external load to the solar panel, the electron will travel from the n-layer through this load and back to the p-layer. This movement of electrons creates an electric current, travelling in the opposite direction, which can be used as electric power in a building [29].

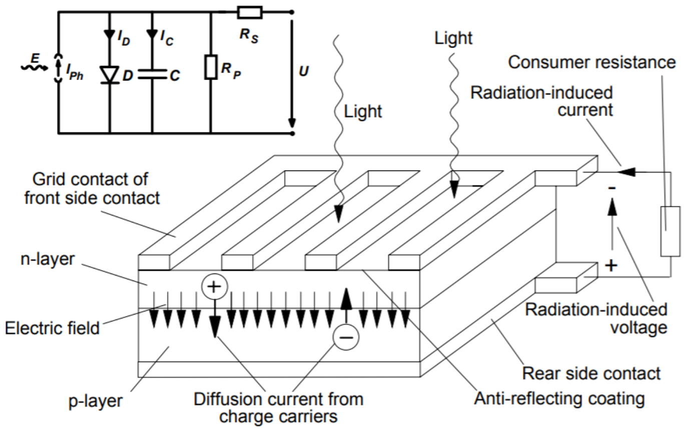


Figure 7: Photovoltaic cell structure and working principle [30, p. 239].

There are several different types of solar panels. The most common and oldest invention is the standard solar panel which one attaches to a roof. Standard solar panels have varying efficiencies depending on the type. Monocrystalline solar panels have a higher efficiency than polycrystalline solar panels, but they are also more expensive. The monocrystalline panels have a black finish which might be more aesthetically pleasing, while the polycrystalline panels have a blue tint to them [31]. Another, more recent invention is solar shingles which resemble and replace traditional roof tiles [32].

3.2 Solar Thermal Collectors

Solar thermal collectors utilise the sun to heat water. The hot water can be used for domestic hot water (DHW), space heating and heating coils. The key principle behind solar thermal collectors is the conversion of short-wave solar radiation into heat [33, p. 123]. The dark surface absorbs up to 95% of the incoming solar radiation and converts it to thermal energy [34].

There are several types of solar thermal collector systems, and the most common type in Northern Europe is closed forced circulation systems [33, p. 152]. These systems consist of collectors, a heat transfer medium, a heat exchanger, pumps, sensors and control systems, see figure 8. Most systems also have a heat storage tank due to the mismatch between solar radiation and heat demand. Energy demand for DHW is similar in different parts of the year. The demand for space heating has a negative correlation with solar radiation, meaning that there is a limited amount of sun and high heating demands during winter, and the opposite in the summer [33, p. 139].

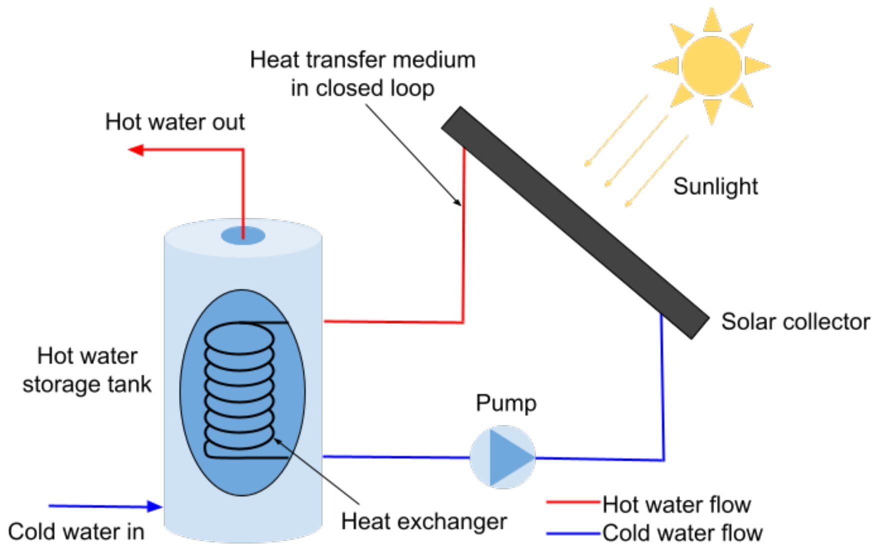


Figure 8: Solar thermal collector working principle. Made by author, inspired by [35].

The collector consists of an absorber, heat insulation, a cover and a frame, as well as pipes for the heat transfer medium. The absorber is the part that transforms short-wave radiation into heat. The absorber has to ensure sufficient heat transfer to the heat transfer medium and tolerate high temperatures. The heat exchanger transfers heat from the heat transfer medium to the water, while keeping the liquids physically separated. A storage tank stores the hot water until it is needed [33, p. 130, 146].

The most important features of a heat transfer medium are a high specific heat capacity, as well as low viscosity to easily flow through the system. Further, it should not freeze or boil at operating temperature, it should not be corrosive, flammable, toxic or biologically degradable. Water could fulfil all these requirements, but in Norway water would freeze during the cold winter months. By adding an antifreeze solution to the water, this problem is solved. An anticorrosive solution is also normally added, as water with antifreeze is more corrosive than plain water. Adding these two solutions has some disadvantages, it lowers the specific heat capacity and it results in higher viscosity. With a higher viscosity, the mixture could seep through pores that plain water cannot get through. This results in higher pressure losses and a lower heat transfer efficiency [33, p. 145].

The most common types of solar thermal collectors available are flat plate collectors and evacuated tube collectors, also called vacuum tube collectors. Flat plate collectors, with a closed forced circulation system, consist of a flat absorber where the heat transfer medium circulates in pipes welded to the underside of the absorber [34]. Flat plate collectors can replace ordinary roofing [36].

In evacuated tube collectors, the absorber circulates in cylindrical vacuum tubes made of glass. These systems have a heat exchanger on top of the panel that transports heat to the accumulator tank. Evacuated tube collectors have good insulation properties, and thus low heat losses. Their good insulation properties also make them vulnerable to overheating in summer. These types of solar thermal collectors are constructed to produce high temperatures and have a higher efficiency than flat plate collectors, especially during low solar radiation. Evacuated tube collectors can be beneficial if the available area is small, as they have a high efficiency. However, the price of this type of solar thermal collector is generally higher than the price of flat plate collectors [34].

The average efficiency is around 0.58 for evacuated tube collectors and 0.42 for flat plate collectors. This is an average efficiency for heating of water with different initial water temperatures [37, p. 5].

3.2.1 Dimensioning Solar Thermal Collector Systems

Dimensioning solar thermal collector systems is important to utilise the available heat, without oversizing the system. Oversizing the system leads to excess heat during warmer months when there is a lot of solar radiation [36].

A combined system is when the solar thermal system is used for both DHW and space heating. This requires a larger area of solar thermal collectors. If there is sufficient solar radiation in spring and autumn, the solar thermal collectors can cover the entire heat demand for space heating or contribute with heat to a hot water storage tank [36].

When solar thermal collectors are used in combination with heat pumps, the solar thermal collector should be prioritised, since it has a higher seasonal coefficient of performance (SCOP) than heat pumps [36]. SCOP expresses how much energy in the form of heat is delivered compared to how much electric energy it uses in a year [38].

Solar thermal collectors and heat pumps can be used in low temperature heating systems. Low temperature heating systems are systems that heat water to temperatures around 40-50 °C [39, p. 8]. These systems are more efficient than systems with higher temperatures [40], and they are well suited for underfloor heating [39, p. 8]. DHW needs to be heated to 65 °C to avoid legionella [40], and a parallel system or a hot water heater is therefore needed to further increase the temperature [39, p. 8].

The solar thermal collector's efficiency depends on the temperature difference between the water going in and the desired water temperature. It is therefore important to prioritise heating in the following order [36]:

1. Preheating of DHW
2. Space heating (low temperature)
3. Heating of DHW

For solar thermal systems used only for DHW heating, it is common to dimension the system to cover ca 50% of the yearly energy demand for DHW. For systems that deliver heat to DHW and space heating, it is common to achieve a coverage of ca 30% of the energy demand [41]. For well-insulated buildings with a lower heat demand, the coverage will be higher than for poorly insulated buildings [36].

3.2.2 Location and Application

Solar thermal collectors and solar panels are usually mounted on the south side of buildings to receive as much solar radiation as possible. The optimal angle of solar thermal collectors depends on which direction the collector is facing. For example, the optimal angle of a SE facing solar thermal collector is 45°. However, 30° gives almost the same solar radiation, see table 2.

Table 2: Difference in solar radiation from a south facing solar thermal collector with an optimal angle of 45° compared to the horizontal plane [36].

Orientation	Angle			
	15°	30°	45°	65°
S	0.91	0.99	1.00	0.96
SW/SE	0.87	0.92	0.93	0.89
W/E	0.79	0.78	0.75	0.69

3.3 Heat Pumps

Heat pumps use electricity to operate, but they deliver more energy than they take from the grid. Coefficient of performance (COP) is the ratio between the delivered energy and the supplied electrical energy. Heat pumps thus have a higher COP than direct electricity, which has a COP of 1. Heat pumps normally have a COP of 3-5 [42]. COP values are instantaneous values and depend on the temperature of the heat source, as well as the temperature the heat pump should deliver to the heating system, while SCOP is an average value over a year [38].

Heat pumps utilise a heat source to heat a working fluid that circulates through a system. The working fluid, also called a refrigerant, changes pressure, temperature and phase throughout the cycle. Heat pump systems consist of four important parts: an evaporator, a compressor, a condenser, and an expansion valve [43, p. 388].

Figure 9 shows the working principle of a heat pump. In the figure, the ground is the heat source, but the same principle applies for other heat sources. Several heat sources could be used in a heat pump: the outdoor air, seawater, groundwater or geothermal energy. The various heat sources have different properties and areas of application [44].

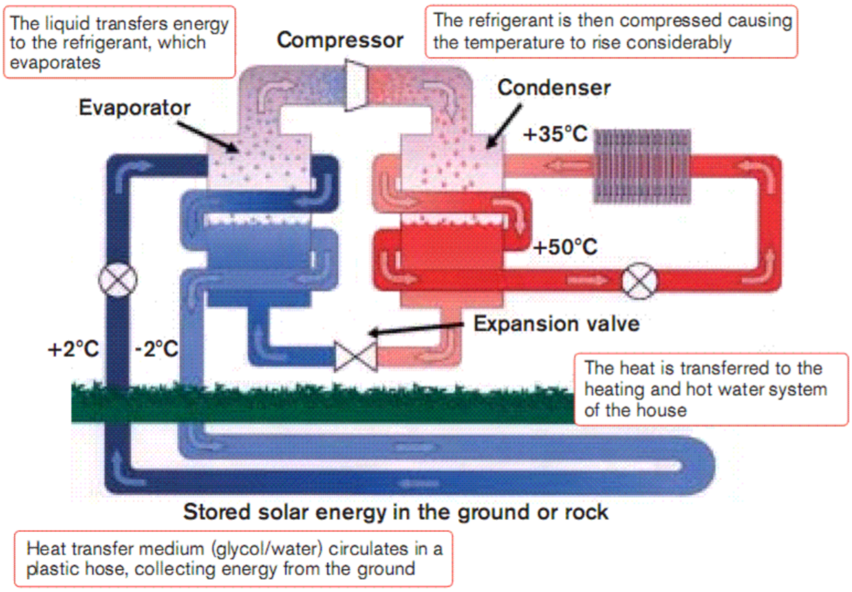


Figure 9: Heat pump working principle [45, p. 1230].

The heat transfer medium is transported from the heat source in pipes and heats the working fluid which is closed off in another circuit. The working fluid vaporises in the evaporator and is then compressed in the compressor. The compression causes the temperature to rise considerably. The working fluid then flows to the condenser where it condenses and releases heat to the water system or the indoor air. The working fluid continues to the expansion valve where pressure is released and returned to the level of the evaporator [45, p. 1230].

When using seawater as a heat source, there are several options for transferring heat, see figure 10. (A) is a direct system where seawater is pumped up and transfers heat directly to the working fluid. This requires the evaporator to be made of corrosion resistant metals, and it is therefore expensive. This solution is only used for large heat pump systems. A more common solution is to use an indirect system, such as (B) and (C). In (B), seawater is pumped up to a heat exchanger where it releases heat to the heat transfer medium, which then heats the working fluid in the evaporator. In (C), the heat exchanger is submerged into the sea and the heat transfer medium circulates in one or more plastic tubes down to the heat exchanger [44].

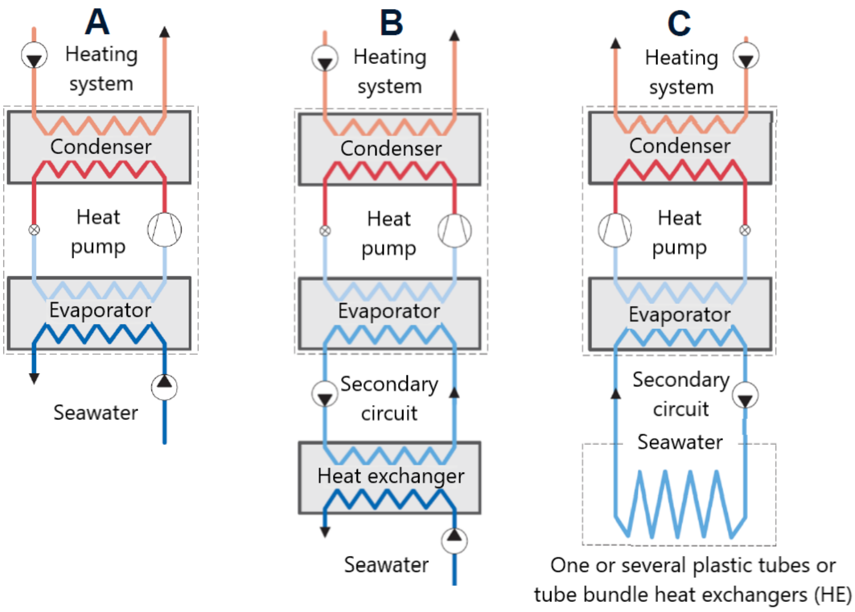


Figure 10: Different heat transfer solutions for seawater heat pump systems [44].

3.3.1 Dimensioning Heat Pumps

It is important to install a heat pump with the right capacity. When a heat pump is operating on a lower capacity than intended, it will result in a lower COP. Oversizing will thus lead to an overall lower COP, as well as higher initial costs [46].

If one wants to install a heat pump which covers approximately 90% of a building's energy demand, the heat pump should cover approximately 60% of the power demand of the building, see figure 11. With the heat pump covering 90% of the energy demand, an additional power source is only needed for the coldest days of the year. Design outdoor temperature (DOT) is the lowest mean air temperature over three days for the last 30 years. DOT is used when dimensioning air-source heat pumps [46].

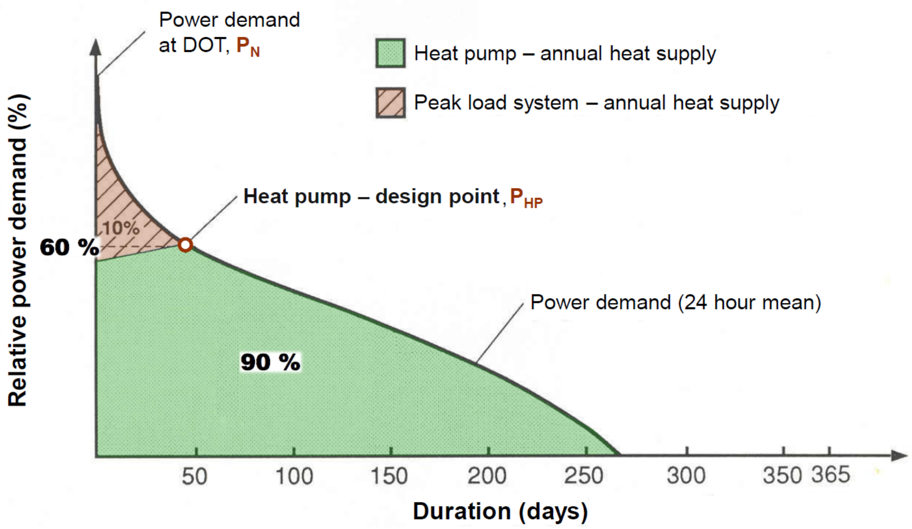


Figure 11: Example of a heat pump with 60% power coverage and 90% energy coverage [46].

When dimensioning water-source heat pumps, one needs to know the temperature of the water. The temperature of seawater depends on location, season and depth. Suitable depths are chosen based on temperature, risk of biofouling and the topography of the seabed. The temperature variation should be measured before dimensioning the system. The depth of the intake should be minimum 20 m. At 25 m below the surface along the Norwegian coast, the temperature varies from 3-5 °C to 9-14 °C [40].

3.3.2 Location and Application

Fjords have a moderate and stable temperature throughout the year, which gives a high COP. Ground source heat pumps also have a high and stable COP, but drilling a borehole to access the source is expensive [47]. With buildings close to the fjord, it is usually cheaper to use the fjord as a heat source. Utilising air as a heat source is also an option. This solution is less expensive and the most common solution in Norway. However, the low air temperatures during winter result in a low COP.

Another advantage with heat pumps is that there is no noise, the system has a long lifetime, and there are no local emissions of particles, as for e.g. burning wood. Operation and maintenance (O&M) costs are also low [47].

3.3.3 Free Cooling

Free cooling using seawater or other heat sources with a relatively low temperature can be used to cover part of or the whole cooling demand of a building [40]. Seawater can be used to cool the ventilation air or water in a building through a heat exchanger without using a chiller. The cooled water circulates in the building and works as a heat sink by absorbing heat [48]. Free cooling uses very little energy as it only needs supply of electrical energy to operate the pumps. The component with the largest electricity need is the compressor, and this does not run when the heat pump is set in free cooling mode [44].

3.4 Greenhouse Gas Emissions from Electricity

In 2019, 94% of the electricity consumed in Norway was produced from renewable energy sources. This results in low greenhouse gas emissions from electricity consumption compared to the rest of Europe. The average direct greenhouse gas emissions related to electricity consumption in Norway in 2019 were only 17 g CO_2e/kWh. In the European Union (EU), this number was 300 g CO_2e/kWh [49].

A CO_2 equivalent (CO_2e) is a measure used to compare emissions from different greenhouse gases. It is based on the global warming potential (GWP) where CO_2 is set to 1. The GWP of other gases is then compared to that of CO_2. For example, methane has a GWP 21 times higher than CO_2, with a time horizon of 100 years [50].

4 Costs

This chapter contains theory regarding costs. First is a section on future electricity prices, section 4.1, then a section on how to conduct a profitability analysis using the net present value (NPV) method, section 4.2.

4.1 Future Electricity Prices

NVE's report "Langsiktig kraftmarkedsanalyse 2020-2040" (Eng. Long-term power market analysis 2020-2040) has predicted the electricity price for the period 2022-2040. They have also included deviations for high and low CO_2 and fuel prices. The electricity price in Norway is predicted to be 38 øre/kWh in 2022, 42 øre/kWh in 2025, 39 øre/kWh in 2030 and 41 øre/kWh in 2040 [51, pp. 2, 23], see figure 12.

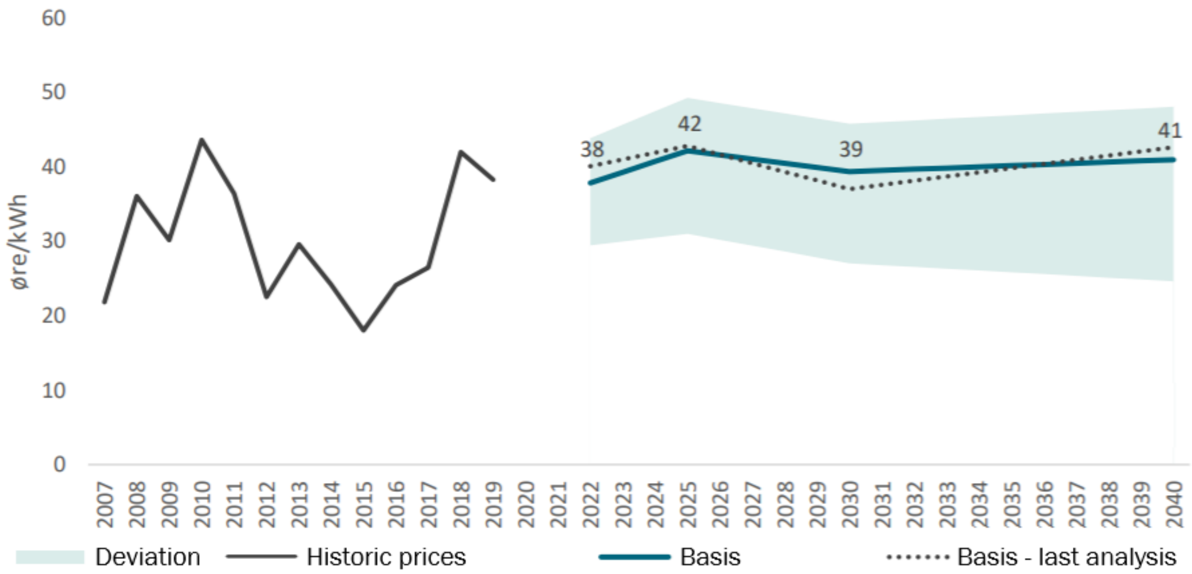


Figure 12: Future predicted electricity prices by NVE [51, p. 2], translated to English by author.

Future electricity prices are uncertain and several factors can impact the price. Some of these factors are changes in CO_2 and fuel prices, changes in consumption, closing of nuclear power plants, and increase in solar and wind power [51, p. 25].

4.2 Profitability Analysis

Profitability analyses can be performed to evaluate the economic profitability of different energy technologies. One common profitability analysis is net present value (NPV). NPV communicates the absolute profitability of a system. If the NPV is above zero, the system is considered to be profitable [52].

Net present costs (NPC) or life cycle costs (LCC) of a system are the present value of all costs related to the system minus all revenue that the system earns over the project lifetime. Costs include costs of hardware, installation, maintenance and replacements, while revenue includes residual value and benefits from for example saved electric energy. The NPC is the same as NPV, but with an opposite sign [53].

Figure 13 shows an example where the initial investment is $96,000, replacement costs are $48,000, and the component has a lifetime of 3.52 years. Costs related to O&M is $2,471 per year, and fuel costs are $34,969 per year. The project has a lifetime of 25 years and an annual real discount rate of 6% [53].

Year	Discount	Nominal Cash Flows						Discounted Cash Flows					
	Factor	Capital	Replace-ment	Salvage	O&M	Fuel	Total	Capital	Replace-ment	Salvage	O&M	Fuel	Total
0	1.000	-96,000					-96,000	-96,000					**-96,000**
1	0.943				-2,471	-34,969	-37,441				-2,331	-32,990	**-35,321**
2	0.890				-2,471	-34,969	-37,441				-2,200	-31,123	**-33,322**
3	0.840				-2,471	-34,969	-37,441				-2,075	-29,361	**-31,436**
3.52	0.815		-48,000				-48,000		-39,098				**-39,098**
4	0.792				-2,471	-34,969	-37,441				-1,958	-27,699	**-29,657**
5	0.747				-2,471	-34,969	-37,441				-1,847	-26,131	**-27,978**
6	0.705				-2,471	-34,969	-37,441				-1,742	-24,652	**-26,394**
7	0.665				-2,471	-34,969	-37,441				-1,644	-23,257	**-24,900**
7.04	0.663		-48,000				-48,000		-31,847				**-31,847**
8	0.627				-2,471	-34,969	-37,441				-1,551	-21,940	**-23,491**
9	0.592				-2,471	-34,969	-37,441				-1,463	-20,698	**-22,161**
10	0.558				-2,471	-34,969	-37,441				-1,380	-19,527	**-20,907**
10.56	0.540		-48,000				-48,000		-25,941				**-25,941**
11	0.527				-2,471	-34,969	-37,441				-1,302	-18,421	**-19,723**
12	0.497				-2,471	-34,969	-37,441				-1,228	-17,379	**-18,607**
13	0.469				-2,471	-34,969	-37,441				-1,159	-16,395	**-17,554**
14	0.442				-2,471	-34,969	-37,441				-1,093	-15,467	**-16,560**
14.08	0.440		-48,000				-48,000		-21,130				**-21,130**
15	0.417				-2,471	-34,969	-37,441				-1,031	-14,592	**-15,623**
16	0.394				-2,471	-34,969	-37,441				-973	-13,766	**-14,738**
17	0.371				-2,471	-34,969	-37,441				-918	-12,986	**-13,904**
17.60	0.359		-48,000				-48,000		-17,212				**-17,212**
18	0.350				-2,471	-34,969	-37,441				-866	-12,251	**-13,117**
19	0.331				-2,471	-34,969	-37,441				-817	-11,558	**-12,375**
20	0.312				-2,471	-34,969	-37,441				-771	-10,904	**-11,674**
21	0.294				-2,471	-34,969	-37,441				-727	-10,286	**-11,013**
21.12	0.292		-48,000				-48,000		-14,020				**-14,020**
22	0.278				-2,471	-34,969	-37,441				-686	-9,704	**-10,390**
23	0.262				-2,471	-34,969	-37,441				-647	-9,155	**-9,802**
24	0.247				-2,471	-34,969	-37,441				-610	-8,637	**-9,247**
24.64	0.238		-48,000				-48,000		-11,420				**-11,420**
25	0.233			43,120	-2,471	-34,969	5,679			10,047	-576	-8,148	**1,323**
Total		**-96,000**	**-336,000**	**43,120**	**-61,784**	**-874,234**	**-1,324,899**	**-96,000**	**-160,668**	**10,047**	**-31,593**	**-447,026**	**-725,239**

Figure 13: Example of an NPV calculation over a period of 25 years [53].

All costs appear as negative values, and positive values are related to revenue. Salvage value is what is left of value at the end of the project life. Salvage value is often called residual value. The residual value, S, is calculated using equation 1 [53].

$$S = C_{rep} \cdot \frac{L_{rem}}{L_{comp}} \tag{1}$$

where C_{rep} is the replacement cost of the component [NOK] and L_{comp} is the lifetime of the component [years]. L_{rem} is the remaining lifetime of the component at the end of the project [years], and it is calculated using equation 2 [53].

$$L_{rem} = L_{comp} - (L_{proj} - R_{rep}) \tag{2}$$

where L_{proj} is the lifetime of the project. R_{rep} is the replacement cost duration [years], which is calculated using equation 3 [53].

$$R_{rep} = L_{comp} \cdot INT\left(\frac{L_{proj}}{L_{comp}}\right) \tag{3}$$

$INT()$ is a function that gives the integer value of a real number, e.g. $INT(8.61) = 8$. The purpose of this is to find the whole number of component lifetimes during the project lifetime.

The initial investment costs occur at the start of the project, or in year zero. O&M costs occur annually, and as the component has a lifetime of 3.52 years, replacement costs occur every 3.52 years.

The nominal cash flows are first inserted, then the discounted cash flows are calculated by multiplying the nominal cash flows with the discount factor. The discount factor, f_d, is calculated using equation 4 [53].

$$f_d = \frac{1}{(1+i)^N} \tag{4}$$

where i is the real discount rate and N is number of years. The discount factor is used to calculate the present value of a cash flow occurring in any year during the project life. The factor decreases with number of years, as one NOK today is worth more than one NOK in the future. The discounted factor accounts for the time value of money and not inflation. By using the real discount rate, it is assumed that the rate of inflation is the same for all costs and all costs are set to year-zero NOK [53].

The discounted cash flows are added together and can be seen in the column on the right. These are then added together to get the total NPV. The total NPV of the project is shown in red in the bottom right corner, and one can see that the project is not profitable as the value is negative.

5 Method

This thesis is a case study of an old concrete building that is to be renovated into a UNESCO World Heritage Centre representing Nærøyfjorden. The focus is on different combinations of energy technologies that either produce electricity or heat, namely heat pumps, solar thermal collectors and solar panels.

18 different combinations of heat pumps, solar thermal collectors and solar panels were investigated. The combinations were assessed based on three parameters, (1) energy savings, (2) CO_2 emissions and (3) costs, see figure 14. Energy simulations were conducted using SIMIEN, see section 5.1. A life cycle assessment (LCA) was conducted using One Click LCA, see section 5.2. Costs were found through research and used in the net present value (NPV) method, see section 5.3.

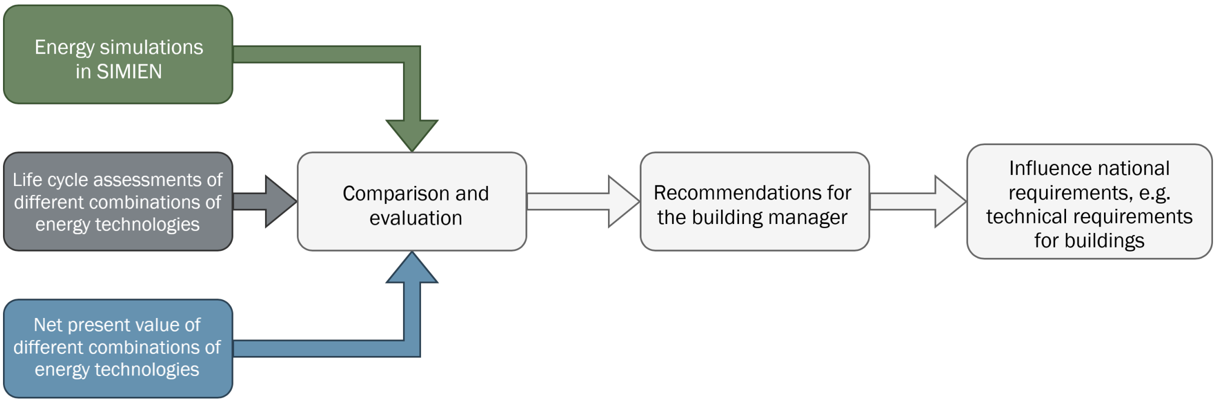


Figure 14: Flow chart showing the methods for the thesis.

An excursion to Aurland took place in the beginning of the master's thesis period. The excursion included documenting the condition of the building, and a meeting with the project leader of Nærøyfjorden World Heritage Centre, Gøran Johansen and the architects who designed the concept building. Later, a meeting was held with the project leader, Gøran Johansen, and the general manager of Nærøyfjorden World Heritage Park, Erling Oppheim.

5.1 SIMIEN

SIMIEN was be used to find the net delivered energy [kWh] for the different combinations of energy technologies. SIMIEN is a building simulation software developed by the Norwegian company Programbyggerne. The program has multiple simulation configurations, among others: evaluation according to the Norwegian building regulations (TEK), evaluation according to Norwegian passive house or low energy requirements (NS3700/NS3701), and profitability calculations [54].

The existing building and the concept building were modelled in SIMIEN with TEK17 standards. This was done in cooperation with the two other master's students. The input data and results from the simulation of the existing building are not included in the thesis. Several models were made, starting with the base model, i.e. the concept building with TEK17 standards using only an electric boiler for energy supply. Then, the concept building was modelled with 18 different combinations of energy technologies.

5.1.1 Base Case - Concept Building With an Electric Boiler and Underfloor Heating

The concept building designed by MAD Architects was modelled in SIMIEN with TEK17 standards. To be able to compare the different combinations of energy technologies in section 6.1.2, the base model was changed to use only electricity from the grid as an energy source.

Since the existing building is going to be completely renovated, it will be a natural solution to add underfloor heating. This solution spreads heat evenly throughout the building, and it can be used for heat pumps and solar thermal collectors as well. The electric boiler and underfloor heating were therefore chosen to be used in the base case.

Various design choices were made in SIMIEN. An electric boiler from after 1995 was chosen. The distribution was set to be waterborne, with normally insulated pipes and low temperatures of 35-45 °C. A low temperature was chosen as this results in a higher distribution efficiency. Waterborne underfloor heating on an insulated cover with heat distribution, TEK07, was chosen. TEK07 was chosen, as the other options were older versions of TEK. Table 3 shows the efficiencies for the electric system, as well as COP, as a result of the choices made above.

Table 3: Efficiencies and COP for the electric boiler, as a result of input choices.

Electricity	Value
System efficiency space heating	0.87
System efficiency DHW	0.97
System efficiency heating coils	0.89
COP space cooling	2.40
COP cooling coils	2.50

For the 18 models including various combinations of energy technologies, only the peak load, 10% of the energy, will be covered by an electric boiler.

5.1.2 Input Data for the Concept Building

The following input data were not changed for the different models. The building category was set to cultural building. Table 4 shows general information about the concept building. Table 5 shows information about the doors on the north east (NE) wall, and table 6 shows information about the walls and windows of the NE wall. The tables concerning the NE side of the building were included to give an overview of what input data are needed in SIMIEN. Tables with information about the south east (SE), north west (NW) and south west (SW) walls, basement, internal loads, heating and ventilation can be found in appendix A.

Table 4: Information about the concept building.

Building	Value	Reasoning/reference
Heated floor area [m^2]	1516.8	Measured from drawing
Heated air volume [m^3]	5547.2	Calculated with values and measurements from drawing
Leakage number [1/h]	0.8	TEK17: § 14-3 (1) a) [55]
Shielding class	Moderate	Educated assumption
Facade situation	More than one wind exposed facade	Educated assumption
Furniture/interior [Wh/m^2K]	2	Educated assumption
Operating days	All days	Educated assumption
Cold bridge [W/m^2K]	0.09	TEK17: § 14-3 (2) [55]

Table 5: Information about doors on the NE wall of the concept building.

North east, NE			Value	Reasoning/reference
Door 1	Number of (equal) doors		1	Counted from drawing
	Door size	Width [m]	1	Measured from drawing
		Height [m]	2.3	Measured from drawing
		Area [m^2]	2.3	Calculated from drawing
	Heat loss properties	Custom total U-value for the door construction [W/m^2K]	1.2	TEK17: § 14-3 (1) a) [55]
Door 2	Number of (equal) doors		1	Counted from drawing
	Door size	Width [m]	1	Measured from drawing
		Height [m]	2.5	Measured from drawing
		Area [m^2]	2.5	Calculated from drawing
	Heat loss properties	Custom total U-value for the door construction [W/m^2K]	1.2	TEK17: § 14-3 (1) a) [55]
Door 3	Number of (equal) doors		1	Counted from drawing
	Door size	Width [m]	1	Measured from drawing
		Height [m]	2.1	Measured from drawing
		Area [m^2]	2.1	Calculated from drawing
	Heat loss properties	Custom total U-value for the door construction [W/m^2K]	1.2	TEK17: § 14-3 (1) a) [55]

Table 6: Information about walls and windows on the NE wall of the concept building.

North east, NE			Value	Reasoning/reference
Outer wall	Total area [m^2]		187.9	Calculated from drawing
	Construction	U-value [W/m^2K]	0.3	Calculated using 0.7 for glass, 0.22 for wall and 0.2 for walls against terrain
		Heat storage in inner layer	13	From SIMIEN: Lettklinker
	Orientation [°]		45	Drawing
Large windows	Number of (equal) windows		6	Counted from drawing
	Window size	Width [m]	1.43	Measured from drawing
		Height [m]	1.50	Measured from drawing
		Width/height window sill and frame	0.05	Assumed value
	Heat loss properties	Custom total U-value for the window construction [W/m^2K]	1.2	TEK17: § 14-3 (1) a) [55]
	Heat gain properties	Variable, manually controlled sun protection	0.38 (active) 0.51 (inactive)	Two layer glass. The inner one is an energy saving glass
Small windows	Number of (equal) windows		2	Counted from drawing
	Window size	Width [m]	1.40	Measured from drawing
		Height [m]	1.05	Measured from drawing
		Width/height window sill and frame	0.05	Assumed value
	Heat loss properties	Custom total U-value for the window construction [W/m^2K]	1.2	TEK17: § 14-3 (1) a) [55]
	Heat gain properties	Variable, manually controlled sun protection	0.38 (active) 0.51 (inactive)	Two layer glass. The inner one is an energy saving glass
Long window	Number of (equal) windows		1	Counted from drawing
	Window size	Width	0.5	Measured from drawing
		Height	2.5	Assumed standard height
		Frame: share of area	0.05	Calculated from drawing
	Heat loss properties	Custom total U-value for the window construction [W/m^2K]	1.2	TEK17: § 14-3 (1) a) [55]
	Heat gain properties	Variable, manually controlled sun protection	0.38 (active) 0.51 (inactive)	Two layer glass. The inner one is an energy saving glass

5.1.3 Solar Energy - Area and Angle of Roof

On this building, solar thermal collectors and solar panels can either be placed on the NW side or the SE side of the roof, see figure 2 in section 1.2. There is a mountain to the south of the building, which might cast a shadow on the building, especially in the winter months. To find the optimal location of the solar thermal collectors and solar panels, Suncurves [56] was used to find the terrain profile surrounding the building, see figure 15. From this figure, one can see that the sun goes down in the west during March equinox, and that the SE side of the roof is much better than the NW side. As the figure shows, placing the solar thermal collectors and solar panels on the NW side will result in no solar radiation reaching the collectors/panels during March equinox.

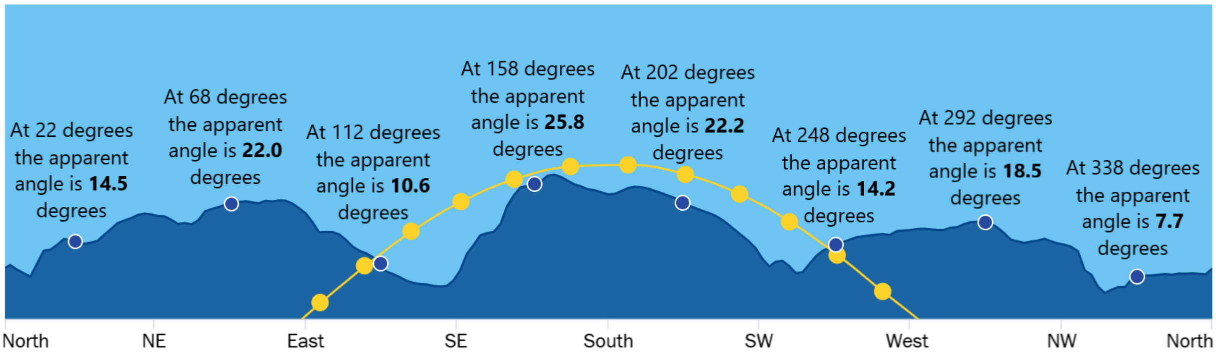


Figure 15: Terrain profile surrounding the building. The yellow curve shows the trajectory of the sun during March equinox, 20 March 2021 [56].

Solar thermal collectors and solar panels will be placed where the original roof was, and not on the extended roof made of glass, see figure 2. The total area of the SE side of the original roof is 190 m^2. However, they plan to make two large windows on each side of the roof. The area of the SE roof, excluding the roof above the windows and the small windows in between, is approximately 140 m^2. This number is calculated from the area of the existing roof minus the area which is removed to add windows, 50 m^2. The new roof area above the large windows is slightly smaller, 42 m^2. It is assumed that the whole roof can be utilised, 182 m^2. The angle of the main roof is 31°, and the angle of the roof above the large windows is 0°.

5.1.4 Dimensioning Solar Thermal Collectors

Solar thermal collectors should be prioritised over heat pumps, as mentioned in section 3.2.1. How the heating capacity is distributed between the different energy technologies was therefore found by dimensioning the solar thermal collector system first.

The load duration curve for the heating system and heating coils (ventilation), see figure 16, were added together. The total load duration curve for heating is seen in figure 17. The heating system is assumed to only include space heating and not DHW. This is because the DHW heating in SIMIEN is constant, and the total curve would therefore not end at 6,500, but at 8,760 hours. The heating demand for space heating and heating coils is zero for the rest of the year. The curve was used to find the needed power of the solar thermal collectors, heat pumps and electric heating to cover a certain percentage of the heating demand.

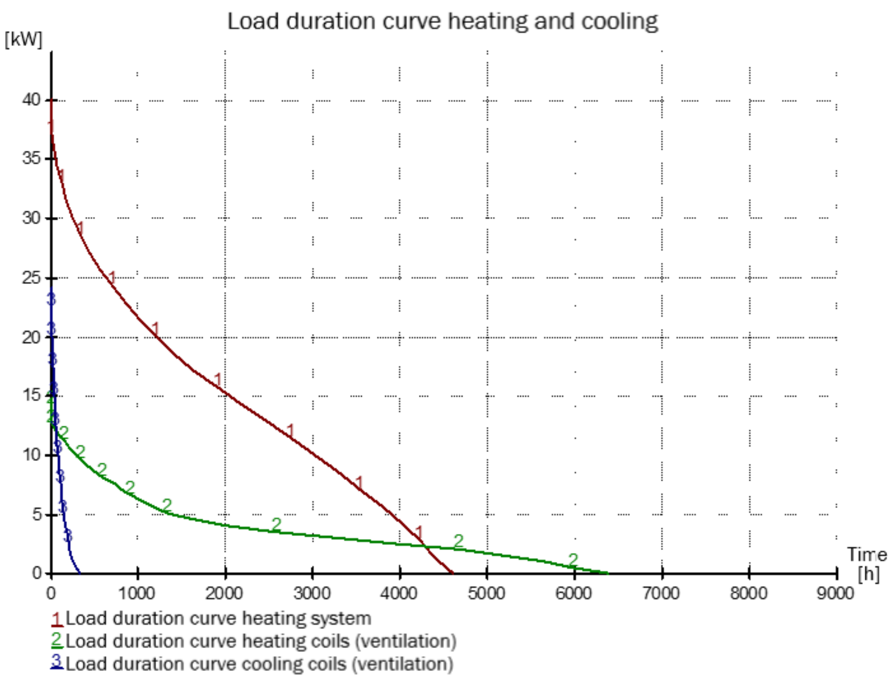


Figure 16: Load duration curve for the heating system, heating coils and cooling coils.

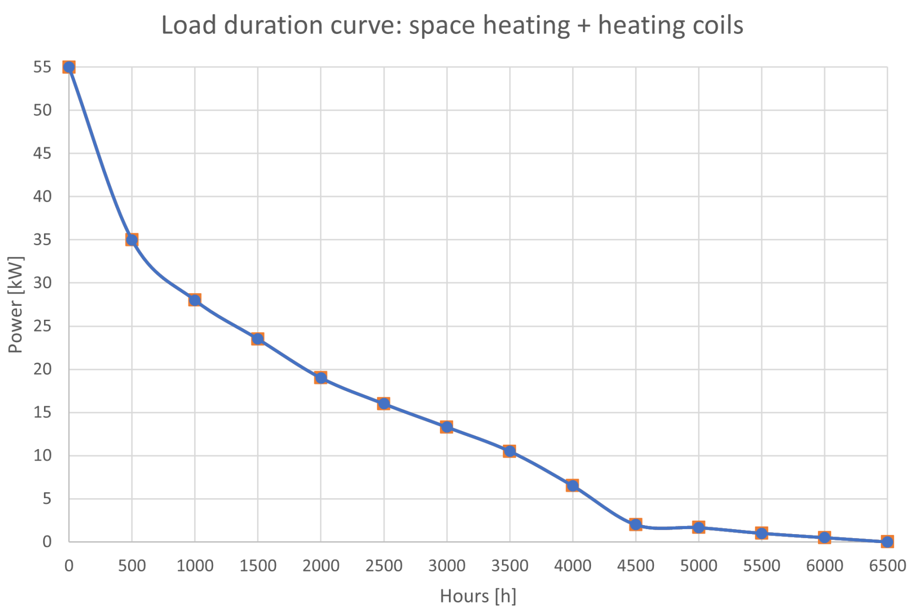


Figure 17: Load duration curve for space heating and heating coils combined.

For solar thermal collector systems that deliver heat to DHW and space heating, it is normal to dimension for a coverage of 30% of the energy demand, as mentioned in section 3.2.1. The solar thermal collector system was therefore dimensioned to cover 30% of the energy needed for space heating, DHW and heating coils. Heat pumps were set to cover 60% of the energy demand for space heating, DHW and heating coils. An electric boiler was set to cover the peak load, 10% of the energy demand.

The power needed for DHW is not included in the load duration curve, but DHW is even throughout the year. The power needed for DHW was set to 1.92 W/m^2, taken from SN-NSPEK 3031:2020, table A.2 [57]. With a heated gross internal area of 1,517 m^2, this gives 2.9 kW. Table 7 shows the power needed for space heating and heating coils, the power needed for DHW and the total power needed from each energy source to cover the heating demand.

Table 7: Power needed from the different energy sources to cover a certain percentage of the heating demand for space heating, heating coils and DHW.

	Percentage covered by source [%]	**Energy demand [kWh]**	**Power needed for space heating and heating coils [kW]**	**Power needed for DHW [kW]**	**Total power needed for heating [kW]**
Solar thermal	30	27,669	5.90	0.87	6.77
Heat pumps	60	55,338	23.43	1.74	25.2
Electric energy	10	9,223	25.67	0.29	26.0
Total	100	92,230	55.00	2.9	57.9

Figure 18 shows the load duration curve with 10% of the energy for space heating and heating coils covered by electric energy, 60% covered by heat pumps and 30% covered by solar thermal collectors.

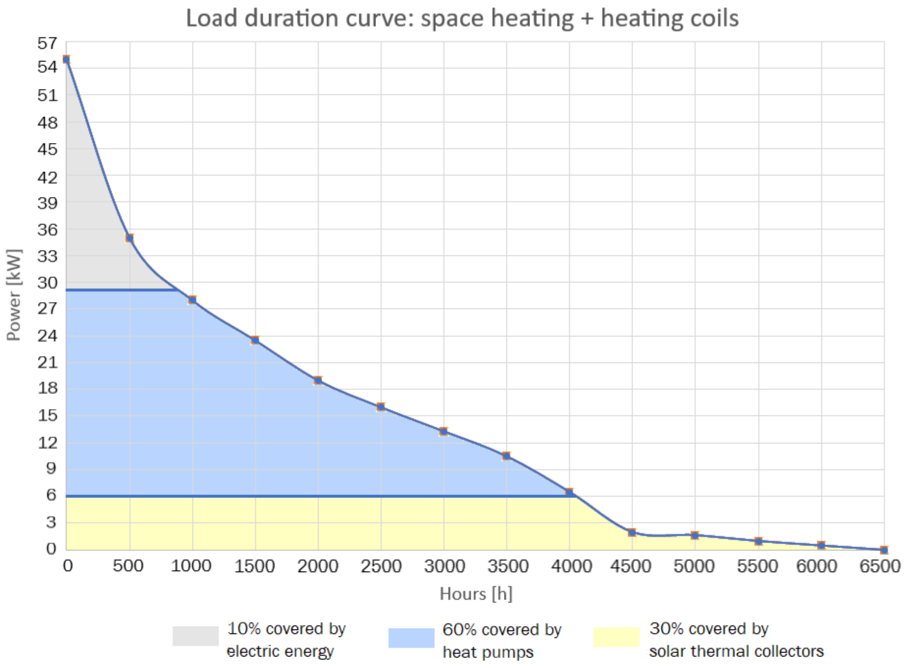


Figure 18: Load duration curve for space heating and heating coils with energy coverage marked.

To find the needed area of solar thermal collectors to get 6.77 kW and 30% coverage, the solar radiation for the SE roof, see figure 19, and the efficiency of the solar thermal collectors were used. The efficiency of the evacuated tube collectors was set to 58% and the efficiency of the flat plate collectors to 42%, as mentioned in section 3.2.

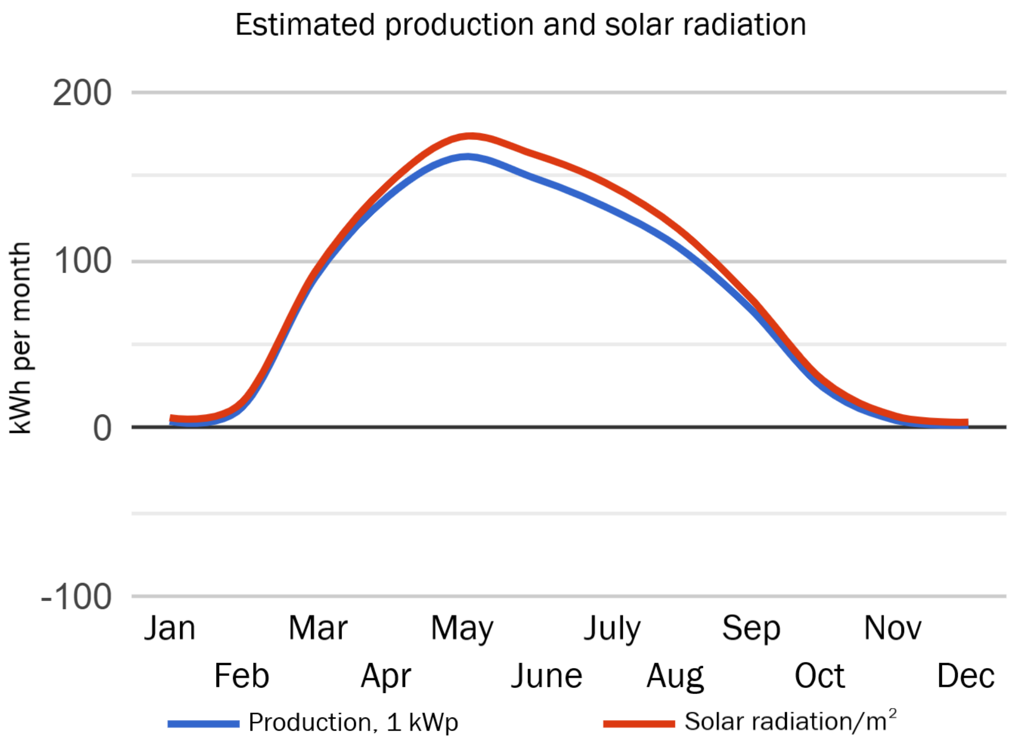


Figure 19: Solar radiation for the SE roof [58], translated to English by author.

Table 8 shows the results for the evacuated tube collector with an efficiency of 58%. The second column shows the solar radiation from figure 19. This is multiplied with hours per month to get power in per m^2. The power in is then multiplied with the efficiency of the solar thermal collector to get power out. The area was adjusted to get the average total power as close to 6.77 kW as possible. This resulted in a needed area of 104 m^2 of evacuated tube collectors. The same was done for the flat plate collectors, and the needed area was then 144 m^2. The larger area is due to the flat plate collectors' lower efficiency.

Solar thermal collectors and solar panels were tested in SIMIEN to find which one gives the lowest energy consumption, and thus which one should be prioritised. One model was made with solar thermal collectors covering 30% of the heating demand for space heating, DHW and heating coils. Another model was made with 144 m^2 of standard solar panels with an angle of 31°. For both cases, the remaining energy demand was covered by electric energy. The flat plate collectors with an efficiency of 42% gave energy savings 2.8 times larger than the standard solar panels with an efficiency of 18%. The recommended coverage of 30% from solar thermal collectors was therefore seen as the best solution from an energy saving perspective.

Table 8: Area needed to get 6.77 kW from evacuated tube collectors.

Month	**Solar radiation** [kWh/m^2 per month]	**Hours per month**	**Power in** [W/m^2]	**Power out** [W/m^2]	**Area** [m^2]	**Total power** [kW]
Jan	6.32	744	8	5	104	0.5
Feb	15.67	672	23	14	104	1.4
Mar	93.03	744	125	73	104	7.5
Apr	144.79	720	201	117	104	12.1
May	173.5	744	233	135	104	14.1
June	163.44	720	227	132	104	13.7
July	146.23	744	197	114	104	11.9
Aug	118.88	744	160	93	104	9.6
Sep	77.62	720	108	63	104	6.5
Oct	28.57	744	38	22	104	2.3
Nov	7.21	720	10	6	104	0.6
Dec	3.63	744	5	3	104	0.3
					Average kW:	6.71

The roof is approximately 182 m^2. 104 or 144 m^2 will be covered by solar thermal collectors depending on the type of collectors being used. The remaining space will be used for solar panels, 78 or 38 m^2. For the flat plate collectors, there is not enough space on the roof with a 31° angle. The space above the large windows therefore has to be utilised to get a 30% coverage from solar thermal collectors. For combinations using the entire roof area, it was assumed that solar panels are placed on the roof with a 31° angle or that the panels are tilted to that angle.

5.1.5 Solar Thermal Collectors - Input SIMIEN

In SIMIEN, there are three options for production efficiency of solar thermal collectors. One can also insert values manually. The best efficiency in SIMIEN is 60% and the worst is 40%. This was adjusted to 58% for the evacuated tube collectors and to 42% for the flat plate collectors, as mentioned in section 3.2.

As for the fully electric system, the distribution was chosen to be waterborne, with normally insulated pipes and low temperatures of 35-45 °C. Waterborne underfloor heating on an insulated cover with heat distribution, TEK07, was chosen. Table 9 shows the efficiencies and COP for the evacuated tube collector, as a result of the choices made above. Table 10 shows the same for the flat plate collector.

Table 9: Efficiencies and COP for the evacuated tube collector, as a result of input choices.

Evacuated tube collector	Value
System efficiency space heating	51.78
System efficiency DHW	58.00
System efficiency heating coils	53.43
COP space cooling	2.40
COP cooling coils	2.50

Table 10: Efficiencies and COP for the flat plate collector, as a result of input choices.

Flat plate collector	Value
System efficiency space heating	37.50
System efficiency DHW	42.00
System efficiency heating coils	38.69
COP space cooling	2.40
COP cooling coils	2.50

5.1.6 Heat Pumps

As the building is located around 15 m from the fjord, it could be beneficial to utilise heat from the fjord in the heat pumps. By utilising heat from the fjord, one could install (1) a water-to-water heat pump that heats water needed for DHW and/or for space heating, or (2) a water-to-air heat pump that heats the indoor air. A water-to-air heat pump will not be investigated in this thesis, as it cannot be used in combination with underfloor heating. As water-to-water heat pumps can be expensive, an air-to-water heat pump will also be investigated. Air-to-water heat pumps are easier to install and cost less than water-source heat pumps [59].

To cover 60% of the heating demand when the heat pump is in combination with solar thermal collectors, the heat pump must have a heating capacity of 25 kW, see table 7. To cover 90% of the heating demand, in combinations without solar thermal collectors, the heat pumps must have a heating capacity of 32 kW.

5.1.7 Heat Pumps - Input SIMIEN

The water-to-water heat pump was chosen to be a brine-to-water heat pump at 35 °C/28 °C, with heat from soil, ground, water or waste heat. The air-to-water heat pump was chosen to be 35 °C/28 °C with heat from outdoor air. Again, low temperatures were chosen as this results in the highest efficiencies.

The distribution was chosen to be the same as for the base case with only electric energy and for the solar thermal collectors. Tables 11 and 12 show efficiencies and COP for the water-to-water heat pump and the air-to-water heat pump, respectively.

Table 11: Efficiencies and COP for the water-to-water heat pump, as a result of input choices.

Water-to-water heat pump	Value
System efficiency space heating	2.95
System efficiency DHW	3.30
System efficiency heating coils	3.04
COP space cooling	2.40
COP cooling coils	2.50

Table 12: Efficiencies and COP for the air-to-water heat pump, as a result of input choices.

Air-to-water heat pump	Value
System efficiency space heating	2.32
System efficiency DHW	2.60
System efficiency heating coils	2.40
COP space cooling	2.40
COP cooling coils	2.50

5.1.8 Solar Panels - Input SIMIEN

The apparent angles for the terrain in figure 15 and the area of the solar panels were entered into SIMIEN. For combinations without solar thermal collectors, the area of solar panels was set to 182 m^2. In combination with evacuated tube collectors, the area was set to 78 m^2, and in combination with flat plate collectors, the area was set to 38 m^2.

Two types of solar panels were investigated, one standard type as well as solar shingles that resemble and replace normal roof tiles. The only differing input between the two types is the efficiency of the solar panels. The automatic input for efficiency in SIMIEN is 18%, and this value was therefore used for standard solar panels. The solar shingles have an efficiency of 14%, which was calculated from the technical data sheet found in appendix B. The basic solar shingle has a nominal output of 108 W_p and is 0.757 m^2. This gives 142.7 W/m^2 at standard test conditions (STC), and an efficiency of 14.27%. The different shingles have different electrical properties listed in the technical data sheet. This is only due to the difference in size and thus number of photovoltaic cells.

Power loss for the panels is automatically set to 0.89 in SIMIEN. This means that it loses 11% due to temperature conditions, sun intensity, cabling etc. Power loss for the inverter is loss due to transformation to 230 V and is automatically set to 0.95, which means that 5% is lost. These numbers were used in the simulations for both types of solar panels. The average efficiency of the solar panel systems can be found by multiplying the efficiency at STC with the two power loss factors.

5.1.9 Different Combinations of Energy Technologies

18 different combinations were modelled in SIMIEN. First, using only heat pumps, then using heat pumps in combination with solar panels or solar thermal collectors, and lastly using a combination of all three energy technologies.

10% of the energy needed for heating and cooling is always covered by an electric boiler. The design choices for the electric system are the same as for the base case, see section 5.1.1. The electric boiler also covers 100% of the energy needed for electricity. For the models using an electric boiler and heat pumps only, the energy coverage from heat pumps was set to 90% for heating and cooling. For the models using heat pumps and solar panels, the energy coverage from heat pumps was still set to 90% for heating and cooling. Solar panels do not contribute to covering the heating and cooling demand, but the electricity produced from the panels reduces the amount of electricity delivered from the grid.

The energy coverage factors for systems including solar thermal collectors were based on section 5.1.4 and table 7. For all the models using heat pumps and solar thermal collectors, with or without solar panels, the energy coverage from heat pumps was set to 60% for heating and 90% for cooling. The energy coverage from solar thermal collectors was set to 30% for heating and 0% for cooling, as solar thermal collectors cannot contribute with cooling.

5.1.10 Methodological Reflections

Simplifications have been made when modelling the concept building. For example, the building consists of the existing building with a glass facade added to the NW and SW sides. On these sides, only the outer glass walls were included and used when calculating the U-value of the walls. The walls of the existing building inside the concept building were not included in SIMIEN.

The performance efficiencies of solar thermal collectors were changed from 60 and 40% to 58 and 42% in SIMIEN. This was done because the average efficiency is around 0.58 for evacuated tube collectors and 0.42 for flat plate collectors, as mentioned in section 3.2. This is however the efficiency of solar radiation conversion and not the performance efficiency. The change is small, so it might not significantly influence the results. However, if the values from SIMIEN are used instead, the evacuated tube collector would have slightly better results from the energy simulations, and the flat plate collector slightly worse results.

5.2 Life Cycle Assessment

An LCA was conducted to find emissions related to energy, materials, replacements, transport and end-of-life for the different combinations. The tool One Click LCA was used to conduct the assessment.

5.2.1 General Input

The calculation period and the required service life of the building were set to 50 years, as the lifetime of a building is often assumed to be 50 years [60, p. 873]. The component lifetime was set to 25 years for solar panels [61] [62, p. 95], 25 years for solar thermal collectors [62, p. 183], 20 years for the water-to-water heat pump, and 15 years for the air-to-water heat pump [52]. The lifetime of the electric boiler was assumed to be 30 years. The calculation period and the component lifetime affect the number of replacements needed and thus the emissions related to replacements. The gross internal floor area of the building is 1,517 m^2, and this was inserted in the program.

It was assumed that all energy technologies are manufactured in Germany and that they are transported the shortest and fastest route to Norway. It was also assumed that the technologies are transported by semi-trailers from Germany to a storage facility in Oslo, and then by a large delivery truck with a capacity of 9 metric tons from Oslo to Aurlandsvangen. The fasted route from Germany to Oslo includes a ship from Hirtshals to Larvik. Here, a distance of 163 km was filled in, as well as the weight of the different energy technologies.

The net delivered energy for the different combinations of energy technologies was filled in. According to One Click LCA, the emission factor for electricity in Norway is 31.1 g CO_2e/kWh.

5.2.2 Solar Panels

The energy technologies were added into One Click LCA. When a specific product has not been chosen and one wants to conduct a life cycle assessment, one should opt to use local generic data. If the local data is not suitable or available, one can use generic data from other countries. It is also possible to choose other manufacturer specific data if no local data is available [63]. The options in One Click LCA are limited, and the options considered to be the best match were therefore chosen. Following are the choices made and reasons for these choices. After finding the best fitting options for the different energy technologies, the options were inserted into the 18 combinations. The CO_2 equivalents (CO_2e) mentioned below are the total impact for all life cycle stages per component.

For solar panels, the option "solar panel photovoltaic system, EU average" from Norway was used, as it was assumed that the solar panels are manufactured in Europe. This was used for both the standard solar panels and the solar shingles. The solar shingles were set to be transported from Switzerland instead of Germany, as the type used in this thesis is manufactured in Switzerland. This option results in 0.36 tons of CO_2e/m^2 for both types of solar panels. The different transportation distances did not impact the number.

Other local generic options available are "Solar panel photovoltaic system, Finland average" and "Solar panel photovoltaic system, 3,000 W_p (Gaia Solar)". Both of these resulted in 0.43 tons of CO_2e/m^2 when the transportation distance was set the same as above. These were however not used.

5.2.3 Solar Thermal Collectors

For the evacuated tube collectors, the option "vacuum solar tube" from Germany was chosen, and the area covered by solar thermal collectors was inserted. For the flat plate collector, the option "flat solar thermal collector" from Germany was chosen, and the area was once again inserted. The option chosen for the evacuated tube collector results in 0.22 tons CO_2e/m^2, and the option for the flat plate collector results in 0.21 tons CO_2e/m^2.

There was one more option for solar thermal collectors in One Click LCA, called "Solar thermal collector, Donnee par default (MDEGD)". This option was not used as the description and the environmental product declaration (EPD) are in French, and it is uncertain which type of solar thermal collector it represents.

The emissions related to the underfloor heating and hot water tank are not included in emissions for solar thermal collectors nor in emissions for heat pumps. The reason for this is that the underfloor heating and hot water tank are needed for the electric boiler, regardless of whether solar thermal collectors or heat pumps are installed.

5.2.4 Heat Pumps

The heat pumps should be 25 kW or 32 kW depending on whether it should cover 60 or 90% of the heating demand, as mentioned in section 5.1.6. Ideally, these two heat pumps would be different when conducting the LCA. However, the closest option in One Click LCA when it comes to rated power for water-to-water heat pumps was in both cases “Heat pump, water/water, for collective housing, P = 30 kW, Donnee par default (MDEGD)” from France. The description and EPD of this option are in French, and there are thus uncertainties concerning what this option includes.

Another option, “Electric heat pump (water-water), 20 kW” from Germany, has a description in English where it seems like pipework is included. However, there is also an option “Pipework for electric heat pump (water-water), 20 kW” also from Germany, which seems to be related to the 20 kW heat pump. One unit of the heat pump results in 0.61 tons of CO_2e, while one unit of the pipework results in 0.36 tons of CO_2e. In total, this is 0.97 tons of CO_2e. The chosen 30 kW option results in 2.4 tons of CO_2e, and it is therefore assumed that this option includes pipework.

For the air-to-water heat pump, there was one option with a rated power of 40 kW. Another option was to use two heat pumps with a rated power of 14 kW each. The first option had CO_2e emissions four times as large as the second option, and the second option, with two smaller heat pumps from Germany, was therefore chosen. Using the two smaller heat pumps results in 2.7 tons of CO_2e. This is not an ideal option, as emissions from manufacturing two heat pumps might differ from manufacturing one larger heat pump. Even when choosing the air-to-water heat pump with the lowest emissions, the air-to-water heat pump still has larger emissions related to materials than the water-to-water heat pump.

5.2.5 Electric Boiler

Emissions related to the electric boiler were also investigated. An electric boiler with rated power of 25 kW was added to all the combinations; this equals 10% energy coverage. The option “Electric boiler, per 1kW / unit - beta” was used. This option is local generic data, but it is a beta version and should only be used when no other information is available. This is however the only option for an electric boiler in One Click LCA. It was assumed that the boiler is transported from Germany and that it takes the same route as the other energy technologies. The weight of the boiler was inserted where the transport by ship was added.

Emissions related to the base case with an electric boiler covering the entire energy demand were also investigated. The size of the boiler was set to 58 kW, and the weight of the boiler was again inserted into the ship transportation. The option is calibrated to fit boilers between 13 to 30 kW, and there are therefore uncertainties about the emissions related to the 58 kW electric boiler.

5.2.6 Methodological Reflections

The options in One Click LCA are limited, and finding an option that fits perfectly with the energy technology can be hard. This can lead to uncertainties when it comes to emissions and comparing the combinations against each other. For example, the same option was chosen for both the standard solar panels and the solar shingles. Emissions related to these panels and the difference between them might therefore not be accurately represented. Local generic data were chosen where available. Other generic data were used when local data were not available or suitable.

Some of the options have little information, or information in a foreign language, and assumptions have been made concerning this. For example, emissions related to materials for the water-to-water heat pump are lower than for the air-to-water heat pump. This can indicate that not everything is included in the option chosen for the water-to-water heat pump.

In One Click LCA, electricity is said to emit 31.1 g CO_2e/kWh, see section 5.2.1. This is quite high compared to what was found in section 3.4, 17 g CO_2e/kWh. This means that the calculated emissions might not be accurate. The many uncertainties in One Click LCA could influence the final results and should be taken into consideration.

To be able to conduct an LCA without all these limitations and uncertainties, one would need to decide on a specific component and find this component in the database. Alternatively, one could find information on materials, production, transportation, maintenance, replacements and end-of-life from the manufacturer and distributor. This is however too laborious for a master's thesis covering more than just emissions, but it could be beneficial before making final choices for the project.

5.3 Costs

The original plan was to use Holte SmartKalk to calculate the costs of the different combinations of energy technologies. SmartKalk is the leading calculation system used in the construction industry [64]. However, costs related to energy technologies were lacking in the database. Costs were therefore found through research and used in the NPV method, as explained in section 4.2.

5.3.1 Electricity Prices

NVE's prediction for future electricity prices was used to calculate an average for the next 50 years, see section 4.1. The electricity price is assumed to increase linearly between 2022-2025 and 2025-2030, and that it will continue to increase linearly from 2030 to 2071, see figure 12. This might not be correct, as future electricity prices are uncertain and many factors affect the electricity price. The electricity price for the year 2071 was calculated using linear regression and was found to be 47.2 øre/kWh. The average for the next 50 years was then calculated, 42.64 øre/kWh.

NVE's report does not include grid rent. The average grid rent, including taxes, for the last five years was therefore added to the electricity price to get the total price. This was calculated to be 55.02 øre/kWh [65], and the total price of electricity is thus 97.66 øre/kWh.

5.3.2 General Input

The lifetime of the project was set to 50 years, as this is the expected lifetime of the building [60, p. 873]. The real discount rate was assumed to be 5% [53]. Investment costs, including installation, were inserted into year zero. Replacement costs were inserted for each energy technology after its lifetime. O&M costs were added annually for the energy technologies requiring maintenance. The residual value of each energy technology was added at the end of the 50 years. The residual value was calculated using equations 1, 2 and 3 from section 4.2. The electricity price was set to 0.9766 NOK/kWh, as calculated above. Electricity saved and benefits were inserted into the calculation. Benefits are saved electricity multiplied with the electricity price.

Enova SF is a Norwegian state enterprise which, among other things, gives financial support to projects investing in environmentally friendly energy technologies [66]. Businesses investing in water-to-water heat pumps can get 1,600 NOK/kW, and businesses investing in solar thermal collectors can get 201 NOK/m^2 [67]. This benefit was subtracted from the initial investment cost. It is assumed that this subsidy is not going to be available when the systems must be replaced in 20-25 years, and it was therefore not included in the replacement costs. Replacement costs were assumed to be the same as the investment cost for all energy technologies, even though not all components must be replaced after the lifetime of the energy technology.

All costs were inserted as negative values, and benefits were inserted as positive values. The nominal cash flows were multiplied with a discount factor to get the discounted cash flows. The discount factor was calculated using equation 4.

5.3.3 Solar Panels

The cost of standard solar panels was found to be approximately 2,655 NOK/m^2; this was assumed to include installation. This number was calculated from NTE's price for 58 m^2 of solar panels [68]. The cost of solar shingles was found to be 1,500 NOK/m^2, with installation costs of 1,500-2,500 NOK/m^2 depending on roof complexity, scaffolding, inverter, removal of old roof etc. [69]. As the building is to be totally renovated, implementation of solar shingles will be planned before building the new roof. Removal of old roof is thus not necessary, and installation costs were therefore set to 1,500 NOK/m^2.

Solar panels have no moving parts and do not require fuel, which reduces the O&M costs to almost zero. O&M costs were therefore set to zero for both standard solar panels and solar shingles. Costs related to ordinary maintenance are negligible, and cost related to faults are generally covered by the warranty of the product [70].

The costs can vary significantly depending on brand and type of solar panel. This applies to both standard solar panels and solar shingles. This could influence the final results and should be taken into consideration.

5.3.4 Solar Thermal Collectors

The cost of a flat plate collector was found to be 7,150 NOK for 2.5 m^2. This gives 2,860 NOK/m^2. The cost of an evacuated tube collector was found to be 16,850 NOK for 1.22 m^2, which gives 13,811 NOK/m^2 [71]. These costs were assumed to include installation. O&M costs were once again set to zero as solar thermal collectors have no moving parts and do not require fuel.

Underfloor heating and a hot water tank are also necessary when only using an electric boiler. Costs for these were therefore not included in the cost for solar thermal collectors nor for the cost of heat pumps.

5.3.5 Heat Pumps

The cost of a water-to-water heat pump was found to be 1,770-4,000 EUR/kW depending on the size of the heat pump. The larger the heat pump system, the lower the cost per kW. The cost was found to be 1,259,630 NOK for a 32 kW heat pump and 997,803 NOK for a 25 kW heat pump. This was assumed to include installation [72, p. 217]. The O&M costs were set to be 2% of the investment cost per year [73]. As mentioned in section 3.3.2, O&M costs for heat pumps are generally low. 2% was therefore considered a reasonable number. However, another source states that the O&M costs for brine-to-water heat pumps are 2-22.6% of the investment cost per year, with a higher cost for smaller heat pumps [72, p. 217]. This would have resulted in O&M costs almost 10 times higher than what was used in this thesis. There are therefore large uncertainties related to the maintenance costs.

The cost of an air-to-water heat pump was found from figure 20. The specific investment cost for a 32 kW heat pump is approximately 3,400 NOK/kW. This source is from year 2000; with inflation, the total cost in 2021 is 166,464 NOK. The specific investment cost for a 25 kW heat pump is approximately 3,750 NOK/kW. With inflation, the total cost in 2021 is 143,438 NOK [74]. These costs only include the heat pump unit, and additional equipment could therefore be needed for the heat pump solution. The cost could therefore be higher. Installation costs were assumed to be 10,000 NOK [75]. The annual O&M costs were again assumed to be 2% of the investment cost [73].

The cost of the air-to-water heat pump found above fits well with another source. This source states that air-to-water heat pumps usually costs 60,000-130,000 NOK, but that there are models that cost over 170,000 NOK. The costs are for heat pumps in residential housing [75]. Heat pumps for residential housing are usually 2 to 15 kW [74]. The heat pumps in this thesis are larger than that, but still relatively small. As seen in figure 20, it is not uncommon with heat pumps up to 1 MW.

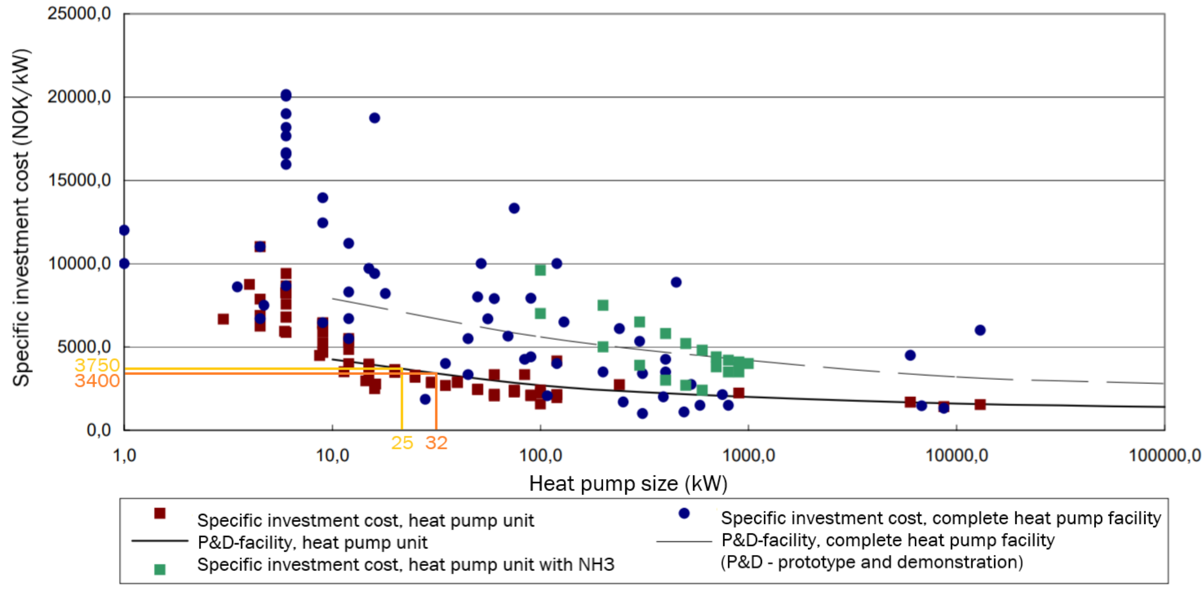


Figure 20: Costs based on prototype and demonstration (P&D) heat pumps [74], translated to English by author.

The fact that the costs of the heat pumps are estimates could influence the final results and should be taken into account. The actual costs of the heat pump systems must be found through professional consulting and by inspecting the area.

5.3.6 Electric Boiler

By adding different energy technologies to cover the base load of the building, a smaller electric boiler is needed than if the electric boiler was the only energy supply. The cost of an electric boiler was found to be 700-800 EUR/kW, with higher costs per kW for smaller boilers [72, p. 217]. By implementing other energy technologies, the size of the electric boiler could be reduced by 32 kW, which resulted in savings of 263,206 NOK every 30 years. The O&M cost for the electric boiler was assumed to be 2% [73], and the O&M cost saved on the reduced size of the electric boiler was then found to be 5,264 NOK per year. This was added to the investment costs, the yearly O&M costs and the replacement costs as positive values.

5.3.7 Methodological Reflections

Future electricity prices are uncertain. Changing the electricity price when calculating the economic savings has a large impact on the results of the profitability analysis. If the electricity price used in the thesis is lower than it actually is in the future, the combination of energy technologies will be more profitable than found in this thesis. If the price used is higher, the combinations will be less profitable than found in this thesis.

Several of the costs used in the profitability analysis are estimates. There are also uncertainties regarding O&M costs, especially for the heat pump systems. Furthermore, there are uncertainties related to the lifetimes of the different components. This could influence the final results and should be taken into consideration. Actual costs vary depending on a multitude of factors. To find the actual costs of the different combinations, professional consulting and an inspection of the area and building are required.

6 Results

This chapter contains results from the energy simulations conducted in SIMIEN, section 6.1, results from the LCA conducted in One Click LCA, section 6.2, results from the profitability analysis, section 6.3, and lastly the results from these assessments combined, section 6.4.

6.1 Results from SIMIEN

The results of the base case with an electric boiler covering the entire energy demand are presented in section 6.1.1. Section 6.1.2 contains results for the 18 combinations of energy technologies. The electric boiler is covering 10% of the energy demand in all combinations. The energy saved in the following tables is the net delivered energy for the base case minus the net delivered energy for the combination.

The results from SIMIEN for the base model and the different combinations can be seen in appendix C. These results include the energy budget showing how much energy is needed for various energy users and the delivered energy to the building.

6.1.1 Base Case: Electric Boiler and Underfloor Heating

The total annual energy demand of the building is 216.1 MWh, see appendix C. Using an electric boiler with underfloor heating without adding any renewable energy technologies, the delivered energy to the building is 228.6 MWh/year, see table 13. The reason this is higher than the energy demand is that the efficiency of the electric boiler system is below 1. The efficiency is 0.87 for space heating, 0.97 for DHW and 0.89 for heating coils. This means that the energy needed from the grid is higher than the energy demand.

Table 13: Net delivered energy for the base case with an electric boiler and underfloor heating.

Base case	**Net delivered energy [MWh/year]**
Electric boiler with underfloor heating	228.6

6.1.2 Different Combinations of Energy Technologies

Combination 1 with a water-to-water heat pump covering 90% of the energy demand resulted in energy savings of 82.5 MWh/year compared to using only an electric boiler. Combination 2 with an air-to-water heat pump gave energy savings of 73 MWh/year, see table 14. The table shows the net delivered energy and the energy saved from installing each of the two heat pumps.

The water-to-water heat pump has a higher amount of annual saved energy than the air-to-water heat pump. This coincides with the fact that the water-to-water heat pump has a higher COP than the

Table 14: Net delivered energy and energy saved for combinations 1 and 2.

	Heat pumps	**Net delivered energy [MWh/year]**	**Energy saved [MWh/year]**
1	Heat pump water-to-water	146.1	82.5
2	Heat pump air-to-water	155.6	73.0

air-to-water heat pump. This is because it utilises the fjord as a heat source, and the fjord has a stable temperature throughout the year, see section 3.3.

Table 15 shows the net delivered energy and the energy saved from installing a water-to-water heat pump or an air-to-water heat pump, with standard solar panels or solar shingles. The heat pump covers 90% of the energy demand for these four combinations, while 10% is covered by the electric boiler. The entire SE roof is covered with solar panels in these combinations, 182 m^2. The electricity produced from solar panels reduces the amount of electricity delivered from the grid, see section 5.1.9.

Table 15: Net delivered energy and energy saved for combinations 3-6.

	Heat pumps and solar panels	**Net delivered energy [MWh/year]**	**Energy saved [MWh/year]**
3	Heat pump water-to-water + standard solar panels	128.7	99.9
4	Heat pump water-to-water + solar shingles	132.6	96.0
5	Heat pump air-to-water + standard solar panels	138.2	90.4
6	Heat pump air-to-water + solar shingles	142.1	86.5

From these results, one can see that the standard solar panels are better than solar shingles from an energy perspective. This was expected as the only differing input is the efficiency of the solar panels, see section 5.1.8.

Table 16 shows the net delivered energy and the energy saved from installing a water-to-water heat pump or an air-to-water heat pump, with evacuated tube collectors or flat plate collectors. The heat pump covers 60% of the heating demand and the solar thermal collectors cover 30%. The heat pump covers 90% of the cooling demand, see section 5.1.9.

From this table, one can see that the evacuated tube collectors are better than flat plate collectors from an energy perspective. This coheres with the only differing input being their performance efficiencies, see section 5.1.5. However, the difference is small between the two solar thermal collectors.

Table 16: Net delivered energy and energy saved for combinations 7-10.

	Heat pumps and solar thermal collectors	**Net delivered energy [MWh/year]**	**Energy saved [MWh/year]**
7	Heat pump water-to-water + evacuated tube collectors	135.8	92.8
8	Heat pump water-to-water + flat plate collectors	136.1	92.5
9	Heat pump air-to-water + evacuated tube collectors	141.7	86.9
10	Heat pump air-to-water + flat plate collectors	142.0	86.6

Table 17 shows the net delivered energy and the energy saved from installing a water-to-water heat pump or an air-to-water heat pump, with evacuated tube collectors or flat plate collectors, and standard solar panels or solar shingles.

Table 17: Net delivered energy and energy saved for combinations 11-18.

	Heat pumps, solar thermal collectors and solar panels	**Net delivered energy [MWh/year]**	**Energy saved [MWh/year]**
11	Heat pump water-to-water + evacuated tube collectors + standard solar panels	128.3	100.2
12	Heat pump water-to-water + evacuated tube collectors + solar shingles	130.0	98.6
13	Heat pump water-to-water + flat plate collectors + standard solar panels	132.4	96.2
14	Heat pump water-to-water + flat plate collectors + solar shingles	133.2	95.4
15	Heat pump air-to-water + evacuated tube collectors + standard solar panels	134.2	94.3
16	Heat pump air-to-water + evacuated tube collectors + solar shingles	135.9	92.7
17	Heat pump air-to-water + flat plate collectors + standard solar panels	138.3	90.3
18	Heat pump air-to-water + flat plate collectors + solar shingles	139.1	89.5

Once again, the heat pump covers 60% of the heating demand and 90% of the cooling demand, and solar thermal collectors cover 30% of the heating demand. Solar panels cover 78 or 38 m^2 of the SE roof for combinations with evacuated tube collectors and flat plate collectors, respectively. The electricity from solar panels reduces the amount of electricity delivered from the grid.

From table 17, one can see that combination 11 with a water-to-water heat pump, evacuated tube collectors and standard solar panels is the best from an energy perspective. Combination 11 saves 43.9% of the energy needed in the base case. Combination 2, which has the lowest energy savings, saves 31.9%.

6.2 Results from One Click LCA

All emissions related to the different combinations are shown in figure 21. The emissions are for the entire calculation period or service life of the building, which was set to 50 years, see section 5.2.1. Combination 0 is the base case with an electric boiler covering the entire energy demand of the building. Combinations 1-18 all include a smaller electric boiler covering 10% of the energy demand.

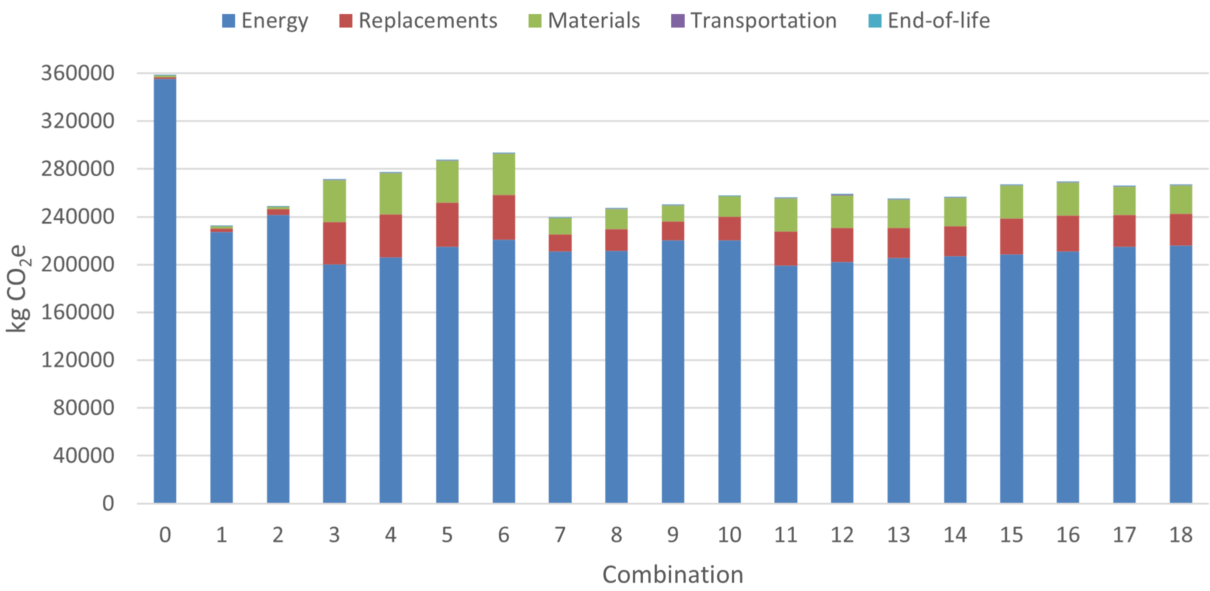


Figure 21: Emissions related to energy, replacements, materials, transportation and end-of-life for all combinations, including the base case, combination 0.

Emissions related to energy come from the net delivered electricity with a greenhouse gas emission factor of 31.1 g CO_2e/kWh. Combinations with a large reduction in energy consumption thus have lower emissions related to energy. Emissions related to materials are emissions from construction of new components at the start of the calculation period, while emissions for replacements are from replacing the components after their lifetime. Emissions related to transportation of the components include all transportation, with a semi trailer, a ship and a large delivery truck. Emissions related to end-of-life are emissions from handling the components after their lifetime. This includes deconstruction, transport to waste processing, waste processing and disposal.

From figure 21, one can see that emissions are highest for the base case, primarily due to a higher net delivered energy than for the other combinations. Emissions related to energy are the primary source of CO_2e for all combinations. Materials and replacements also have notable emissions, especially for combinations with solar panels and/or solar thermal collectors. Combination 1 with only a water-to-water heat pump has the lowest emissions out of all the combinations. However, the emissions are over a period of 50 years, and the difference between the best and worst options is therefore small.

Emissions related to transport and end-of-life are negligible compared to energy, replacements and materials. These are therefore not included in the following figures. Figures showing emissions related to transport and end-of-life for all combinations can be found in appendix D.

Figure 22 shows emissions related to combinations 1 and 2.

1	Heat pump water-to-water
2	Heat pump air-to-water

The water-to-water heat pump comes out better than the air-to-water heat pump when it comes to emissions. The main source of emissions is related to production of electric energy. Installing the water-to-water heat pump results in a lower net delivered energy than the air-to-water heat pump, and the emissions are therefore lower for the water-to-water heat pump.

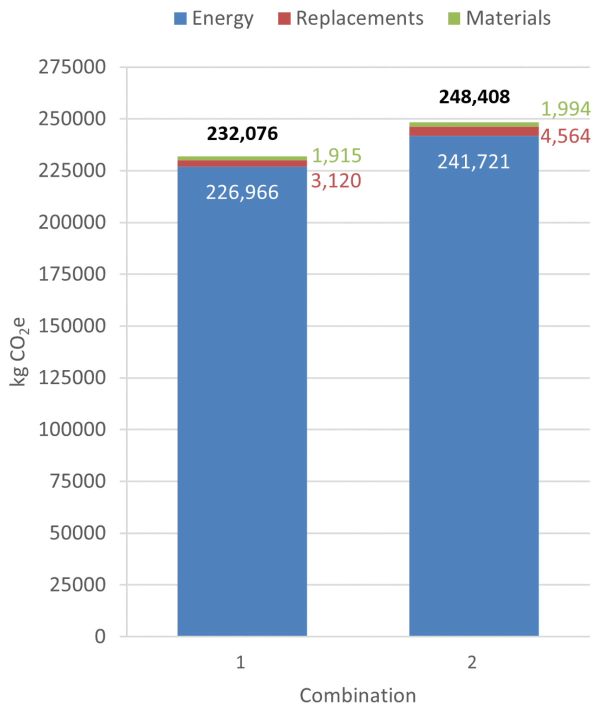


Figure 22: Emissions related to energy, replacements and materials for combinations 1 and 2.

Emissions from replacements of the heat pumps are higher than emissions from materials. This is because the lifetimes of the water-to-water heat pump and the air-to-water heat pump are 20 and 15 years, respectively. The heat pumps must therefore be replaced more than once during the lifetime of the building.

Figure 23 shows emissions related to water-to-water heat pumps and air-to-water heat pumps in combination with standard solar panels or solar shingles.

3	Heat pump water-to-water + standard solar panels
4	Heat pump water-to-water + solar shingles
5	Heat pump air-to-water + standard solar panels
6	Heat pump air-to-water + solar shingles

By comparing combinations 3 and 4, one can see that the standard solar panels are best when it comes to emissions. As the same option was chosen for standard solar panels and solar shingles, the only difference between the two is the transportation distance and the efficiency of the panels. The two types of solar panels thus have the same emissions related to materials and replacements. The

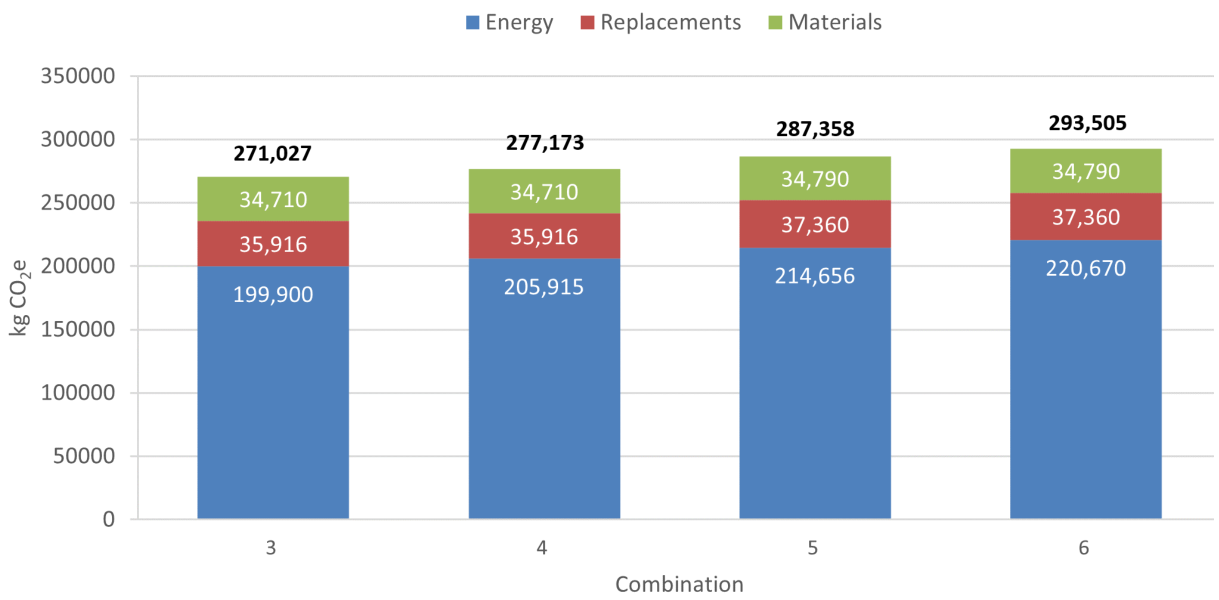


Figure 23: Emissions related to energy, replacements and materials for combinations 3-6.

efficiency affects the net delivered energy and thus the emissions related to energy. Emissions related to transport are, as mentioned above, negligible compared to energy, replacements and materials and are therefore not included in the figure. Out of these options, combination 3 with a water-to-water heat pump and standard solar panels has the lowest total emissions at 271.0 tons CO_2e.

Comparing figures 22 and 23, the solar panels have much larger emissions related to materials and maintenance than the heat pumps. The production of solar panels leads to high emissions of CO_2 and sulphide. This is due to extraction of materials needed for the construction of the solar panels, as well as high temperatures during production [76]. The emissions related to replacements are high because the lifetime of the solar panels is 25 years. This means that the solar panels are replaced once during the 50-year service time of the building.

Figure 24 shows emissions related to water-to-water heat pumps and air-to-water heat pumps in combination with evacuated tube collectors or flat plate collectors. Out of these, combination 7 with a water-to-water heat pump and evacuated tube collectors has the lowest total emissions at 239.3 tons CO_2e.

7	Heat pump water-to-water + evacuated tube collectors
8	Heat pump water-to-water + flat plate collectors
9	Heat pump air-to-water + evacuated tube collectors
10	Heat pump air-to-water + flat plate collectors

By comparing combinations 7 and 8, one can see that the evacuated tube collectors have lower emissions related to energy, materials and replacements than the flat plate collectors. Combinations with evacuated tube collectors resulted in lower delivered energy than combinations with flat plate

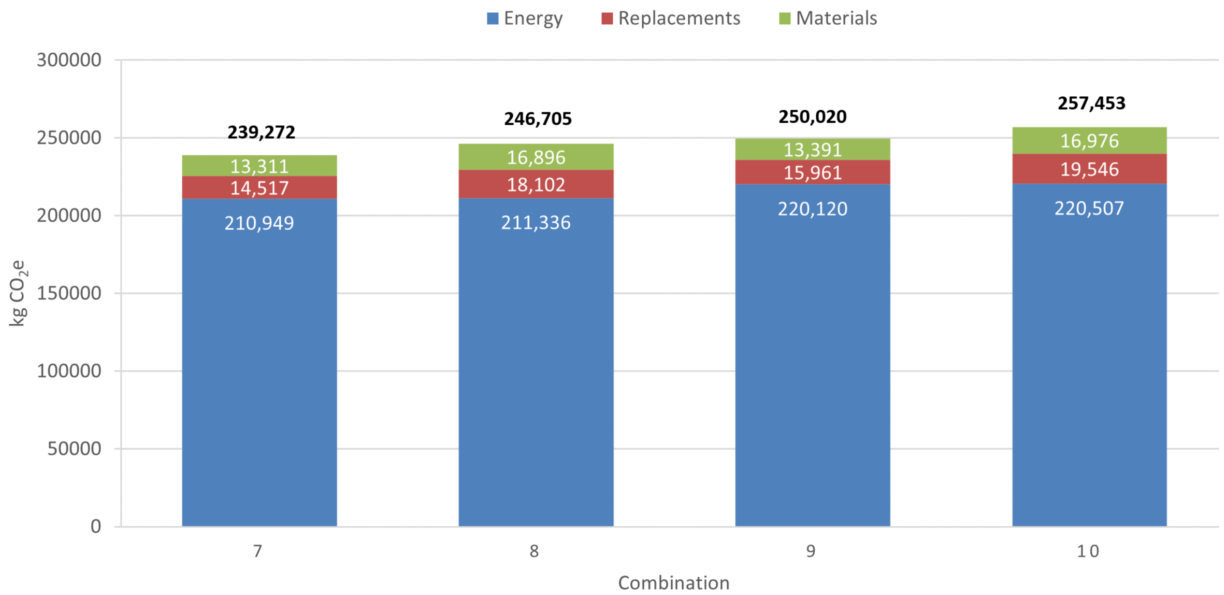


Figure 24: Emissions related to energy, replacements and materials for combinations 7-10.

collectors, due to their efficiency being higher, see section 6.1.2. The difference in energy consumption between the combinations is small, which results in similar emissions related to energy. Emissions related to materials and replacements are higher for flat plate collectors because 144 m^2 of collectors is needed to cover 30% of the heating demand, compared to 104 m^2 for evacuated tube collectors, see section 5.1.4.

Figure 25 shows emissions related to water-to-water heat pumps and air-to-water heat pumps in combination with evacuated tube collectors or flat plate collectors, and standard solar panels or solar shingles.

11	Heat pump water-to-water + evacuated tube collectors + standard solar panels
12	Heat pump water-to-water + evacuated tube collectors + solar shingles
13	Heat pump water-to-water + flat plate collectors + standard solar panels
14	Heat pump water-to-water + flat plate collectors + solar shingles
15	Heat pump air-to-water + evacuated tube collectors + standard solar panels
16	Heat pump air-to-water + evacuated tube collectors + solar shingles
17	Heat pump air-to-water + flat plate collectors + standard solar panels
18	Heat pump air-to-water + flat plate collectors + solar shingles

Here, one can see that pairs of the combinations have the same amount of emissions related to materials and replacements. This is again due to the same option being chosen for the standard solar panels and the solar shingles. Out of these combinations, combination 13 has the lowest total emissions at 254.8 tons CO_2e.

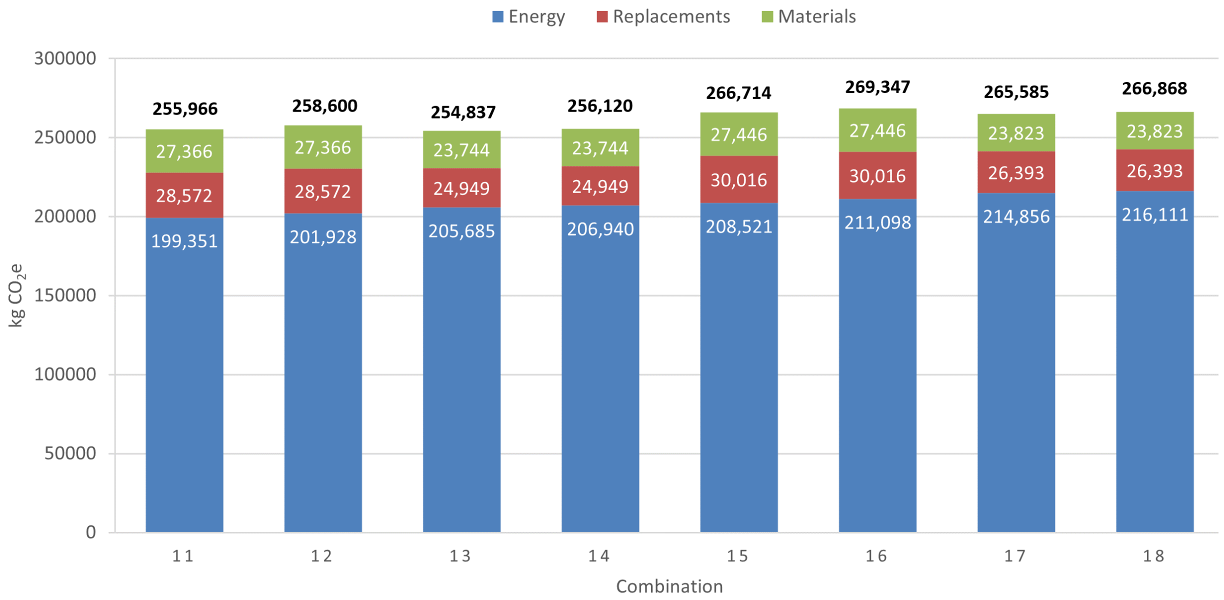


Figure 25: Emissions related to energy, replacements and materials for combinations 11-18.

6.2.1 Emissions Related to Electricity

As mentioned in section 5.2.6, the greenhouse gas emission factor for electricity is set to 31.1 g CO_2e/kWh in One Click LCA. This is quite high compared to what was found in section 3.4, 17 g CO_2e/kWh. Figure 26 shows emissions related to energy, replacements, materials, transportation and end-of-life for all combinations, including the base case, with an emission factor of 17 g CO_2e/kWh for electricity.

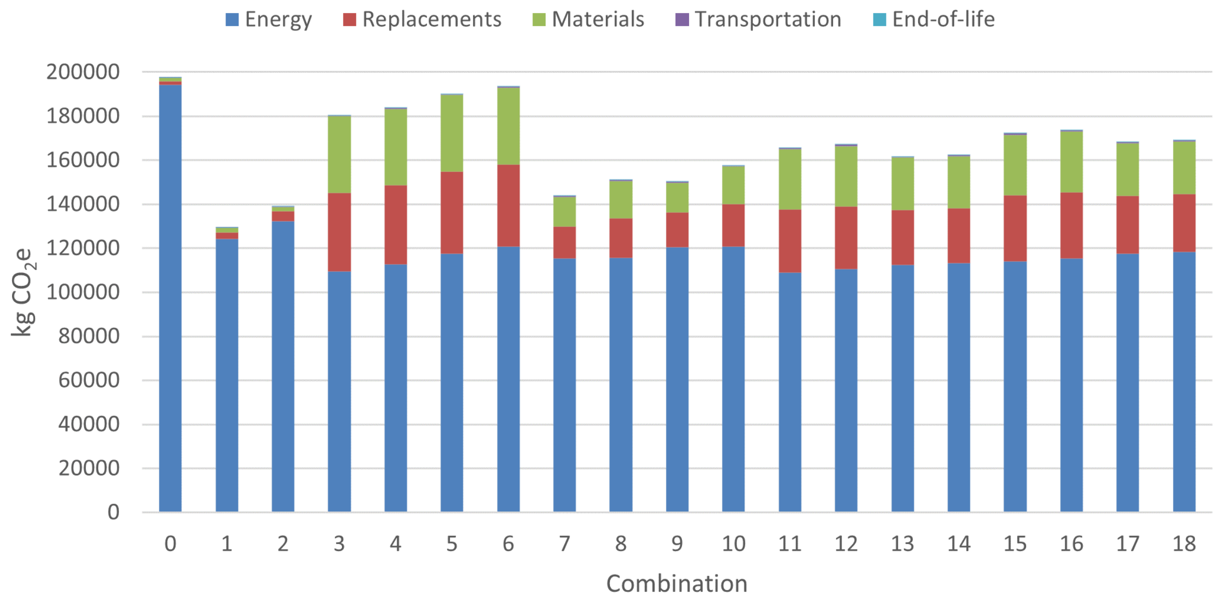


Figure 26: Emissions for all combinations, including the base case, with an emission factor of 17 g CO_2e/kWh for electricity.

Compared to figure 21, one can see that emissions related to materials and replacements play a larger role than before. The lower emission factor also results in a smaller difference between the base case and some of the other combinations.

6.3 Results from the Profitability Analysis

Below are results from the net present value (NPV) calculations. Detailed results for each combination are found in appendix E.

Table 18 shows the initial investment cost (IIC) and the NPV for combinations 1 and 2. A positive NPV means that the combination is profitable over the project lifetime of 50 years. Positive NPVs are coloured green. From this, one can see that implementing only a water-to-water heat pump will not be profitable, but using an air-to-water heat pump is very profitable. The IIC includes financial support from Enova and saved costs from the reduced size of the electric boiler. The IICs are shown as negative values in the tables. The air-to-water heat pump costs less than what is saved on the reduced size of the boiler. The IIC is therefore positive, meaning that you earn 86,742 NOK by implementing the air-to-water heat pump.

Table 18: IIC and NPV of combinations 1 and 2.

	Combinations 1-2	**IIC [NOK]**	**NPV [NOK]**
1	Heat pump water-to-water	-945,225	-269,591
2	Heat pump air-to-water	86,742	1,336,817

As costs are uncertain, the cost reduction needed to make the combinations profitable was calculated. The original cost of the water-to-water heat pump is 1,259,630 NOK for combinations 1, 3 and 4. Combination 1 is profitable if the cost of the water-to-water heat pump is reduced by 12.3% to 1,104,969 NOK. This gives IIC of 790,290 NOK, due to financial support from ENOVA and saved costs from the reduced size of the electric boiler. The new IIC is lower than the original IIC, see table 18.

Table 19 shows the IIC and the NPV of combinations 3-6. One can see that combinations 5 and 6, with air-to-water heat pumps will be profitable over 50 years.

Table 19: IIC and NPV of combinations 3-6.

	Combinations 3-6	**IIC [NOK]**	**NPV [NOK]**
3	Heat pump water-to-water + standard solar panels	-1,428,435	-584,846
4	Heat pump water-to-water + solar shingles	-1,491,225	-737,444
5	Heat pump air-to-water + standard solar panels	-396,468	1,239,965
6	Heat pump air-to-water + solar shingles	-459,258	873,600

Combination 3 will be profitable if the cost of the combination is reduced by 19.2%. Alternatively, the cost of the water-to-water heat pump could be reduced by 26.6% to 924,569 NOK. This gives IIC of 1,093,373 NOK. Combination 4 is profitable if the cost of the combination is reduced by 23.4%, or if the cost of the water-to-water heat pump is reduced by 33.5% to 837,654 NOK. This gives IIC of 1,069,249 NOK.

Table 20 shows the IIC and the NPV of combinations 7-10. Only combination 10, with an air-to-water heat pump and flat plate collectors, will be profitable over 50 years. This is because the evacuated tube collectors are much more expensive than the flat plate collectors.

Table 20: IIC and NPV of combinations 7-10.

	Combinations 7-10	**IIC [NOK]**	**NPV [NOK]**
7	Heat pump water-to-water + evacuated tube collectors	-2,110,037	-1,561,905
8	Heat pump water-to-water + flat plate collectors	-1,077,493	-231,261
9	Heat pump air-to-water + evacuated tube collectors	-1,305,672	-203,768
10	Heat pump air-to-water + flat plate collectors	-71,672	1,328,332

The original cost of the water-to-water heat pump in combinations 7-18 is 997,802 NOK. The original cost of the air-to-water heat pump is 153,438 NOK. Combination 7 will be profitable with a total cost reduction of 35.4%, or a cost reduction for the water-to-water heat pump of 85.6% to 143,684 NOK. The IIC for this combination is then 1,255,918 NOK. Combination 8 is profitable if the cost of the combination is reduced by 9.2%, or if the cost of the water-to-water heat pump is reduced by 12.7% to 871,082 NOK. This gives IIC of 950,772 NOK. Combination 9 will become profitable with cost reductions of 6.1%, or if the cost of the air-to-water heat pump is reduced by 62.9% to 56,926 NOK. This gives IIC of 1,209,282 NOK.

The evacuated tube collectors in combinations 7 and 9 are very expensive. However, it is the costs of the heat pumps that are most uncertain, and a very large cost reduction for the heat pump is needed for these combinations to become profitable. This is considered very unlikely, and it is thus unrealistic that these combinations can be profitable. The smaller cost reduction in combination 8 is more realistic.

Table 21 shows the IIC and the NPV of combinations 11-18. Here, one can see that combinations 17 and 18 are very profitable. The rest of the combinations are not going to be profitable, but several of the combinations have negative NPVs of only a few hundred thousand NOK.

As for combination 7, combinations 11 and 12 include both a water-to-water heat pump and evacuated tube collectors. It is unlikely that a cost reduction can make these combinations profitable. Combination 13 becomes profitable if the cost is reduced by 11.4%, or if the cost of the water-to-water heat pump is reduced by 16.2% to 836,159 NOK. This gives IIC of 1,016,739 NOK.

Table 21: IIC and NPV of combinations 11-18.

	Combination 11-18	**IIC [NOK]**	**NPV [NOK]**
11	Heat pump water-to-water + evacuated tube collectors + standard solar panels	-2,317,127	-1,697,022
12	Heat pump water-to-water + evacuated tube collectors + solar shingles	-2,344,037	-1,759,712
13	Heat pump water-to-water + flat plate collectors + standard solar panels	-1,178,383	-295,339
14	Heat pump water-to-water + flat plate collectors + solar shingles	-1,191,493	-326,726
15	Heat pump air-to-water + evacuated tube collectors + standard solar panels	-1,512,762	-243,603
16	Heat pump air-to-water + evacuated tube collectors + solar shingles	-1,539,672	-403,319
17	Heat pump air-to-water + flat plate collectors + standard solar panels	-374,018	1,061,054
18	Heat pump air-to-water + flat plate collectors + solar shingles	-387,128	1,030,102

Combination 14 is profitable with a cost reduction of 12.7% or a reduction in the cost of the water-to-water heat pump of 17.9% to 819,196 NOK. This gives IIC of 1,012,887 NOK. Combination 15 is profitable if the cost is reduced by 19.2%. This results in an IIC of 1,168,040 NOK. A reduction in the cost of the air-to-water heat pump will not make the combination profitable, as the evacuated tube collectors are the most expensive technology in this combination. Combination 16 will be profitable with a cost reduction of 22.1%, which results in an IIC of 1,136,060 NOK. A reduction in the cost of the air-to-water heat pump will not make this combination profitable either. It is therefore seen as unlikely that combinations 15 and 16 can become profitable.

6.4 Combined Results

Table 22 shows results from SIMIEN, One Click LCA and the NPV calculations. The five best combinations for saved energy, emissions and costs are coloured green. The best combination when it comes to saved energy is combination 11. The best combination when it comes to emissions is combination 1. Combination 2 is the best when it comes to costs.

Table 22: Combined results from SIMIEN, One Click LCA and NPV calculations.

		Saved energy [MWh/year]	**Emissions [ton CO_2e]**	**NPV [NOK]**
1	Heat pump water-to-water	82.5	232.1	-269,591
2	Heat pump air-to-water	73.0	248.4	1,336,817
3	Heat pump water-to-water + standard solar panels	99.9	271.0	-584,846
4	Heat pump water-to-water + solar shingles	96.0	277.2	-737,444
5	Heat pump air-to-water + standard solar panels	90.4	287.4	1,023,965
6	Heat pump air-to-water + solar shingles	86.5	293.5	873,600
7	Heat pump water-to-water + evacuated tube collectors	92.8	239.3	-1,561,905
8	Heat pump water-to-water + flat plate collectors	92.5	246.7	-231,261
9	Heat pump air-to-water + evacuated tube collectors	86.9	250.0	-203,768
10	Heat pump air-to-water + flat plate collectors	86.6	257.5	1,328,332
11	Heat pump water-to-water + evacuated tube collectors + standard solar panels	100.2	256.0	-1,697,022
12	Heat pump water-to-water + evacuated tube collectors + solar shingles	98.6	258.6	-1,759,712
13	Heat pump water-to-water + flat plate collectors + standard solar panels	96.2	254.8	-295,339
14	Heat pump water-to-water + flat plate collectors + solar shingles	95.4	256.1	-326,726
15	Heat pump air-to-water + evacuated tube collectors + standard solar panels	94.3	266.7	-343,603
16	Heat pump air-to-water + evacuated tube collectors + solar shingles	92.7	269.3	-403,319
17	Heat pump air-to-water + flat plate collectors + standard solar panels	90.3	265.6	1,061,054
18	Heat pump air-to-water + flat plate collectors + solar shingles	89.5	266.9	1,030,102

7 Discussion

7.1 Weighing Saved Energy, Emissions and Costs

As mentioned in section 1.1, there is a large potential for reducing the energy consumption of Norwegian buildings. Reducing the energy consumption of buildings is important as it can relieve large amounts of energy that can be used in other sectors, for example electrification of the transport sector. If energy efficiency measures are implemented in enough buildings, it could prevent the need to build new power plants. It could also prevent the need for a large expansion of the electric power system.

Reducing energy consumption and greenhouse gas emissions are essential parts of the SDGs and thus important to ensure a sustainable future. As mentioned in section 2.1, the SDGs are seen as the world's plan to eradicate poverty, fight inequality and limit climate change.

On the other hand, investing in renewable energy technologies can be very expensive, and costs play a role in all building projects. How much can we pay for these solutions before it is seen as unacceptable? How the importance of energy savings, emissions and costs are weighed against each other will influence what choices are considered to be best. There will be synergies and trade-offs regardless of which combination is chosen.

7.2 Comparing the Combinations

If energy savings are seen as the most important aspect, combination 11 with a water-to-water heat pump, evacuated tube collectors and standard solar panels comes out on top. If emissions are seen as the most important aspect, combination 1 with only a water-to-water heat pump would be the recommended solution. And if costs are seen as the most important aspect, combination 2 with only an air-to-water heat pump is best. The results from the energy simulations in SIMIEN are input parameters in the LCA and the NPV method. This causes energy savings to be weighed as more important from the beginning.

The differences in emissions between all combinations are small. The difference between the best and worst combination is 61.4 tons CO_2e over the calculation period of 50 years. This equals only 1.2 tons CO_2e per year. Comparatively, the average person in Norway contributes with around 9 tons CO_2e every year [77]. Emissions can therefore, in this case, be excluded from the assessment.

The difference in saved energy between the best and worst combination is 27.2 MWh per year. This can be compared to a large house. In 2012, the average household in Norway used 20.2 MWh [78]. This is a considerable difference, and energy savings are therefore seen as an important aspect.

During the meeting with project leader, Gøran Johansen, and the general manager of Nærøyfjorden World Heritage Park, Erling Oppheim, 16 April 2021, they expressed that costs are not very important. Energy savings are therefore seen as the most important aspect, but costs still play a role in the recommendation.

Combination 1 is ruled out, as it saves 17.7 MWh/year less than the best combination in terms of energy savings. This combination is also not profitable. Combination 2 is also ruled out, as it has the lowest energy savings out of all the combinations.

Combination 11 has an IIC of 2,317,127 NOK and an NPV of -1,697,022 NOK. As this solution is very expensive, the focus is moved to the next best combinations when it comes to saved energy. Combination 3 with a water-to-water heat pump and standard solar panels is the second best when it comes to energy savings. This combination has an IIC of 1,428,435 NOK and an NPV of -584,846 NOK. The third best combination when it comes to energy savings is combination 12. This solution is even less profitable than combination 11. The fourth best combination is combination 13, with a water-to-water heat pump, flat plate collectors and standard solar panels. Combination 13 has an IIC of 1,178,383 NOK and an NPV of -295,339 NOK. The fifth best combination when it comes to energy savings is combination 4. This solution is less profitable than combinations 3 and 13.

Out of these five combinations, combinations 3 and 13 are best when it comes to costs. The difference in energy savings between these two is 3.7 MWh/year. This is not considered to be significant compared to the difference in NPV, and combination 13 is therefore recommend. Furthermore, a negative NPV of almost 300,000 NOK is seen as acceptable, as costs are not the most important factor. This expense is also relatively small in such a large project.

The wish to utilise the fjord as a heat source is fulfilled if combination 13 is implemented. A water-to-water heat pump can also be used for cooling during summer, see section 3.3.3. This is another advantage of water-to-water heat pumps compared to air-to-water heat pumps.

If costs are weighed as more important than above, the results show that combination 5 with an air-to-water heat pump and standard solar panels is the best combination. It has 6.0% lower energy savings than the recommended combination, but it is profitable. This combination could be recommended if the project wishes to invest in profitable solutions, and if utilising the fjord as a heat source is not important. As discussed in section 5.3.5, the cost of the air-to-water heat pump only includes the heat pump unit. Additional equipment could be needed, and the costs could therefore be higher. However, it is unlikely that the additional costs would make the combination unprofitable.

Even if costs are seen as important, a solution with a water-to-water heat pump should be investigated further. The cost of the water-to-water heat pump is uncertain. If the cost of the heat pump is reduced by 16.2% to 836,159 NOK, combination 13 is profitable. This is not seen as unlikely. In addition, the costs of the water-to-water heat pump system could be reduced if neighbouring buildings are connected to the system. The specific investment cost [NOK/kW] of heat pump systems decreases with an increasing size, as mentioned in section 5.3.5. Including more buildings will therefore give lower costs per kW of installed capacity. This will lead to even larger energy savings and will be a stable energy source throughout the year for the connected buildings.

Aesthetics might also play a role when choosing energy technologies in this project, and some solutions can be seen as more aesthetically pleasing than others. This is of course a subjective opinion, but solar shingles and flat plate collectors can be perceived as more aesthetically pleasing than the two other options. Combination 13 includes flat plate collectors, but not solar shingles. However, the flat plate collectors cover 144 m^2 of the roof area, and only 38 m^2 will be covered by solar panels. The area of standard solar panels is so small that it fits on the flat part of the roof, above the large windows. To best utilise the solar radiation, the solar panels should be tilted to an angle of 25-45°[30, p. 270]. As mentioned in section 3.1, there are two types of standard solar panels. Monocrystalline solar panels have a black finish and could be seen as the more aesthetically pleasing option. However, they are more expensive than polycrystalline solar panels and might thus cost more than the costs used in this thesis. Monocrystalline solar panels also have a higher efficiency than polycrystalline solar panels, which can result in even higher energy savings.

By implementing renewable energy technologies and other energy efficiency measures, the building might be able to achieve a BREEAM-NOR certification or another type of environmental certification. The exact criteria for the BREEAM-NOR energy category are unknown. However, there is no reason to believe that one type of renewable energy technology is better than others, as long as the technology reduces energy consumption and emissions.

7.3 Sustainable Development Goals

By choosing one of the best combinations when it comes to energy consumption and emissions, the project contributes towards the sustainable development goals (SDGs) and a sustainable future. A combination with lower emissions could have been chosen, but the differences were so small that it is negligible. Reducing the amount of electric energy needed from the grid will decrease the share of fossil energy and increase the share of renewable energy in the total final energy consumption. The project will thus contribute to goal (7) Affordable and Clean Energy, especially target 7.2: "By 2030, increase substantially the share of renewable energy in the global energy mix" [24].

Investing in different energy technologies will support R&D and help towards innovation and technological advancements. This will contribute to goal (9) Industry, Innovation and Infrastructure. The project as a whole focuses on responsible consumption, as they plan to renovate the building instead of tearing it down. They are also focusing on using environmentally and climate friendly materials. This contributes to goal (12) Responsible Consumption and Production. Components for the renewable energy technologies in this thesis will be new, but there is a large potential for recycling. For example, 80-100% of the materials in solar panels can be recycled and used again [79]. This should be further looked into before choosing the final energy technologies and specific brands.

There is no reason to believe that working towards one of these SDGs will hinder developments towards other SDGs. Finally, there might be other solutions and combinations not investigated in this thesis that could contribute even more to the SDGs. This could include solar panels that can follow the sun, other types of heat pumps or multiple smaller heat pumps.

8 Conclusion

The purpose of this thesis was to discuss how the aspects energy savings, CO_2 emissions and costs can be weighed against each other in implementation of different energy technologies, and to recommend a combination of energy technologies for Nærøyfjorden World Heritage Centre.

18 different combinations of energy technologies were investigated. The combinations include one or several of the following technologies: a water-to-water heat pump, an air-to-water heat pump, evacuated tube collectors, flat plate collectors, standards solar panels and solar shingles.

How the importance of energy savings, emissions and costs is weighed against each other will influence what choices are considered to be best. The difference in emissions between the combinations was minimal, and this was therefore excluded from the assessment. Energy savings were weighed as most important, as there was a considerable difference between the combinations. The reduced energy consumption can, on a larger scale, be used in other sectors, such as electrification of the transport sector. Reducing emissions and energy consumption are also important parts of the sustainable development goals (SDGs). Costs were not seen as the most important aspect, as the project leader, Gøran Johansen, and the general manager of Nærøyfjorden World Heritage Park, Erling Oppheim, expressed this opinion during a meeting. Costs still play a role in the recommendation, but a slightly negative net present value (NPV) is seen as acceptable.

The recommended combination is combination 13 with a water-to-water heat pump, flat plate collectors and standard solar panels. This combination gave the fourth largest energy savings, saving 42.1% of the energy needed for the base case. It has initial investment costs (IIC) of 1,178,383 NOK and an NPV of -295,339 NOK.

If costs are seen as more important, the results show that combination 5 with an air-to-water heat pump and standard solar panels is the best choice. It has 6.0% lower energy savings than combination 13, but it is profitable. It could also be beneficial to investigate if neighbouring buildings could be connected to the water-to-water heat pump in combination 13, as the cost per kW decreases with increasing heat pump size. Furthermore, the costs for the heat pumps are estimates and thus uncertain. If the cost of the water-to-water heat pump is reduced by 16.2% to 836,159 NOK, combination 13 is profitable. This is not seen as unlikely.

Before deciding on a final combination for the UNESCO World Heritage Centre, professional consulting and an inspection of the area and building are required. This is to ensure that the recommended combination is suitable, and to find actual costs of the different components.

9 The Full Concept Recommendation

This thesis has been conducted in connection to a larger project, which includes three master's theses. In this chapter, the conclusions from the three theses are presented, in desire to create a complete concept recommendation. Advice for implementation into the project will also be briefly discussed. This chapter has been written in collaboration with Berit Johanne Skogvang and Halldór Þrastarson.

9.1 Study Conducted by Berit

UNESCO World Heritage Center in Aurlandsvangen: Balancing Energy Efficiency, CO_2-Emissions and Costs when Remodeling the Building Structure

For the building structure, it is recommended to choose the 400 mm wood fibre concept for the roof, the 300 mm glass wool concept for the wall, new triple pane windows with gas filling, new doors with a U-value of 0.8 W/(m^2K) and the 800 mm Glasopor concept for slab on ground. This will result in 11,988 kWh saved energy each year compared to the TEK17 concept, emissions of 37.1 tons of CO_2e and a cost of 2,867,581 NOK. When considering saved emissions and saved cost from saved energy, this combination of concepts will result in a total cost of 2,560,256 NOK and total emissions of 24.85 tons of CO_2e. These concepts were chosen as a result of the balancing process that was carried out, in an attempt to balance energy efficiency, CO_2 emissions and costs.

9.2 Study Conducted by Halldór

Keeping Old Buildings Green with Relevant Technology - A Case Study of UNESCO World Heritage Center, Nærøyfjordområdet

The recommended Building Management system (BMS) for the building is Model Predictive Control (MPC). This control method uses a model to predict future states of the building and can therefore reduce energy use by 15-20%. MPC has great potential to act on external disturbances and includes for example weather forecasts in the model and can therefore adapt to future climate change. This method is complicated and expensive but it is believed that this will pay off in the long run.

The Water-Thermal Energy Production System (WEPS) was chosen as an energy source for the Heating Ventilation and Air Conditioning (HVAC) system. This system uses the least amount of energy, has the lowest CO_2 emissions of the systems that were researched. However WEPS costs significantly more than the other systems. The practical pros and cons as well as the low energy use and CO_2 emissions out value the other systems and therefore this system was chosen.

9.3 Study Conducted by Sylvi

Weighing the Importance of Energy Savings, CO_2 Emissions and Costs When Implementing Renewable Energy Technologies. Case: Nærøyfjorden UNESCO World Heritage Centre

The recommended combination of energy technologies is a combination with a water-to-water heat pump, flat plate collectors and standard solar panels. This combination gave energy savings of 96.2 MWh/year, emissions of 254.8 tons CO_2e, an initial cost of 1,178,383 NOK and a net present value of -295,339 NOK.

9.4 Implementation into the Project

When implementing these recommendations to the project, it is important to be aware that the recommended WEPS system and the recommended combination of energy technologies does not correlate perfectly. The WEPS system in Halldór's thesis is covering 90% of the energy need, while the water-to-water heat pump in Sylvi's thesis is covering 60%, while the solar thermal collector system is covering 30%. It is therefore not possible to implement all the recommended solutions. Nevertheless, both these recommendations include a water-to-water heat pump, which indicates that these recommendations should be taken into account. With proper control methods for these systems, such as the MPC, the efficiency of the system output can be increased by 15-20%.

All the concepts must be seen in relation to each other, as the energy consumption of the various concepts will impact each other. It is all a part of a bigger system that comprises the whole building, where many factors are working simultaneously. That is, if one recommendation is fully implemented, then that affects the energy consumption of the other recommendations. Thus, when implementing the recommendations it is possible to opt out parts of the recommendations, and still end up with a highly efficient building. Furthermore, more concepts were considered and assessed than what is presented in this recommendation. These are also concepts that are relevant for the building. More information can be found in the respective master's theses:

Berit Johanne Skogvang (2021) *UNESCO World Heritage Center in Aurlandsvangen: Balancing Energy Efficiency, CO_2-Emissions and Costs when Remodeling the Building Structure*

Halldór Þrastarson (2021) *Keeping Old Buildings Green with Relevant Technology - A Case Study of UNESCO World Heritage Center, Nærøyfjordområdet*

References

[1] M. R. Allen, O. P. Dube, W. Solecki, F. Aragón-Durand, W. Cramer, S. Humphreys, M. Kainuma, J. Kala, N. Mahowald, Y. Mulugetta, R. Perez, M. Wairiu and K. Zickfeld, "Framing and Context" in *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor and T. Waterfield (eds.)]. In Press., 2018.

[2] D. G. Victor, D. Zhou, E. H. M., Ahmed, P. K. Dadhich, J. G. J. Olivier, H-H. Rogner, K. Sheikho and M. Yamaguchi, "Introductory Chapter" in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J. C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014.

[3] A. Guterres, "Secretary-General's remarks on Climate Change [as delivered]", 2018. Available: https://www.un.org/sg/en/content/sg/statement/2018-09-10/secretary-generals-remarks-climate-change-delivered (Accessed: 17.03.21).

[4] "Buildings, a source of enormous untapped efficiency potential", International Energy Agency (IEA). Available: https://www.iea.org/topics/buildings (Accessed: 02.02.21).

[5] D. Splide, L. E. Hodge, I. H. Magnussen, J. Hole, M. Buvik and H. Horne, "Strømforbruk mot 2040. Analyse av strømforbruk i Fastlands-Norge, Norden og utvalgte EU-land", Norwegian Water Resources and Energy Directorate (NVE), Oslo, Norway, NVE report no. 22/2019, 2019. Available: http://publikasjoner.nve.no/rapport/2019/rapport2019_22.pdf.

[6] T. Karlsen, "Miljøsertifisering - bygg og anlegg", Store norske leksikon, 2020. Available: https://snl.no/milj%C3%B8sertifisering_-_bygg_og_anlegg (Accessed: 08.03.21).

[7] N. H. Sandberg, H. Brattebø and A. Gustavsen, "Energieffektive bygg er avgjørende i det grønne skiftet", Forskersonen, 18 August 2019. Available: https://forskersonen.no/arkitekturbygningsmaterialer-energi/energieffektive-bygg-er-avgjorende-i-det-gronne-skiftet/1367253 (Accessed: 12.01.21).

[8] Norwegian Association of Municipal Engineers (NKF), "Tekniske krav ved tiltak i eksisterende bygg", Oslo, Norway, 1. utgave, april 2015. Available: https://dibk.no/globalassets/eksisterende-bygg/veiledningsstoff/tekniske-krav-ved-tiltak-i-eksisterende-bygg_eksempelsamling_nkf.pdf.

[9] "Vestnorsk Fjordlandskap", Nærøyfjorden Verdensarvpark. Available: https://www.naroyfjorden.no/vestnorsk-fjordlandskap (Accessed: 08.03.21).

[10] "The Criteria for Selection", World Heritage Convention, United Nations Educational, Scientific and Cultural Organization (UNESCO). Available: https://whc.unesco.org/en/criteria/ (Accessed: 10.02.21).

[11] Nærøyfjorden Verdsarvpark and Aurland Kjøle- og Fruktlager SA, "UNESCO Verdsarvsenter – Nærøyfjordområdet, Forprosjekt", 2020. Available: https://www.naroyfjorden.no/nyhende/unesco-verdsarvsenter-forprosjektrapport.

[12] "Welcome to the World Heritage and the Norwegian Fjord Centre in Geiranger", The West Norwegian Fjords. Available: https://www.fjordsenter.com/en/ (Accessed: 06.05.21).

[13] O. Starheim, "Industri og næring i Aurland", Allkunne, 2013. Available: https://www.allkunne.no/framside/fylkesleksikon-sogn-og-fjordane/samfunn/industri-naring-og-bedrifter/industri-og-naring-i-aurland/1900/81196/ (Accessed: 08.06.21).

[14] G. Johansen, project leader of the UNESCO World Heritage Centre – Nærøyfjorden, email communication, 3 March, 2021.

[15] "Odden, Aurlandsvangen" in *Finn Kart*, The planned World Heritage Centre in Aurlandsvangen, Aurland, Norway: Finn, [Map]. Available: https://kart.finn.no/?lng=7.18479&lat=60.90590&zoom=18&mapType=historicalm-Aurland-2019%40c&markers=7.18484,60.90580,r,Brukerdefinert (Accessed: 07.05.21).

[16] "Western Norway" in *Finn Kart*, World Heritage Centres in Geiranger and Aurlandsvangen, Norway: Finn, [Map]. Available: https://kart.finn.no/?lng=7.32112&lat=61.55434&zoom=8&mapType=normaphd&markers=7.18484,60.90580,r,Brukerdefinert%7C7.20958,62.09574,b,Brukerdefinert (Accessed: 07.05.21).

[17] D. Leraand and United Nations Association of Norway, "UNESCO", Store norske leksikon, 2019. Available: https://snl.no/UNESCO (Accessed: 01.02.21).

[18] Ø. Byrkjedal and E. Åkervik, "Vindkart for Norge, Kartbok 1a: Årsmiddelvind i 80m høyde", NVE, Oslo, Norway, Appendix to NVE report no. KVT/ØB/2009/038, 2009. Available: https://www.nve.no/media/2462/vind_80m_kartbok1a_4140.pdf.

[19] R. Hosseinalizadeh, E. s. Rafiei, A. S. Alavijeh and S. F. Ghaderi, "Economic analysis of small wind turbines in residential energy sector in Iran", *Sustainable Energy Technologies and Assessments*, vol 20, pp. 58-71, apr. 2017. Available: https://doi.org/10.1016/j.seta.2017.02.018.

[20] K. Olerud and A. Tjernshaugen, "Bærekraftig utvikling", Store norske leksikon, 2020. Available: https://snl.no/b%C3%A6rekraftig_utvikling (Accessed: 19.02.21).

[21] G . H. Brundtland, Report of the World Commission on Environment and Development: "Our Common Future, Chapter 2: Towards Sustainable Development", Oxford: Oxford University Press., United Nations General Assembly document A/42/427, 1987. Available: http://www.un-documents.net/ocf-02.htm.

[22] "Contributions to Agenda 2030", Stockholm Resilience Centre, 2017. Available: https://www.stockholmresilience.org/research/research-news/2017-02-28-contributions-to-agenda-2030.html (Accessed: 26.04.21).

[23] "Sustainable development goals (SDGs) - Communications materials", United Nations (UN). Available: https://www.un.org/sustainabledevelopment/news/communications-material/ (Accessed: 29.01.21).

[24] "Take Action for the Sustainable Development Goals", United Nations (UN). Available: https://www.un.org/sustainabledevelopment/sustainable-development-goals/ (Accessed: 01.03.21).

[25] *Byggteknisk forskrift (TEK17) med veiledning, Veiledning om tekniske krav til byggverk*, 2017. Available: https://dibk.no/regelverk/byggteknisk-forskrift-tek17/ (Accessed: 06.04.21).

[26] *Lov om planlegging og byggesaksbehandling, § 31-2. Tiltak på eksisterende byggverk*, 2008. Available: https://lovdata.no/dokument/NL/lov/2008-06-27-71/KAPITTEL_4-12#KAPITTEL_4-12 (Accessed: 08.05.21).

[27] "Nysgjerrig på BREEAM-NOR?", Norwegian Green Building Council. Available: https://byggalliansen.no/sertifisering/om-breeam/nysgjerrig-pa-breeam-nor/ (Accessed: 12.04.21).

[28] M. Kaltschmitt and W. Streicher, "Introduction and Structure" in *Renewable Energy: Technology, Economics and Environment*, M. Kaltschmitt, W. Streicher and A. Wiese, Eds., Berlin: Springer, 2007, pp. 1-22. Available: https://link.springer.com/content/pdf/10.1007%2F3-540-70949-5.pdf.

[29] "From sunlight to electricity", Australian Academy of Science. Available: https://www.science.org.au/curious/technology-future/solar-pv (Accessed: 06.04.21).

[30] M. Kaltschmitt, U. Rau, D. U. Sauer, G. Schröder and S. Schneider, "Photovoltaic Power Generation" in *Renewable Energy: Technology, Economics and Environment*, M. Kaltschmitt, W. Streicher and A. Wiese, Eds., Berlin: Springer, 2007, pp. 229-294. Available: https://link.springer.com/content/pdf/10.1007%2F3-540-70949-5.pdf.

[31] "Monocrystalline and polycrystalline solar panels: what you need to know", EnergySage, LLC, 2020. Available: https://www.energysage.com/solar/101/monocrystalline-vs-polycrystalline-solar-panels/ (Accessed: 03.05.21).

[32] "Solar Shingles: Make Your Roof Solar-Powered", Solar Magazine, 2020. Available: https://solarmagazine.com/solar-roofs/solar-shingles/#What_are_solar_shingles_and_how_do_they_work (Accessed: 10.05.21).

[33] M. Kaltschmitt and W. Streicher, "Solar Thermal Heat Utilisation" in *Renewable Energy: Technology, Economics and Environment*, M. Kaltschmitt, W. Streicher and A. Wiese, Eds., Berlin: Springer, 2007, pp. 123-170. Available: https://link.springer.com/content/pdf/10.1007%2F3-540-70949-5.pdf.

[34] "SOLFANGERE", The Norwegian Solar Energy Society. Available: https://www.solenergi.no/solvarme (Accessed: 10.02.21).

[35] "Active solar energy system", Chegg Study. Available: https://www.chegg.com/learn/engineering-and-technology/introduction-to-engineering/active-solar-energy-system (Accessed: 10.03.21).

[36] "552.455 Vannbaserte solfangere. Funksjon og energiutbygge", SINTEF Byggforsk, 2011. Available: https://www.byggforsk.no/dokument/542/vannbaserte_solfangere_funksjon_og_energiutbytte (Accessed: 21.04.21).

[37] S. Kurpaska, H. Latała, M. Malinowski and P. Kiełbasa, "Efficiency of solar conversion in flat plate and vacuum tube solar collectors", *IOP Conference Series: Earth and Environmental Science*, vol 214, 012033, 2019. Available: https://doi.org/10.1088/1755-1315/214/1/012033.

[38] "Nyttige begreper", Norsk varmepumpeforening, 2020. Available: https://www.varmepumpeinfo.no/verdt-a-vite-om-varmepumper/nyttige-begreper (Accessed: 30.04.21).

[39] "Prosjektveileder, VVS-bransjens, forenklet anlegg for vannbåren oppvarming av boliger", SINTEF Byggforsk, Trondheim, Norway, 2009. Available: https://dibk.no/globalassets/miljo/publikasjoner/forenklet-anlegg-for-vannbaren-oppvarming-av-boliger.pdf (Accessed: 30.04.21).

[40] "552.403 Varmepumper i bygninger. Funksjonsbeskrivelse", SINTEF Byggforsk, 2009. Available: https://www.byggforsk.no/dokument/541/varmepumper_i_bygninger_funksjonsbeskrivelse (Accessed: 14.04.21).

[41] "Solfanger", Enova. Available: https://www.enova.no/privat/alle-energitiltak/solenergi/solfanger-/ (Accessed: 21.04.21).

[42] A. M. Bredesen and G. Lorentzen, "Varmepumpe", Store norske leksikon, 2020. Available: https://snl.no/varmepumpe (Accessed: 10.02.21).

[43] W. Streicher, M. Kaltschmitt, B. Sanner and G. Schröder, "Utilisation of Ambient Air and Shallow Geothermal Energy" in *Renewable Energy: Technology, Economics and Environment*, M. Kaltschmitt, W. Streicher and A. Wiese, Eds., Berlin: Springer, 2007, pp. 385-436. Available: https://link.springer.com/content/pdf/10.1007%2F3-540-70949-5.pdf.

[44] J. Stene, "(4) Heat Sources and Heat Source Systems for Heat Pump Plants" in *Lecture notes TEP4260 - Heat Pumps for Heating and Cooling of Buildings*, Norwegian University of Science and Technology (NTNU), 2021, pp. 16 and 94-125.

[45] A. V. Craciun, F. Sandu and G. Pana, "Monitoring of a ground source heat pump with horizontal collectors" presented at 2010 12th International Conference on Optimization of Electrical and Electronic Equipment, Brasov, Romania, 2010, p. 1230. Available: https://doi.org/10.1109/OPTIM.2010.5510546.

[46] J. Stene, "(5) Dimensioning of Heat Pump Plants for Heating and Cooling" in *Lecture notes TEP4260 - Heat Pumps for Heating and Cooling of Buildings*, Norwegian University of Science and Technology (NTNU), 2021, pp. 48-85.

[47] "Væske-til-vann-varmepumpe", Enova. Available: https://www.enova.no/privat/alle-energitiltak/varmepumper/vaske-til-vann-varmepumpe-/ (Accessed: 10.02.21).

[48] "Brønnparker", Geological Survey of Norway (NGU), 2020. Available: https://www.ngu.no/grunnvanninorge/bore-en-bronn/energibronn/bronnparker (Accessed: 22.04.21).

[49] "Strømforbruk i Norge har lavt klimagassutslipp", Norwegian Water Resources and Energy Directorate (NVE), 2021. Available: https://www.nve.no/nytt-fra-nve/nyheter-energi/stromforbruk-i-norge-har-lavt-klimagassutslipp/ (Accessed: 14.06.21).

[50] "TERM: carbon dioxide equivalent", European Environment Agency. Available: https://www.eea.europa.eu/help/glossary/eea-glossary/carbon-dioxide-equivalent (Accessed: 15.06.21).

[51] I. V. Sem, J. Hole, F. H. Aulie, D. Spilde, F. Arnesen, S. Jelsness, E. Veirød, C. A. Veie, M. Sidelnikova, M. E. Henriksen and A. G. Stavseng, "Langsiktig kraftmarkedsanalyse 2020-2040", Norwegian Water Resources and Energy Directorate (NVE), Oslo, Norway, NVE report no. 37/2020, 2020. Available: https://publikasjoner.nve.no/rapport/2020/rapport2020_37.pdf.

[52] J. Stene, "(10) Investment Analysis for Heat Pump Systems" in *Lecture notes TEP4260 - Heat Pumps for Heating and Cooling of Buildings*, Norwegian University of Science and Technology (NTNU), 2021, pp. 48-85.

[53] "HOMER Grid 1.8, Glossary", Sections Discount Factor, Net Present Cost and Total Net Present Cost, HOMER Energy LCC. Available: https://www.homerenergy.com/products/grid/docs/latest/glossary.html (Accessed: 25.05.21).

[54] "COMMERCIAL SOFTWARE Simien", IBPSA-NORDIC. Available: https://ibpsa-nordic.org/commercial%20software/simien (Accessed: 17.11.20).

[55] *Byggteknisk forskrift (TEK17) med veiledning, Kapittel 14 Energi*, 2017. Available: https://dibk.no/regelverk/byggteknisk-forskrift-tek17/14/ (Accessed: 06.04.21).

[56] "Nøyaktige solforhold for alle steder i verden", Analyse av solforhold, adr. Odden 15, 5745, Suncurves AS. Available: https://suncurves.com/no/ (Accessed: 23.02.21).

[57] *Energy performance of buildings — Calculation of energy needs and energy supply*, Standard Norge, SN-NSPEK 3031:2020, 2020.

[58] "Med et solcelleanlegg på taket, kan du lage din egen strøm fra kun 25 øre/kWh* fast de neste 30 årene! Sjekk ditt tak nå!", solkart, adr. Odden 15, Aurland. Available: https://solkart.no/ (Accessed: 19.05.21).

[59] "Luft-til-vann-varmepumpe", Enova. Available: https://www.enova.no/privat/alle-energitiltak/varmepumper/luft-til-vann-varmepumpe/ (Accessed: 14.04.21).

[60] A. Sharma, A. Saxena, M. S. Sethi, V. Shree and V. Goel, "Life cycle assessment of buildings: A review", *Renewable and Sustainable Energy Reviews*, 15(1):871-875, 2011. Available: https://doi.org/10.1016/j.rser.2010.09.008.

[61] "TECHNICAL DATA", SUNSTYLE, 2017. Available: https://www.sunstyle.com/en/Documents.html#technical_data (Accessed: 21.02.21).

[62] M. Sidelnikova, D. E. Weir, L. H. Groth, K. Nybakke, K. E. Stensby, B. Langseth, J. E. Fonneløp, O. Isachsen, I. Haukeli, S-L. Paulen, I. Magnussen, L. I. Husabø, T. Ericson and T. H. Qureishy, "Kostnader i energisektoren, Kraft, varme og effektivisering", Norwegian Water Resources and Energy Directorate (NVE), Oslo, Norway, NVE report no. 2/2015, part 1, 2015, pp. 95 and 183. Available: https://publikasjoner.nve.no/rapport/2015/rapport2015_02a.pdf.

[63] "Life Cycle Assessment software", One Click LCA. Available: https://www.oneclicklca.com/ (Accessed: 03.02.21).

[64] "SmartKalk", Holte. Available: https://holte.no/produkt/smartkalk-kalkulasjonssystem/ (Accessed: 28.04.21).

[65] "Electricity prices", Statistics Norway (SSB). Available: https://www.ssb.no/en/statbank/table/09007/ (Accessed: 01.06.21).

[66] "Enova SF", Store norske leksikon. Available: https://snl.no/Enova_SF (Accessed: 1.06.21).

[67] "Varmesentraler", Enova. Available: https://www.enova.no/bedrift/bygg-og-eiendom/varmesentraler/ (Accessed: 1.06.21).

[68] "Solenergi", NTE. Available: https://nte.no/privat/strom/solenergi?gclid=CjwKCAjwnPOEBhA0EiwA609RecCq0BGmqVhmwhLPc6qnZq3SKUg0czEQ_g1jjsYN1Bi3_EL0LcwjdRoCiSoQAvD_BwE# (Accessed: 13.05.21).

[69] Project manager at Otovo, email communication, 30 March, 2021.

[70] "Lønnsomhet og tilbakebetalingstid for solceller", Otovo, 2017. Available: https://www.otovo.no/blog/solcellepanel-solceller/lonnsomhet-og-tilbakebetalingstid-for-solceller/ (Accessed: 13.05.21).

[71] Sales engineer at SGP, email communication, 27 April, 2021.

[72] A. F. Sandvall, E. O. Ahlgren and T. Ekvall, "Cost-efficiency of urban heating strategies – Modelling scale effects of low-energy building heat supply", *Energy Strategy Reviews*, vol 18, 2017, pp. 212-223. Available: https://doi.org/10.1016/j.esr.2017.10.003.

[73] G. Eggen and G. Vangsnes, "HEAT PUMP FOR DISTRICT COOLING AND HEATING AT OSLO AIRPORT, GARDERMOEN", 2005, p. 7. Available: https://www.sintef.no/globalassets/project/annex29/installasjoner/gshp_gardermoenhp_no1.pdf.

[74] J. Stene, "Varmepumper for oppvarming og kjøling av bygninger", SINTEF Energiforskning AS, Avdeling Energiprosesser, 2000, p. 16. Available: http://www.ivt.ntnu.no/ept/fag/tep4115/innhold/Laboppgaver/Varmepumpe%20Notat%20J%20Stene.pdf.

[75] "Hva koster varmepumpe? Pris i 2021", Boligsmart. Available: https://www.boligsmart.no/pris/varmepumpe (Accessed: 30.05.21).

[76] A. Masili, "The true carbon footprint of photovoltaic energy", Only Natural Energy, 16 July 2018. Available: https://www.onlynaturalenergy.com/the-true-carbon-footprint-of-photovoltaic-energy/ (Accessed: 16.05.21).

[77] M. Crippa, D. Guizzardi, M. Muntean, E. Schaaf, E. Solazzo, F. Monforti-Ferrario, J. G. J. Olivier and E. Vignati, "Fossil CO_2 emissions of all world countries", 2020 Report, EUR 30358 EN, Publications Office of the European Union, Luxembourg, 2020, JRC121460, p. 169. Available: http://dx.doi.org/10.2760/143674.

[78] "Energibruk i husholdningene", Statistics Norway (SSB), 2014. Available: https://www.ssb.no/energi-og-industri/energi/statistikk/energibruk-i-husholdningene (Accessed: 03.06.21).

[79] A. T. Vekony, "The Opportunities of Solar Panel Recycling", Greenmatch, 2021. Available: https://www.greenmatch.co.uk/blog/2017/10/the-opportunities-of-solar-panel-recycling (Accessed: 15.06.21).

[80] "471.014 U-verdier. Gulv på grunnen og vegger mot terreng", SINTEF Byggforsk, 2018. Available: https://www.byggforsk.no/dokument/1536/u-verdier_gulv_paa_grunnen_og_vegger_mot_terreng (Accessed: 17.02.21).

A SIMIEN Input Data for Concept Building

Table A.1: South east wall, information about walls, windows and doors.

<table>
<tr><th colspan="3">South east, SE</th><th>Value</th><th>Reasoning/reference</th></tr>
<tr><td rowspan="4">Outer wall</td><td colspan="2">Total area [m²]</td><td>310.53</td><td>Calculated from drawing</td></tr>
<tr><td rowspan="2">Construction</td><td>U-value [W/m²K]</td><td>0.29</td><td>Calculated using 0.7 for glass, 0.22 for walls and 0.18 for walls against terrain [80]</td></tr>
<tr><td>Heat storage in inner layer</td><td>13</td><td>Value from SIMIEN - Lettklinker</td></tr>
<tr><td colspan="2">Orientation [°]</td><td>135</td><td>Drawing</td></tr>
<tr><td rowspan="6">Large windows</td><td colspan="2">Number of (equal) windows</td><td>6</td><td>Counted from drawing</td></tr>
<tr><td rowspan="3">Window size</td><td>Width [m]</td><td>1.43</td><td>Measured from drawing</td></tr>
<tr><td>Height [m]</td><td>1.50</td><td>Measured from drawing</td></tr>
<tr><td>Width/height window sill and frame</td><td>0.05</td><td>Assumed value</td></tr>
<tr><td>Heat loss properties</td><td>Custom total U-value for the window construction [W/m²K]</td><td>1.2</td><td>TEK17: § 14-3 (1) a) [55]</td></tr>
<tr><td>Heat gain properties</td><td>Variable, manually controlled sun protection</td><td>0.38 (active)
0.51 (inactive)</td><td>Two layer glass. The inner one is a energy saving glass</td></tr>
<tr><td rowspan="5">Door 1</td><td colspan="2">Number of (equal) doors</td><td>1</td><td>Counted from drawing</td></tr>
<tr><td rowspan="3">Door size</td><td>Width [m]</td><td>1</td><td>Measured from drawing</td></tr>
<tr><td>Height [m]</td><td>2.1</td><td>Measured from drawing</td></tr>
<tr><td>Area [m²]</td><td>2.1</td><td>Calculated from drawing</td></tr>
<tr><td>Heat loss properties</td><td>Custom total U-value for the window construction [W/m²K]</td><td>1.2</td><td>TEK17: § 14-3 (1) a) [55]</td></tr>
<tr><td rowspan="5">Door 2 (double)</td><td colspan="2">Number of (equal) doors</td><td>2</td><td>Counted from drawing</td></tr>
<tr><td rowspan="3">Window size</td><td>Width [m]</td><td>1.56</td><td>Measured from drawing</td></tr>
<tr><td>Height [m]</td><td>2.77</td><td>Measured from drawing</td></tr>
<tr><td>Area [m²]</td><td>4.3</td><td>Calculated from drawing</td></tr>
<tr><td>Heat loss properties</td><td>Custom total U-value for the window construction [W/m²K]</td><td>1.2</td><td>TEK17: § 14-3 (1) a) [55]</td></tr>
</table>

Table A.2: North west wall, information about walls and doors.

North west, NW			Value	Reasoning/reference
Outer wall	Total area [m^2]		250.0	Calculated from drawing
	Construction	U-value [W/m^{2}K]	0.70	Best found U-value for glass
		Heat storage in inner layer [Wh/m^{2}K]	0.8	Low value for glass
	Orientation [°]		315	Drawing
Door 1 (double)	Number of (equal) doors		1	Counted from drawing
	Door size	Width [m]	2.37	Measured from drawing
		Height [m]	2..77	Measured from drawing
		Area [m^2]	6.5	Calculated from drawing
	Heat loss properties	Custom total U-value for the window construction [W/m^{2}K]	1.2	TEK17: § 14-3 (1) a) [55]
Door 2	Number of (equal) doors		2	Counted from drawing
	Window size	Width [m]	1.2	Measured from drawing
		Height [m]	2.77	Measured from drawing
		Area [m^2]	3.3	Calculated from drawing
	Heat loss properties	Custom total U-value for the window construction [W/m^{2}K]	1.2	TEK17: § 14-3 (1) a) [55]

Table A.3: South west wall, information about walls and doors.

South west, SW			Value	Reasoning/reference
Outer wall	Total area [m^2]		188.7	Calculated from drawing
	Construction	U-value [W/m^{2}K]	0.70	Best found U-value for glass
		Heat storage in inner layer [Wh/m^{2}K]	0.8	Low value for glass
	Orientation [°]		225	Drawing
Door	Number of (equal) doors		2	Counted from drawing
	Window size	Width [m]	1.3	Measured from drawing
		Height [m]	2.77	Measured from drawing
		Area [m^2]	3.6	Calculated from drawing
	Heat loss properties	Custom total U-value for the window construction [W/m^{2}K]	1.2	TEK17: § 14-3 (1) a) [55]

Table A.4: Information about the basement of the concept building.

Basement		Value	Reasoning/reference
Size	Floor area [m^2]	497.3	Measured in drawing
	Outer circumference [m]	96.8	Measured in drawing
	Thickness of walls [m]	0.3	Measured in drawing
Construction	U-value [W/m^2K]	0.18	
	Heat storage in inner layer [Wh/m^2K]	63	Value from SIMIEN: Very heavy construction (concrete >100 mm)
Ground/soil conditions	Thermal conductivity [W/mK]	2.00	Value from SIMIEN: clay/silt
	Heat capacity [Wh/m^3K]	556	Value from SIMIEN: clay/silt

Table A.5: Information about internal loads of the concept building.

Internal loads			Value	Reasoning/reference
Lighting	During operating time	Mean power [W/m^2]	3.7	SN-NSPEK 3031:2020, table A.6 [57]
		Heat gain [%]	100	SN-NSPEK 3031:2020, table A.6 [57]
	Outside operating time	Mean power [W/m^2]	0.4	SN-NSPEK 3031:2020, table A.6 [57]
		Heat gain [%]	100	SN-NSPEK 3031:2020, table A.6 [57]
	Operating time		7/52	Open every day
Technical equipment	During operating time	Mean power [W/m^2]	5.42	SN-NSPEK 3031:2020, table A.3 [57]
		Heat gain [%]	100	SN-NSPEK 3031:2020, table A.3 [57]
	Outside operating time	Mean power [W/m^2]	0.89	SN-NSPEK 3031:2020, table A.3 [57]
		Heat gain [%]	100	SN-NSPEK 3031:2020, table A.3 [57]
	Operating time		7/52	Open every day
Tap water	During operating time	Mean power [W/m^2]	1.92	SN-NSPEK 3031:2020, table A.2 [57]
		Heat gain [%]	0	SN-NSPEK 3031:2020, table A.2 [57]
	Outside operating time	Mean power [W/m^2]	0	SN-NSPEK 3031:2020, table A.2 [57]
		Heat gain [%]	0	SN-NSPEK 3031:2020, table A.2 [57]
	Operating time		7/52	Open every day
Heat gain people	During working hours	Mean power [W/m^2]	5	SN-NSPEK 3031:2020, table A.5 [57]
	Outside working hours	Mean power [W/m^2]	0	SN-NSPEK 3031:2020, table A.5 [57]
	Operating time		7/52	Open every day

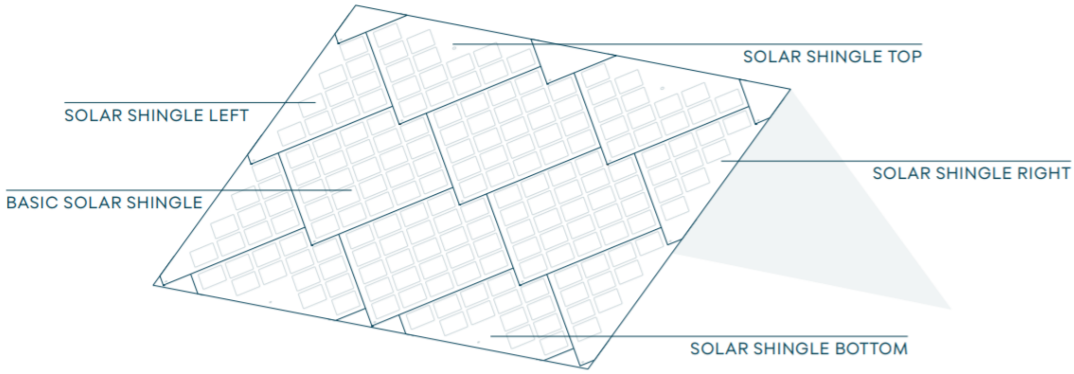
Table A.6: Information about heating and ventilation in the concept building.

Heating and ventilation			Value	Reasoning/reference
Heating	Capacity heating system	Maximum power output per area [W/m^2]	50	Value from SIMIEN
		⇒ maximum power output [kW]	75.8	Automatically calculated in SIMIEN
		Convective portion of maximum power output [°C]	0.5	Value from SIMIEN
	Operating strategy	Set temperature during working hours [°C]	21	Value from SIMIEN
		Set temperature outside of working hours [°C]	19	Value from SIMIEN
	Operating strategy summer	Set temperature during working hours [°C]	19	Value from SIMIEN
		Set temperature outside of working hours [°C]	16	Value from SIMIEN
		Summer months	May-Sept.	From SIMIEN
Ventilation	Type		Balanced	Chosen system
	Air volume	Supply air during operating hours [m^3/hm^2]	8.15	Chosen value
		Supply air outside of operating hours [m^3/hm^2]	2	Chosen value
		Extract air in operating hours [m^3/hm^2]	8.15	Chosen value
		Extract air outside operating hours [m^3/hm^2]	2	Chosen value
	Supply air temperature (constant) [°C]		19	Chosen value
	Components	SPF-factor [kW/m^3/s]	1.5	Chosen value
		Heat recovery efficiency [%]	82	Chosen value

B Technical Data Sheet - Solar Shingles [61]

SUNSTYLE® SOLAR ROOF

TECHNICAL DATA



GENERAL CHARACTERISTICS	
Dimension basic shingles	870 × 870 mm
Glass properties	Transmission optimized solar glass (ESG)
Glass thickness	6 mm
Solar cell type	Monocristalline silicon cells
Laminate structure	Glass | EVA | Cells | EVA | Back sheet
Junction box	Multi-Contact or equal
Bypass diode	One diode per shingle
Connection cable	Solar cable 4 mm², lenght 800 mm each
Connector	Multi-Contact (MC4) or equal
Weight	19.5 kg/m²
Substructure	Wooden slats or steel tubes
Temperature range	−40°C to +85°C
System power	Up to 162 Wp/m²

QUALITY AND WARRANTY	
Product guarantee	10 years
Performance guarantee	10 years at 90 % of the nominal output 25 years at 80 % of the nominal output
Quality and Certification	IEC 61215 IEC 61730 (protection class II)
Fire safety	DIN-EN 13501-5
Hail resistance class	HW 4 (withstands 40 mm Ø hailstones)
Certified pressure load	5 400 N/m²
Certified pressure load alpine	15 400 N/m²
Accessibility	Can be accessed without any guarantee restrictions
Watertightness	Min. slope 3° (cf. notice sheet: requirement roof-buildup)

ELECTRICAL PROPERTIES AT STC (1000 W/m², 25°C and AM 1,5)

Type of solar shingle	BASIC SHINGLE	SHINGLE TOP	SHINGLE BOTTOM	SHINGLE LEFT	SHINGLE RIGHT
Nominal output	108 Wp	63 Wp	58 Wp	45 Wp	45 Wp
Voltage Umpp	12.7 V	7.4 V	6.9 V	5.3 V	5.3 V
Current Impp	8.5 A	8.5 A	8.5 A	8.5 A	8.5 A
Open circuit voltage Uoc	15.9 V	8.8 V	8.2 V	6.3 V	6.3 V
Short circuit current Ioc	9.1 A	9.1 A	9.1 A	9.1 A	9.1 A
Maximum system voltage	1000 V DC	1000 V DC	1000 V DC	1000 V DC	1000 V DC
Reverse current overload	18 A	18 A	18 A	18 A	18 A
Tolerance nominal output	±3 %	±3 %	±3 %	±3 %	±3 %

TEMPERATURE COEFFICIENTS	
Temperature coefficient voltage (Uoc)	−0,3 %/K
Temperature coefficient nominal output (Pmpp)	−0,4 %/K
Temperature coefficient short circuit current (Isc)	+0,05 %/K

SYSTEM EXTENSIONS	
Customizable SUNSTYLE® shingles	Compound plates
Snow stopper	Stainless steel, black
Alpine substructure	Wood

SWISS ENGINEERED

SUNSTYLE LTD
BERNSTRASSE 54, CH-3072 OSTERMUNDIGEN, PHONE +41 (0)31 300 30 20
CONTACT@SUNSTYLE.COM, WWW.SUNSTYLE.COM

C Results from SIMIEN

Figure C.1 shows the energy budget and the delivered energy to the building when the energy supply consists of only an electric boiler.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	228583 kWh	150,7 kWh/m²
1b El. til varmepumpesystem	0 kWh	0,0 kWh/m²
1c El. til solfangersystem	0 kWh	0,0 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-0 kWh	-0,0 kWh/m²
Totalt levert energi, sum 1-7	228583 kWh	150,7 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	228583 kWh	150,7 kWh/m²

Figure C.1: Results from SIMIEN for the base case.

Figures C.2-C.19 shows the energy budget and the delivered energy to the building for combinations 1-18.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	110980 kWh	73,2 kWh/m²
1b El. til varmepumpesystem	35134 kWh	23,2 kWh/m²
1c El. til solfangersystem	0 kWh	0,0 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-0 kWh	-0,0 kWh/m²
Totalt levert energi, sum 1-7	146114 kWh	96,3 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	146114 kWh	96,3 kWh/m²

Figure C.2: Results from SIMIEN for combination 1.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111192 kWh	73,3 kWh/m²
1b El. til varmepumpesystem	44422 kWh	29,3 kWh/m²
1c El. til solfangersystem	0 kWh	0,0 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-0 kWh	-0,0 kWh/m²
Totalt levert energi, sum 1-7	155613 kWh	102,6 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	155613 kWh	102,6 kWh/m²

Figure C.3: Results from SIMIEN for combination 2.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	110980 kWh	73,2 kWh/m²
1b El. til varmepumpesystem	35134 kWh	23,2 kWh/m²
1c El. til solfangersystem	0 kWh	0,0 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-17202 kWh	-11,3 kWh/m²
Totalt levert energi, sum 1-7	128912 kWh	85,0 kWh/m²
Solstrøm til eksport	-222 kWh	-0,1 kWh/m²
Netto levert energi	128690 kWh	84,8 kWh/m²

Figure C.4: Results from SIMIEN for combination 3.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	110980 kWh	73,2 kWh/m²
1b El. til varmepumpesystem	35134 kWh	23,2 kWh/m²
1c El. til solfangersystem	0 kWh	0,0 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-13548 kWh	-8,9 kWh/m²
Totalt levert energi, sum 1-7	132566 kWh	87,4 kWh/m²
Solstrøm til eksport	-4 kWh	-0,0 kWh/m²
Netto levert energi	132562 kWh	87,4 kWh/m²

Figure C.5: Results from SIMIEN for combination 4.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111192 kWh	73,3 kWh/m²
1b El. til varmepumpesystem	44422 kWh	29,3 kWh/m²
1c El. til solfangersystem	0 kWh	0,0 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-17222 kWh	-11,4 kWh/m²
Totalt levert energi, sum 1-7	138392 kWh	91,2 kWh/m²
Solstrøm til eksport	-203 kWh	-0,1 kWh/m²
Netto levert energi	138189 kWh	91,1 kWh/m²

Figure C.6: Results from SIMIEN for combination 5.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111192 kWh	73,3 kWh/m²
1b El. til varmepumpesystem	44422 kWh	29,3 kWh/m²
1c El. til solfangersystem	0 kWh	0,0 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-13550 kWh	-8,9 kWh/m²
Totalt levert energi, sum 1-7	142063 kWh	93,7 kWh/m²
Solstrøm til eksport	-3 kWh	-0,0 kWh/m²
Netto levert energi	142061 kWh	93,7 kWh/m²

Figure C.7: Results from SIMIEN for combination 6.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111479 kWh	73,5 kWh/m²
1b El. til varmepumpesystem	23671 kWh	15,6 kWh/m²
1c El. til solfangersystem	653 kWh	0,4 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-0 kWh	-0,0 kWh/m²
Totalt levert energi, sum 1-7	135803 kWh	89,5 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	135803 kWh	89,5 kWh/m²

Figure C.8: Results from SIMIEN for combination 7.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111479 kWh	73,5 kWh/m²
1b El. til varmepumpesystem	23671 kWh	15,6 kWh/m²
1c El. til solfangersystem	901 kWh	0,6 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-0 kWh	-0,0 kWh/m²
Totalt levert energi, sum 1-7	136052 kWh	89,7 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	136052 kWh	89,7 kWh/m²

Figure C.9: Results from SIMIEN for combination 8.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111192 kWh	73,3 kWh/m²
1b El. til varmepumpesystem	29863 kWh	19,7 kWh/m²
1c El. til solfangersystem	653 kWh	0,4 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-0 kWh	-0,0 kWh/m²
Totalt levert energi, sum 1-7	141707 kWh	93,4 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	141707 kWh	93,4 kWh/m²

Figure C.10: Results from SIMIEN for combination 9.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111192 kWh	73,3 kWh/m²
1b El. til varmepumpesystem	29863 kWh	19,7 kWh/m²
1c El. til solfangersystem	901 kWh	0,6 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-0 kWh	-0,0 kWh/m²
Totalt levert energi, sum 1-7	141956 kWh	93,6 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	141956 kWh	93,6 kWh/m²

Figure C.11: Results from SIMIEN for combination 10.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111479 kWh	73,5 kWh/m²
1b El. til varmepumpesystem	23671 kWh	15,6 kWh/m²
1c El. til solfangersystem	653 kWh	0,4 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-7468 kWh	-4,9 kWh/m²
Totalt levert energi, sum 1-7	128336 kWh	84,6 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	128336 kWh	84,6 kWh/m²

Figure C.12: Results from SIMIEN for combination 11.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111479 kWh	73,5 kWh/m²
1b El. til varmepumpesystem	23671 kWh	15,6 kWh/m²
1c El. til solfangersystem	653 kWh	0,4 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-5808 kWh	-3,8 kWh/m²
Totalt levert energi, sum 1-7	129995 kWh	85,7 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	129995 kWh	85,7 kWh/m²

Figure C.13: Results from SIMIEN for combination 12.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111479 kWh	73,5 kWh/m²
1b El. til varmepumpesystem	23671 kWh	15,6 kWh/m²
1c El. til solfangersystem	901 kWh	0,6 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-3638 kWh	-2,4 kWh/m²
Totalt levert energi, sum 1-7	132414 kWh	87,3 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	132414 kWh	87,3 kWh/m²

Figure C.14: Results from SIMIEN for combination 13.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111479 kWh	73,5 kWh/m²
1b El. til varmepumpesystem	23671 kWh	15,6 kWh/m²
1c El. til solfangersystem	901 kWh	0,6 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-2830 kWh	-1,9 kWh/m²
Totalt levert energi, sum 1-7	133222 kWh	87,8 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	133222 kWh	87,8 kWh/m²

Figure C.15: Results from SIMIEN for combination 14.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111192 kWh	73,3 kWh/m²
1b El. til varmepumpesystem	29863 kWh	19,7 kWh/m²
1c El. til solfangersystem	653 kWh	0,4 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-7468 kWh	-4,9 kWh/m²
Totalt levert energi, sum 1-7	134240 kWh	88,5 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	134240 kWh	88,5 kWh/m²

Figure C.16: Results from SIMIEN for combination 15.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111192 kWh	73,3 kWh/m²
1b El. til varmepumpesystem	29863 kWh	19,7 kWh/m²
1c El. til solfangersystem	653 kWh	0,4 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-5808 kWh	-3,8 kWh/m²
Totalt levert energi, sum 1-7	135899 kWh	89,6 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	135899 kWh	89,6 kWh/m²

Figure C.17: Results from SIMIEN for combination 16.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111192 kWh	73,3 kWh/m²
1b El. til varmepumpesystem	29863 kWh	19,7 kWh/m²
1c El. til solfangersystem	901 kWh	0,6 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-3638 kWh	-2,4 kWh/m²
Totalt levert energi, sum 1-7	138318 kWh	91,2 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	138318 kWh	91,2 kWh/m²

Figure C.18: Results from SIMIEN for combination 17.

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	66835 kWh	44,1 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	23780 kWh	15,7 kWh/m²
2 Varmtvann (tappevann)	25509 kWh	16,8 kWh/m²
3a Vifter	28100 kWh	18,5 kWh/m²
3b Pumper	640 kWh	0,4 kWh/m²
4 Belysning	27248 kWh	18,0 kWh/m²
5 Teknisk utstyr	41925 kWh	27,6 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	2073 kWh	1,4 kWh/m²
Totalt netto energibehov, sum 1-6	216111 kWh	142,5 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	111192 kWh	73,3 kWh/m²
1b El. til varmepumpesystem	29863 kWh	19,7 kWh/m²
1c El. til solfangersystem	901 kWh	0,6 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-2830 kWh	-1,9 kWh/m²
Totalt levert energi, sum 1-7	139126 kWh	91,7 kWh/m²
Solstrøm til eksport	-0 kWh	-0,0 kWh/m²
Netto levert energi	139126 kWh	91,7 kWh/m²

Figure C.19: Results from SIMIEN for combination 18.

D Results from One Click LCA

Figure D.1 shows emissions related to transportation and end-of-life for all combinations, including the base case, combination 0. Emissions related to transportation and end-of-life are negligible compared to energy, materials and replacements. Combination 15 has the highest emissions related to transportation and end-of-life with almost 800 kg CO_2e.

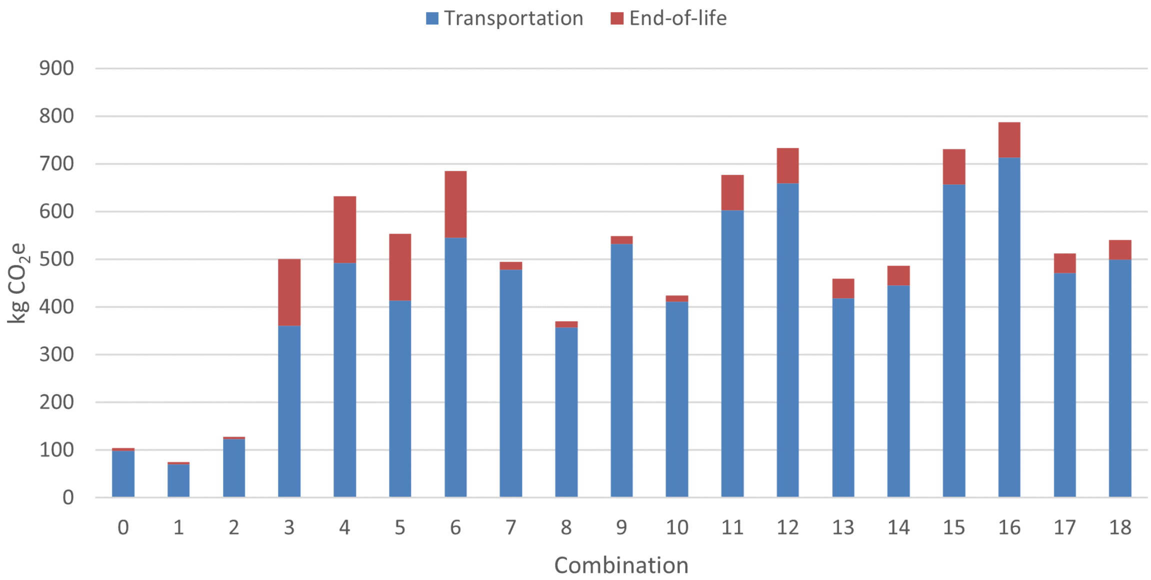


Figure D.1: Emissions related to transport and end-of-life for all combinations, including the base case.

E Results from the Profitability Analysis

Combination 1: Water-to-Water Heat Pump

Figure E.1 shows the input for the NPV calculation for combination 1.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	20		
		Electric boiler	30		
El. saved [kWh]	82469				
Benefits [NOK]	80539	**Maintenance cost [NOK]**			
		Heat pump		-25193	
Water-to-water hp	32	Saved on electric boiler		5264	
Hardware	-1259630	Total		-19928	
Installation	0				
Enova	51200	**Residual value [NOK]**			
Investment [NOK]	-1208430		**Rrep**	**Rrem**	**S**
		heat pump	40	10	629815
Saved costs on reduced size of		Electric boiler	30	10	-87735
electric boiler [NOK]	263206	Total			542080
Enova heat pump	1600				

Figure E.1: Input for the NPV calculation for combination 1.

Figure E.26 shows the NPV calculation for combination 1 completed in Excel.

Combination 1		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-945225				-945225					-945225
1	0.952			-19928				-18980		76704	57725
2	0.907			-19928				-18076		73051	54976
3	0.864			-19928				-17215		69573	52358
4	0.823			-19928				-16395		66260	49865
5	0.784			-19928				-15614		63105	47490
6	0.746			-19928				-14871		60100	45229
7	0.711			-19928				-14163		57238	43075
8	0.677			-19928				-13488		54512	41024
9	0.645			-19928				-12846		51916	39070
10	0.614			-19928				-12234		49444	37210
11	0.585			-19928				-11652		47090	35438
12	0.557			-19928				-11097		44847	33750
13	0.530			-19928				-10569		42712	32143
14	0.505			-19928				-10065		40678	30613
15	0.481			-19928				-9586		38741	29155
16	0.458			-19928				-9129		36896	27766
17	0.436			-19928				-8695		35139	26444
18	0.416			-19928				-8281		33466	25185
19	0.396			-19928				-7886		31872	23986
20	0.377		-1259630	5264			-371972	1984		30354	-339634
21	0.359			-19928				-7153		28909	21756
22	0.342			-19928				-6813		27532	20720
23	0.326			-19928				-6488		26221	19733
24	0.310			-19928				-6179		24973	18793
25	0.295			-19928				-5885		23783	17899
26	0.281			-19928				-5605		22651	17046
27	0.268			-19928				-5338		21572	16234
28	0.255			-19928				-5084		20545	15461
29	0.243			-19928				-4842		19567	14725
30	0.231		263206	-25193			60900	-5829		18635	73706
31	0.220			-19928				-4391		17748	13356
32	0.210			-19928				-4182		16902	12720
33	0.200			-19928				-3983		16098	12114
34	0.190			-19928				-3793		15331	11538
35	0.181			-19928				-3613		14601	10988
36	0.173			-19928				-3441		13906	10465
37	0.164			-19928				-3277		13244	9967
38	0.157			-19928				-3121		12613	9492
39	0.149			-19928				-2972		12012	9040
40	0.142		-1259630	5264			-178925	748		11440	-166737
41	0.135			-19928				-2696		10895	8200
42	0.129			-19928				-2568		10377	7809
43	0.123			-19928				-2445		9883	7437
44	0.117			-19928				-2329		9412	7083
45	0.111			-19928				-2218		8964	6746
46	0.106			-19928				-2112		8537	6425
47	0.101			-19928				-2012		8130	6119
48	0.096			-19928				-1916		7743	5827
49	0.092			-19928				-1825		7374	5550
50	0.087			-19928	542080			-1738	47271	7023	52557
		-945225	-2256055	-951304		-945225	-489998	-351958		0	-269591

Figure E.2: NPV calculation for combination 1 completed in Excel.

Combination 2: Air-to-Water Heat Pump

Figure E.3 shows the input for the NPV calculation for combination 2.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	15		
		Electric boiler	30		
El. saved [kWh]	72970				
Benefits [NOK]	71263	**Maintenance cost [NOK]**			
		Heat pump		-3529	
Air-to-water	32	Saved on electric boiler		5264	
Hardware	-166464	Total		1735	
Installation	-10000				
Investment [NOK]	-176464	**Residual value [NOK]**			
			Rrep	**Rrem**	**S**
Saved costs on reduced size of		Heat pump	45	10	117643
electric boiler [NOK]	263206	Electric boiler	30	10	-87735
		Total			29907

Figure E.3: Input for the NPV calculation for combination 2.

Figure E.4 shows the NPV calculation for combination 2 completed in Excel.

Combination 2		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	86742				86742					86742
1	0.952			516				492		67869	68361
2	0.907			516				468		64637	65105
3	0.864			516				446		61559	62005
4	0.823			516				425		58628	59053
5	0.784			516				404		55836	56241
6	0.746			516				385		53177	53562
7	0.711			516				367		50645	51012
8	0.677			516				349		48233	48583
9	0.645			516				333		45936	46269
10	0.614			516				317		43749	44066
11	0.585			516				302		41666	41968
12	0.557			516				287		39682	39969
13	0.530			516				274		37792	38066
14	0.505			516				261		35992	36253
15	0.481		-176464	37070			-84882	17831		34278	-32772
16	0.458			516				236		32646	32883
17	0.436			516				225		31092	31317
18	0.416			516				215		29611	29826
19	0.396			516				204		28201	28405
20	0.377			516				195		26858	27053
21	0.359			516				185		25579	25764
22	0.342			516				176		24361	24538
23	0.326			516				168		23201	23369
24	0.310			516				160		22096	22256
25	0.295			516				152		21044	21196
26	0.281			516				145		20042	20187
27	0.268			516				138		19088	19226
28	0.255			516				132		18179	18310
29	0.243			516				125		17313	17438
30	0.231		86742	0			20070	0		16489	36559
31	0.220			516				114		15703	15817
32	0.210			516				108		14956	15064
33	0.200			516				103		14243	14347
34	0.190			516				98		13565	13663
35	0.181			516				94		12919	13013
36	0.173			516				89		12304	12393
37	0.164			516				85		11718	11803
38	0.157			516				81		11160	11241
39	0.149			516				77		10629	10706
40	0.142			516				73		10123	10196
41	0.135			516				70		9641	9710
42	0.129			516				67		9181	9248
43	0.123			516				63		8744	8808
44	0.117			516				60		8328	8388
45	0.111		-176464	37070			-19640	4126		7931	-7583
46	0.106			516				55		7554	7608
47	0.101			516				52		7194	7246
48	0.096			516				50		6851	6901
49	0.092			516				47		6525	6572
50	0.087			516	29907			45	2608	6214	8867
		86742	-266186	98403		86742	-84452	30956		1300963	1336817

Figure E.4: NPV calculation for combination 2 completed in Excel.

Combination 3: Water-to-Water Heat Pump + Standard Solar Panels

Figure E.5 shows the input for the NPV calculation for combination 3.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	20		
		Electric boiler	30		
El. saved [kWh]	82469				
Benefits [NOK]	80539	**Maintenance cost [NOK]**			
		Heat pump		-25193	
Water-to-water hp	32	Saved on electric boiler		5264	
Hardware	-1259630	Total		-19928	
Installation	0				
Enova	51200	**Residual value [NOK]**			
Investment [NOK]	-1208430		**Rrep**	**Rrem**	**S**
		heat pump	40	10	629815
Saved costs on reduced size of		Electric boiler	30	10	-87735
electric boiler [NOK]	263206	Total			542080
Enova heat pump	1600				

Figure E.5: Input for the NPV calculation for combination 3.

Figure E.6 shows the NPV calculation for combination 3 completed in Excel.

Combination 3		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-1428435				-1428435					-1428435
1	0.952			-19928				-18980		92910	73930
2	0.907			-19928				-18076		88486	70410
3	0.864			-19928				-17215		84272	67057
4	0.823			-19928				-16395		80259	63864
5	0.784			-19928				-15614		76437	60823
6	0.746			-19928				-14871		72797	57926
7	0.711			-19928				-14163		69331	55168
8	0.677			-19928				-13488		66029	52541
9	0.645			-19928				-12846		62885	50039
10	0.614			-19928				-12234		59891	47656
11	0.585			-19928				-11652		57039	45387
12	0.557			-19928				-11097		54323	43226
13	0.530			-19928				-10569		51736	41167
14	0.505			-19928				-10065		49272	39207
15	0.481			-19928				-9586		46926	37340
16	0.458			-19928				-9129		44691	35562
17	0.436			-19928				-8695		42563	33868
18	0.416			-19928				-8281		40536	32256
19	0.396			-19928				-7886		38606	30720
20	0.377		-1259630	5264			-371972	1984		36768	-333221
21	0.359			-19928				-7153		35017	27864
22	0.342			-19928				-6813		33349	26537
23	0.326			-19928				-6488		31761	25273
24	0.310			-19928				-6179		30249	24070
25	0.295		-483210	-19928			-142693	-5885		28808	-119770
26	0.281			-19928				-5605		27437	21832
27	0.268			-19928				-5338		26130	20792
28	0.255			-19928				-5084		24886	19802
29	0.243			-19928				-4842		23701	18859
30	0.231		263206	-25193			60900	-5829		22572	77643
31	0.220			-19928				-4391		21497	17106
32	0.210			-19928				-4182		20474	16291
33	0.200			-19928				-3983		19499	15516
34	0.190			-19928				-3793		18570	14777
35	0.181			-19928				-3613		17686	14073
36	0.173			-19928				-3441		16844	13403
37	0.164			-19928				-3277		16042	12765
38	0.157			-19928				-3121		15278	12157
39	0.149			-19928				-2972		14550	11578
40	0.142		-1259630	5264			-178925	748		13857	-164320
41	0.135			-19928				-2696		13197	10502
42	0.129			-19928				-2568		12569	10001
43	0.123			-19928				-2445		11970	9525
44	0.117			-19928				-2329		11400	9072
45	0.111			-19928				-2218		10858	8640
46	0.106			-19928				-2112		10341	8228
47	0.101			-19928				-2012		9848	7836
48	0.096			-19928				-1916		9379	7463
49	0.092			-19928				-1825		8933	7108
50	0.087			-19928	542080			-1738	47271	8507	54041
		-1428435	-2739265	-951304		-1428435	-632691	-351958		0	-584846

Figure E.6: NPV calculation for combination 3 completed in Excel.

Combination 4: Water-to-Water Heat Pump + Solar Shingles

Figure E.7 shows the input for the NPV calculation for combination 4.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	20		
		Electric boiler	30		
El. saved [kWh]	82469				
Benefits [NOK]	80539	**Maintenance cost [NOK]**			
		Heat pump		-25193	
Water-to-water hp	32	Saved on electric boiler		5264	
Hardware	-1259630	Total		-19928	
Installation	0				
Enova	51200	**Residual value [NOK]**			
Investment [NOK]	-1208430		**Rrep**	**Rrem**	**S**
		heat pump	40	10	629815
Saved costs on reduced size of		Electric boiler	30	10	-87735
electric boiler [NOK]	263206	Total			542080
Enova heat pump	1600				

Figure E.7: Input for the NPV calculation for combination 4.

Figure E.8 shows the NPV calculation for combination 4 completed in Excel.

Combination 4			Nominal cash flows				Discounted cash flows				
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-1491225				-1491225					-1491225
1	0.952			-19928				-18980		89309	70329
2	0.907			-19928				-18076		85056	66980
3	0.864			-19928				-17215		81006	63791
4	0.823			-19928				-16395		77148	60753
5	0.784			-19928				-15614		73474	57860
6	0.746			-19928				-14871		69976	55105
7	0.711			-19928				-14163		66644	52481
8	0.677			-19928				-13488		63470	49982
9	0.645			-19928				-12846		60448	47602
10	0.614			-19928				-12234		57569	45335
11	0.585			-19928				-11652		54828	43176
12	0.557			-19928				-11097		52217	41120
13	0.530			-19928				-10569		49730	39162
14	0.505			-19928				-10065		47362	37297
15	0.481			-19928				-9586		45107	35521
16	0.458			-19928				-9129		42959	33830
17	0.436			-19928				-8695		40913	32219
18	0.416			-19928				-8281		38965	30684
19	0.396			-19928				-7886		37110	29223
20	0.377		-1259630	5264			-371972	1984		35342	-334646
21	0.359			-19928				-7153		33660	26506
22	0.342			-19928				-6813		32057	25244
23	0.326			-19928				-6488		30530	24042
24	0.310			-19928				-6179		29076	22897
25	0.295		-546000	-19928			-161235	-5885		27692	-139428
26	0.281			-19928				-5605		26373	20768
27	0.268			-19928				-5338		25117	19779
28	0.255			-19928				-5084		23921	18838
29	0.243			-19928				-4842		22782	17941
30	0.231		263206	-25193			60900	-5829		21697	76768
31	0.220			-19928				-4391		20664	16273
32	0.210			-19928				-4182		19680	15498
33	0.200			-19928				-3983		18743	14760
34	0.190			-19928				-3793		17850	14057
35	0.181			-19928				-3613		17000	13387
36	0.173			-19928				-3441		16191	12750
37	0.164			-19928				-3277		15420	12143
38	0.157			-19928				-3121		14686	11565
39	0.149			-19928				-2972		13986	11014
40	0.142		-1259630	5264			-178925	748		13320	-164857
41	0.135			-19928				-2696		12686	9990
42	0.129			-19928				-2568		12082	9514
43	0.123			-19928				-2445		11506	9061
44	0.117			-19928				-2329		10959	8630
45	0.111			-19928				-2218		10437	8219
46	0.106			-19928				-2112		9940	7827
47	0.101			-19928				-2012		9466	7455
48	0.096			-19928				-1916		9016	7100
49	0.092			-19928				-1825		8586	6762
50	0.087			-19928	516480			-1738	45039	8177	51479
		-1491225	-2802055	-951304		-1491225	-651233	-351958		0	-737444

Figure E.8: NPV calculation for combination 4 completed in Excel.

Combination 5: Air-to-Water Heat Pump + Standard Solar Panels

Figure E.9 shows the input for the NPV calculation for combination 5.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	15		
		Electric boil	30		
El. saved [kWh]	90394	Solar panel	25		
Benefits [NOK]	88279				
		Maintenance cost [NOK]			
Air-to-water	32	Heat pump		-3529	
Hardware	-166464	Saved on electric boile		5264	
Installation	-10000	Total		1735	
Investment [NOK]	**-176464**				
		Residual value			
Standard solar panels			**Rrep**	**Rrem**	**S**
m2	182	heat pump	45	10	117643
Costs	-2655	El boiler	30	10	-87735
Investment [NOK]	-483210	Total			29907
Saved costs on reduced size of					
electric boiler [NOK]	263206				

Figure E.9: Input for the NPV calculation for combination 5.

Figure E.10 shows the NPV calculation for combination 5 completed in Excel.

Combination 5		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-396468				-396468					-396468
1	0.952			1735				1652		84075	85727
2	0.907			1735				1574		80071	81645
3	0.864			1735				1499		76259	77757
4	0.823			1735				1427		72627	74054
5	0.784			1735				1359		69169	70528
6	0.746			1735				1295		65875	67170
7	0.711			1735				1233		62738	63971
8	0.677			1735				1174		59751	60925
9	0.645			1735				1118		56905	58024
10	0.614			1735				1065		54196	55261
11	0.585			1735				1014		51615	52629
12	0.557			1735				966		49157	50123
13	0.530			1735				920		46816	47736
14	0.505			1735				876		44587	45463
15	0.481		-176464	5264			-84882	2532		42464	-39886
16	0.458			1735				795		40442	41236
17	0.436			1735				757		38516	39273
18	0.416			1735				721		36682	37403
19	0.396			1735				687		34935	35621
20	0.377			1735				654		33271	33925
21	0.359			1735				623		31687	32310
22	0.342			1735				593		30178	30771
23	0.326			1735				565		28741	29306
24	0.310			1735				538		27372	27910
25	0.295		-483210	1735			-142693	512		26069	-116112
26	0.281			1735				488		24828	25315
27	0.268			1735				465		23645	24110
28	0.255			1735				443		22519	22962
29	0.243			1735				421		21447	21868
30	0.231		86742	0			20070	0		20426	40496
31	0.220			1735				382		19453	19835
32	0.210			1735				364		18527	18891
33	0.200			1735				347		17645	17991
34	0.190			1735				330		16804	17135
35	0.181			1735				315		16004	16319
36	0.173			1735				300		15242	15542
37	0.164			1735				285		14516	14801
38	0.157			1735				272		13825	14097
39	0.149			1735				259		13167	13425
40	0.142			1735				246		12540	12786
41	0.135			1735				235		11942	12177
42	0.129			1735				224		11374	11597
43	0.123			1735				213		10832	11045
44	0.117			1735				203		10316	10519
45	0.111		-176464	5264			-19640	586		9825	-9229
46	0.106			1735				184		9357	9541
47	0.101			1735				175		8912	9087
48	0.096			1735				167		8487	8654
49	0.092			1735				159		8083	8242
50	0.087			1735	29907			151	2608	7698	10458
		-396468	-749396	92065		-396468	-227145	33360		1611611	1023965

Figure E.10: NPV calculation for combination 5 completed in Excel.

Combination 6: Air-to-Water Heat Pump + Solar Shingles

Figure E.11 shows the input for the NPV calculation for combination 6.

El. price [NOK/kWh]	0.9766		**Lifetime**			
Real discount rate	0.05		Heat pump	**15**		
			Electric boiler	30		
El. saved [kWh]	86522		Solar panel	25		
Benefits [NOK]	84497					
			Maintenance cost [NOK]			
Air-to-water	32		Heat pump	-3529		
Hardware	-166464		Saved on electric b	5264		
Installation	-10000		Total	1735		
Investment [NOK]	-176464					
			Residual value			
Solar shingles				**Rrep**	**Rrem**	**S**
m2	182		heat pump	45	10	117643
costs	-3000		El boiler	30	10	-87735
Investment [NOK]	-546000		Total			29907
Saved costs on reduced size of						
electric boiler [NOK]	263206					

Figure E.11: Input for the NPV calculation for combination 6.

Figure E.12 shows the NPV calculation for combination 6 completed in Excel.

Combination 6		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-459258				-459258					-459258
1	0.952			1735				1652		80474	82126
2	0.907			1735				1574		76642	78215
3	0.864			1735				1499		72992	74491
4	0.823			1735				1427		69516	70943
5	0.784			1735				1359		66206	67565
6	0.746			1735				1295		63053	64348
7	0.711			1735				1233		60051	61284
8	0.677			1735				1174		57191	58365
9	0.645			1735				1118		54468	55586
10	0.614			1735				1065		51874	52939
11	0.585			1735				1014		49404	50418
12	0.557			1735				966		47051	48017
13	0.530			1735				920		44811	45731
14	0.505			1735				876		42677	43553
15	0.481		-176464	5264			-84882	2532		40645	-41705
16	0.458			1735				795		38709	39504
17	0.436			1735				757		36866	37623
18	0.416			1735				721		35110	35831
19	0.396			1735				687		33438	34125
20	0.377			1735				654		31846	32500
21	0.359			1735				623		30330	30952
22	0.342			1735				593		28885	29478
23	0.326			1735				565		27510	28075
24	0.310			1735				538		26200	26738
25	0.295		-546000	1735			-161235	512		24952	-135771
26	0.281			1735				488		23764	24252
27	0.268			1735				465		22632	23097
28	0.255			1735				443		21555	21997
29	0.243			1735				421		20528	20950
30	0.231		86742	0			20070	0		19551	39621
31	0.220			1735				382		18620	19002
32	0.210			1735				364		17733	18097
33	0.200			1735				347		16889	17235
34	0.190			1735				330		16084	16415
35	0.181			1735				315		15319	15633
36	0.173			1735				300		14589	14889
37	0.164			1735				285		13894	14180
38	0.157			1735				272		13233	13504
39	0.149			1735				259		12603	12861
40	0.142			1735				246		12002	12249
41	0.135			1735				235		11431	11666
42	0.129			1735				224		10887	11110
43	0.123			1735				213		10368	10581
44	0.117			1735				203		9874	10077
45	0.111		-176464	5264			-19640	586		9404	-9650
46	0.106			1735				184		8956	9140
47	0.101			1735				175		8530	8705
48	0.096			1735				167		8124	8291
49	0.092			1735				159		7737	7896
50	0.087			1735	29907			151	2608	7368	10128
		-459258	-812186	92065		-459258	-245687	33360		1542578	873600

Figure E.12: NPV calculation for combination 6 completed in Excel.

Combination 7: Water-to-Water Heat Pump + Evacuated Tube Collectors

Figure E.13 shows the input for the NPV calculation for combination 7.

El. price [NOK/kWh]	0.9766		**Lifetime**			
Real discount rate	0.05		Heat pump	20		
			Electric boiler	30		
El. saved [kWh]	92780		Solar panel	25		
Benefits [NOK]	90609					
Water-to-water hp	25		**Maintenance cost [NOK]**			
Hardware	-997803		Heat pump		-19956.1	
Installation	0		Saved on electric boiler		5264	
Enova	40000		Total		-14691.9	
Investment [NOK]	-957803					
			Residual value			
Evacuated				**Rrep**	**Rrem**	**S**
m2	104		heat pump	40	10	478901
costs	-13811		El boiler	30	10	-87735
Enova	20904		Total			391166
Investment [NOK]	-1415440					
Saved costs on reduced size of			Enova hp	1600		
electric boiler [NOK]	263206		Enova solar th.	201		

Figure E.13: Input for the NPV calculation for combination 7.

Figure E.14 shows the NPV calculation for combination 7 completed in Excel.

Combination 7		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-2110037				-2110037					-2110037
1	0.952			-14692				-13992		86294	72302
2	0.907			-14692				-13326		82185	68859
3	0.864			-14692				-12691		78271	65580
4	0.823			-14692				-12087		74544	62457
5	0.784			-14692				-11512		70994	59483
6	0.746			-14692				-10963		67614	56650
7	0.711			-14692				-10441		64394	53953
8	0.677			-14692				-9944		61328	51384
9	0.645			-14692				-9471		58407	48937
10	0.614			-14692				-9020		55626	46606
11	0.585			-14692				-8590		52977	44387
12	0.557			-14692				-8181		50454	42273
13	0.530			-14692				-7791		48052	40260
14	0.505			-14692				-7420		45764	38343
15	0.481			-14692				-7067		43584	36517
16	0.458			-14692				-6731		41509	34778
17	0.436			-14692				-6410		39532	33122
18	0.416			-14692				-6105		37650	31545
19	0.396			-14692				-5814		35857	30043
20	0.377		-997803	5264			-376061	1984		34150	-339928
21	0.359			-14692				-5274		32523	27250
22	0.342			-14692				-5022		30975	25952
23	0.326			-14692				-4783		29500	24716
24	0.310			-14692				-4556		28095	23539
25	0.295		-1436344	-14692			-424156	-4339		26757	-401738
26	0.281			-14692				-4132		25483	21351
27	0.268			-14692				-3935		24269	20334
28	0.255			-14692				-3748		23114	19366
29	0.243			-14692				-3569		22013	18444
30	0.231		263206	-19956			60900	-4617		20965	77247
31	0.220			-14692				-3238		19967	16729
32	0.210			-14692				-3083		19016	15932
33	0.200			-14692				-2937		18110	15174
34	0.190			-14692				-2797		17248	14451
35	0.181			-14692				-2664		16427	13763
36	0.173			-14692				-2537		15644	13108
37	0.164			-14692				-2416		14899	12483
38	0.157			-14692				-2301		14190	11889
39	0.149			-14692				-2191		13514	11323
40	0.142		-997803	5264			-141734	748		12871	-128115
41	0.135			-14692				-1988		12258	10270
42	0.129			-14692				-1893		11674	9781
43	0.123			-14692				-1803		11118	9315
44	0.117			-14692				-1717		10589	8872
45	0.111			-14692				-1635		10084	8449
46	0.106			-14692				-1557		9604	8047
47	0.101			-14692				-1483		9147	7664
48	0.096			-14692				-1413		8711	7299
49	0.092			-14692				-1345		8297	6951
50	0.087			-14692	391166			-1281	34111	7901	40731
		-2110037	-3168744	-699949		-2110037	-881052	-259077		0	-1561905

Figure E.14: NPV calculation for combination 7 completed in Excel.

Combination 8: Water-to-Water Heat Pump + Flat Plate Collectors

Figure E.15 shows the input for the NPV calculation for combination 8.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	20		
		Electric boiler	30		
El. saved [kWh]	92531	Solar panel	25		
Benefits [NOK]	90366				
Water-to-water hp	25	**Maintenance cost [NOK]**			
Hardware	-997803	Heat pump		-19956	
Installation	0	Saved on electric boiler		5264	
Enova	40000	Total		-14692	
Investment [NOK]	-957803				
Flat		**Residual value**			
m2	144		**Rrep**	**Rrem**	**S**
costs	-2860	heat pump	40	10	478901
Enova	28944	El boiler	30	10	-87735
Investment [NOK]	-382896	Total			391166
Saved costs on reduced size of		Enova hp	1600		
electric boiler [NOK]	263206	Enova solar th.	201		

Figure E.15: Input for the NPV calculation for combination 8.

Figure E.16 shows the NPV calculation for combination 8 completed in Excel.

Combination 8		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-1077493				-1077493					-1077493
1	0.952			-14692				-13992		86063	72070
2	0.907			-14692				-13326		81964	68638
3	0.864			-14692				-12691		78061	65370
4	0.823			-14692				-12087		74344	62257
5	0.784			-14692				-11512		70804	59292
6	0.746			-14692				-10963		67432	56469
7	0.711			-14692				-10441		64221	53780
8	0.677			-14692				-9944		61163	51219
9	0.645			-14692				-9471		58251	48780
10	0.614			-14692				-9020		55477	46457
11	0.585			-14692				-8590		52835	44245
12	0.557			-14692				-8181		50319	42138
13	0.530			-14692				-7791		47923	40131
14	0.505			-14692				-7420		45641	38220
15	0.481			-14692				-7067		43467	36400
16	0.458			-14692				-6731		41398	34667
17	0.436			-14692				-6410		39426	33016
18	0.416			-14692				-6105		37549	31444
19	0.396			-14692				-5814		35761	29947
20	0.377		-997803	5264			-376061	1984		34058	-340020
21	0.359			-14692				-5274		32436	27163
22	0.342			-14692				-5022		30892	25869
23	0.326			-14692				-4783		29421	24637
24	0.310			-14692				-4556		28020	23464
25	0.295		-411840	-14692			-121617	-4339		26685	-99271
26	0.281			-14692				-4132		25415	21283
27	0.268			-14692				-3935		24204	20269
28	0.255			-14692				-3748		23052	19304
29	0.243			-14692				-3569		21954	18385
30	0.231		263206	-19956			60900	-4617		20909	77191
31	0.220			-14692				-3238		19913	16675
32	0.210			-14692				-3083		18965	15881
33	0.200			-14692				-2937		18062	15125
34	0.190			-14692				-2797		17202	14405
35	0.181			-14692				-2664		16382	13719
36	0.173			-14692				-2537		15602	13066
37	0.164			-14692				-2416		14859	12443
38	0.157			-14692				-2301		14152	11851
39	0.149			-14692				-2191		13478	11287
40	0.142		-997803	5264			-141733.6016	748		12836	-128150
41	0.135			-14692				-1988		12225	10237
42	0.129			-14692				-1893		11643	9750
43	0.123			-14692				-1803		11088	9286
44	0.117			-14692				-1717		10560	8843
45	0.111			-14692				-1635		10057	8422
46	0.106			-14692				-1557		9578	8021
47	0.101			-14692				-1483		9122	7639
48	0.096			-14692				-1413		8688	7275
49	0.092			-14692				-1345		8274	6929
50	0.087			-14692	391166			-1281	34111	7880	40710
		-1077493	-2144240	-699949		-1077493	-578513	-259077		0	-231261

Figure E.16: NPV calculation for combination 8 completed in Excel.

Combination 9: Air-to-Water Heat Pump + Evacuated Tube Collectors

Figure E.17 shows the input for the NPV calculation for combination 9.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	15		
		Electric boiler	30		
El. saved [kWh]	86876	Solar panel	25		
Benefits [NOK]	84843				
Air-to-water	25	**Maintenance cost [NOK]**			
Hardware	-143438	Heat pump	-3069		
Installation	-10000	Saved on electr	5264		
Investment [NOK]	-153438	Total	2195		
Evacuated					
m2	104	**Residual value**			
costs	-13811		**Rrep**	**Rrem**	**S**
Enova	20904	heat pump	45	10	102292
Investment [NOK]	-1415440	El boiler	30	10	-87735
		Sum			14557
Saved costs on reduced size of					
electric boiler [NOK]	263206	Enova hp	1600		
		Enova solar th.	201		

Figure E.17: Input for the NPV calculation for combination 9.

Figure E.18 shows the NPV calculation for combination 9 completed in Excel.

Combination 9		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-1305672				-1305672					-1305672
1	0.952			2195				2091		80803	82894
2	0.907			2195				1991		76955	78946
3	0.864			2195				1896		73291	75187
4	0.823			2195				1806		69801	71607
5	0.784			2195				1720		66477	68197
6	0.746			2195				1638		63311	64949
7	0.711			2195				1560		60296	61857
8	0.677			2195				1486		57425	58911
9	0.645			2195				1415		54691	56106
10	0.614			2195				1348		52086	53434
11	0.585			2195				1284		49606	50890
12	0.557			2195				1222		47244	48466
13	0.530			2195				1164		44994	46158
14	0.505			2195				1109		42852	43960
15	0.481		-153438	5264			-73806	2532		40811	-30463
16	0.458			2195				1006		38868	39873
17	0.436			2195				958		37017	37975
18	0.416			2195				912		35254	36166
19	0.396			2195				869		33575	34444
20	0.377			2195				827		31976	32804
21	0.359			2195				788		30454	31242
22	0.342			2195				750		29004	29754
23	0.326			2195				715		27622	28337
24	0.310			2195				681		26307	26988
25	0.295		-1436344	2195			-424156	648		25054	-398454
26	0.281			2195				617		23861	24479
27	0.268			2195				588		22725	23313
28	0.255			2195				560		21643	22203
29	0.243			2195				533		20612	21146
30	0.231		109768	0			25398	0		19631	45029
31	0.220			2195				484		18696	19180
32	0.210			2195				461		17806	18266
33	0.200			2195				439		16958	17397
34	0.190			2195				418		16150	16568
35	0.181			2195				398		15381	15779
36	0.173			2195				379		14649	15028
37	0.164			2195				361		13951	14312
38	0.157			2195				344		13287	13631
39	0.149			2195				327		12654	12982
40	0.142			2195				312		12052	12363
41	0.135			2195				297		11478	11775
42	0.129			2195				283		10931	11214
43	0.123			2195				269		10411	10680
44	0.117			2195				257		9915	10171
45	0.111		-153438	5264			-17077	586		9443	-7048
46	0.106			2195				233		8993	9226
47	0.101			2195				222		8565	8786
48	0.096			2195				211		8157	8368
49	0.092			2195				201		7769	7970
50	0.087			2195	14557			191	1269	7399	8859
		-1305672	-1633452	113710		-1305672	-489642	41388		1548889	-203768

Figure E.18: NPV calculation for combination 9 completed in Excel.

Combination 10: Air-to-Water Heat Pump + Flat Plate Collectors

Figure E.19 shows the input for the NPV calculation for combination 10.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	15		
		Electric boiler	30		
El. saved [kWh]	86627	Solar panel	25		
Benefits [NOK]	84600				
Air-to-water	25	**Maintenance cost [NOK]**			
Hardware	-143438	Heat pump		-3069	
Installation	-10000	Saved on electric boiler		5264	
Investment [NOK]	-153438	Total		2195	
Flat		**Residual value**			
m2	144		**Rrep**	**Rrem**	**S**
costs	-2860	heat pump	45	10	102292
Enova	230400	El boiler	30	10	-87735
Investment [NOK]	-181440	Sum			14557
Saved costs on reduced size of		Enova hp	1600		
electric boiler [NOK]	263206	Enova solar th.	201		

Figure E.19: Input for the NPV calculation for combination 10.

Figure E.20 shows the NPV calculation for combination 10 completed in Excel.

Combination 10		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-71672				-71672					-71672
1	0.952			2195				2091		80571	82662
2	0.907			2195				1991		76735	78726
3	0.864			2195				1896		73081	74977
4	0.823			2195				1806		69601	71407
5	0.784			2195				1720		66286	68006
6	0.746			2195				1638		63130	64768
7	0.711			2195				1560		60124	61684
8	0.677			2195				1486		57261	58746
9	0.645			2195				1415		54534	55949
10	0.614			2195				1348		51937	53285
11	0.585			2195				1284		49464	50747
12	0.557			2195				1222		47108	48331
13	0.530			2195				1164		44865	46029
14	0.505			2195				1109		42729	43838
15	0.481		-153438	5264			-73806	2532		40694	-30580
16	0.458			2195				1006		38756	39762
17	0.436			2195				958		36911	37868
18	0.416			2195				912		35153	36065
19	0.396			2195				869		33479	34348
20	0.377			2195				827		31885	32712
21	0.359			2195				788		30366	31155
22	0.342			2195				750		28920	29671
23	0.326			2195				715		27543	28258
24	0.310			2195				681		26232	26912
25	0.295		-411840	2195			-121617	648		24983	-95987
26	0.281			2195				617		23793	24410
27	0.268			2195				588		22660	23248
28	0.255			2195				560		21581	22141
29	0.243			2195				533		20553	21087
30	0.231		109768	0			25398	0		19575	44972
31	0.220			2195				484		18642	19126
32	0.210			2195				461		17755	18215
33	0.200			2195				439		16909	17348
34	0.190			2195				418		16104	16522
35	0.181			2195				398		15337	15735
36	0.173			2195				379		14607	14986
37	0.164			2195				361		13911	14272
38	0.157			2195				344		13249	13593
39	0.149			2195				327		12618	12945
40	0.142			2195				312		12017	12329
41	0.135			2195				297		11445	11742
42	0.129			2195				283		10900	11183
43	0.123			2195				269		10381	10650
44	0.117			2195				257		9886	10143
45	0.111		-153438	5264			-17077	586		9416	-7076
46	0.106			2195				233		8967	9200
47	0.101			2195				222		8540	8762
48	0.096			2195				211		8134	8345
49	0.092			2195				201		7746	7947
50	0.087			2195	14557			191	1269	7377	8838
		-71672	-608948	113710		-71672	-187103	41388		1544450	1328332

Figure E.20: NPV calculation for combination 10 completed in Excel.

Combination 11: Water-to-Water Heat Pump + Evacuated Tube Collectors + Standard Solar Panels

Figure E.21 shows the input for the NPV calculation for combination 11.

El. price [NOK/kWh]	0.9766				
Real discount rate	0.05	**Lifetime**			
		Heat pump		20	
El. saved [kWh]	100247	Electric boiler		30	
Benefits [NOK]	97901	Solar panel		25	
		Solar thermal		25	
Water-to-water hp	25				
Hardware	-997803	**Maintenance cost [NOK]**			
Installation	0	Heat pump		-19956.1	
Enova	40000	Saved on electric boiler		5264	
Investment [NOK]	-957803	Total		-14691.9	
Evacuated		**Residual value**			
m2	104		**Rrep**	**Rrem**	**S**
costs	-13811	heat pump	40	10	478901
Enova	20904	El boiler	30	10	-87735
Investment [NOK]	-1415440	Sum			391166
Standard solar					
m2	78	Enova hp	1600		
costs	-2655	Enova solar th.	201		
Investment [NOK]	-207090				
Saved costs on reduced size of electric boiler [NOK]	263206				

Figure E.21: Input for the NPV calculation for combination 11.

Figure E.22 shows the NPV calculation for combination 11 completed in Excel.

Combination 11		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-2317127				-2317127					-2317127
1	0.952			-14692				-13992		93239	79247
2	0.907			-14692				-13326		88799	75473
3	0.864			-14692				-12691		84571	71879
4	0.823			-14692				-12087		80544	68456
5	0.784			-14692				-11512		76708	65197
6	0.746			-14692				-10963		73055	62092
7	0.711			-14692				-10441		69577	59135
8	0.677			-14692				-9944		66263	56319
9	0.645			-14692				-9471		63108	53637
10	0.614			-14692				-9020		60103	51083
11	0.585			-14692				-8590		57241	48651
12	0.557			-14692				-8181		54515	46334
13	0.530			-14692				-7791		51919	44128
14	0.505			-14692				-7420		49447	42026
15	0.481			-14692				-7067		47092	40025
16	0.458			-14692				-6731		44850	38119
17	0.436			-14692				-6410		42714	36304
18	0.416			-14692				-6105		40680	34575
19	0.396			-14692				-5814		38743	32929
20	0.377		-997803	5264			-376061	1984		36898	-337180
21	0.359			-14692				-5274		35141	29867
22	0.342			-14692				-5022		33468	28445
23	0.326			-14692				-4783		31874	27091
24	0.310			-14692				-4556		30356	25801
25	0.295		-1643434	-14692			-485311	-4339		28911	-460739
26	0.281			-14692				-4132		27534	23402
27	0.268			-14692				-3935		26223	22287
28	0.255			-14692				-3748		24974	21226
29	0.243			-14692				-3569		23785	20215
30	0.231		263206	-19956			60900	-4617		22652	78935
31	0.220			-14692				-3238		21573	18336
32	0.210			-14692				-3083		20546	17463
33	0.200			-14692				-2937		19568	16631
34	0.190			-14692				-2797		18636	15839
35	0.181			-14692				-2664		17749	15085
36	0.173			-14692				-2537		16903	14367
37	0.164			-14692				-2416		16098	13683
38	0.157			-14692				-2301		15332	13031
39	0.149			-14692				-2191		14602	12410
40	0.142		-997803	5264			-141734	748		13906	-127079
41	0.135			-14692				-1988		13244	11257
42	0.129			-14692				-1893		12614	10721
43	0.123			-14692				-1803		12013	10210
44	0.117			-14692				-1717		11441	9724
45	0.111			-14692				-1635		10896	9261
46	0.106			-14692				-1557		10377	8820
47	0.101			-14692				-1483		9883	8400
48	0.096			-14692				-1413		9412	8000
49	0.092			-14692				-1345		8964	7619
50	0.087			-14692	391166			-1281	34111	8537	41367
		-2317127	-3375834	-699949		-2317127	-942206	-259077		0	-1697022

Figure E.22: NPV calculation for combination 11 completed in Excel.

Combination 12: Water-to-Water Heat Pump + Evacuated Tube Collectors + Solar Shingles

Figure E.23 shows the input for the NPV calculation for combination 12.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	20		
		Electric boiler	30		
El. saved [kWh]	98588	Solar panel	25		
Benefits [NOK]	96281	Solar thermal	25		
Water-to-water hp	25	**Maintenance cost [NOK]**			
Hardware	-997803	Heat pump		-19956.1	
Installation	0	Saved on electric boiler		5264	
Enova	40000	Total		-14691.9	
Investment [NOK]	-957803				
Evacuated		**Residual value**			
m2	104		**Rrep**	**Rrem**	**S**
costs	-13811	heat pump	40	10	498901
Enova	20904	El boiler	30	10	-87735
Investment [NOK]	-1415440	Total			411166
Solar shingles					
m2	78				
costs	-3000	Enova hp	1600		
Investment [NOK]	-234000	Enova solar th.	201		
Saved costs on reduced size of					
electric boiler [NOK]	263206				

Figure E.23: Input for the NPV calculation for combination 12.

Figure E.24 shows the NPV calculation for combination 12 completed in Excel.

Combination 12		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-2344037				-2344037					-2344037
1	0.952			-14692				-13992		91696	77704
2	0.907			-14692				-13326		87330	74004
3	0.864			-14692				-12691		83171	70480
4	0.823			-14692				-12087		79211	67124
5	0.784			-14692				-11512		75439	63927
6	0.746			-14692				-10963		71846	60883
7	0.711			-14692				-10441		68425	57984
8	0.677			-14692				-9944		65167	55223
9	0.645			-14692				-9471		62064	52593
10	0.614			-14692				-9020		59108	50089
11	0.585			-14692				-8590		56294	47703
12	0.557			-14692				-8181		53613	45432
13	0.530			-14692				-7791		51060	43268
14	0.505			-14692				-7420		48628	41208
15	0.481			-14692				-7067		46313	39246
16	0.458			-14692				-6731		44107	37377
17	0.436			-14692				-6410		42007	35597
18	0.416			-14692				-6105		40007	33902
19	0.396			-14692				-5814		38102	32288
20	0.377		-997803	5264			-376061	1984		36287	-337790
21	0.359			-14692				-5274		34559	29286
22	0.342			-14692				-5022		32914	27891
23	0.326			-14692				-4783		31346	26563
24	0.310			-14692				-4556		29854	25298
25	0.295		-1670344	-14692			-493257	-4339		28432	-469164
26	0.281			-14692				-4132		27078	22946
27	0.268			-14692				-3935		25789	21854
28	0.255			-14692				-3748		24561	20813
29	0.243			-14692				-3569		23391	19822
30	0.231		263206	-19956			60900	-4617		22277	78560
31	0.220			-14692				-3238		21216	17979
32	0.210			-14692				-3083		20206	17123
33	0.200			-14692				-2937		19244	16307
34	0.190			-14692				-2797		18328	15531
35	0.181			-14692				-2664		17455	14791
36	0.173			-14692				-2537		16624	14087
37	0.164			-14692				-2416		15832	13416
38	0.157			-14692				-2301		15078	12777
39	0.149			-14692				-2191		14360	12169
40	0.142		-997803	5264			-141734	748		13676	-127310
41	0.135			-14692				-1988		13025	11038
42	0.129			-14692				-1893		12405	10512
43	0.123			-14692				-1803		11814	10011
44	0.117			-14692				-1717		11252	9535
45	0.111			-14692				-1635		10716	9081
46	0.106			-14692				-1557		10205	8648
47	0.101			-14692				-1483		9719	8236
48	0.096			-14692				-1413		9257	7844
49	0.092			-14692				-1345		8816	7471
50	0.087			-14692	411166			-1281	35855	8396	42970
		-2344037	-3402744	-699949		-2344037	-950152	-259077		0	-1759712

Figure E.24: NPV calculation for combination 12 completed in Excel.

Combination 13: Water-to-Water Heat Pump + Flat Plate Collectors + Standard Solar Panels

Figure E.25 shows the input for the NPV calculation for combination 13.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	20		
		Electric boiler	30		
El. saved [kWh]	96169	Solar panel	25		
Benefits [NOK]	93919	Solar thermal	25		
Water-to-water hp	25	**Maintenance cost [NOK]**			
Hardware	-997803	Heat pump		-19956	
Installation	0	Saved on electric boiler		5264	
Enova	40000	Total		-14692	
Investment [NOK]	-957803				
Flat plate collector		**Residual value**			
m2	144		**Rrep**	**Lrem**	**S**
costs	-2860	heat pump	40	10	498901
Enova	28944	El boiler	30	10	-87735
Investment [NOK]	-382896	Total			411166
Standard					
m2	38				
Costs	-2655	Enova hp	1600		
Investment [NOK]	-100890	Enova solar th.	201		
Saved costs on reduced size of electric boiler [NOK]	263206				

Figure E.25: Input for the NPV calculation for combination 13.

Figure E.26 shows the NPV calculation for combination 13 completed in Excel.

Combination 13		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-1178383				-1178383					-1178383
1	0.952			-14692				-13992		89446	75454
2	0.907			-14692				-13326		85187	71861
3	0.864			-14692				-12691		81130	68439
4	0.823			-14692				-12087		77267	65180
5	0.784			-14692				-11512		73588	62076
6	0.746			-14692				-10963		70084	59120
7	0.711			-14692				-10441		66746	56305
8	0.677			-14692				-9944		63568	53624
9	0.645			-14692				-9471		60541	51070
10	0.614			-14692				-9020		57658	48638
11	0.585			-14692				-8590		54912	46322
12	0.557			-14692				-8181		52297	44116
13	0.530			-14692				-7791		49807	42016
14	0.505			-14692				-7420		47435	40015
15	0.481			-14692				-7067		45176	38109
16	0.458			-14692				-6731		43025	36295
17	0.436			-14692				-6410		40976	34566
18	0.416			-14692				-6105		39025	32920
19	0.396			-14692				-5814		37167	31353
20	0.377		-997803	5264			-376061	1984		35397	-338681
21	0.359			-14692				-5274		33711	28438
22	0.342			-14692				-5022		32106	27084
23	0.326			-14692				-4783		30577	25794
24	0.310			-14692				-4556		29121	24566
25	0.295		-512730	-14692			-151411	-4339		27734	-128015
26	0.281			-14692				-4132		26414	22282
27	0.268			-14692				-3935		25156	21221
28	0.255			-14692				-3748		23958	20210
29	0.243			-14692				-3569		22817	19248
30	0.231		263206	-19956			60900	-4617		21731	78013
31	0.220			-14692				-3238		20696	17458
32	0.210			-14692				-3083		19710	16627
33	0.200			-14692				-2937		18772	15835
34	0.190			-14692				-2797		17878	15081
35	0.181			-14692				-2664		17027	14363
36	0.173			-14692				-2537		16216	13679
37	0.164			-14692				-2416		15444	13028
38	0.157			-14692				-2301		14708	12407
39	0.149			-14692				-2191		14008	11817
40	0.142		-997803	5264			-141734	748		13341	-127645
41	0.135			-14692				-1988		12705	10718
42	0.129			-14692				-1893		12100	10208
43	0.123			-14692				-1803		11524	9721
44	0.117			-14692				-1717		10975	9259
45	0.111			-14692				-1635		10453	8818
46	0.106			-14692				-1557		9955	8398
47	0.101			-14692				-1483		9481	7998
48	0.096			-14692				-1413		9030	7617
49	0.092			-14692				-1345		8600	7254
50	0.087			-14692	411166			-1281	35855	8190	42764
		-1178383	-2245130	-699949		-1178383	-608306	-259077		0	-295339

Figure E.26: NPV calculation for combination 13 completed in Excel.

Combination 14: Water-to-Water Heat Pump + Flat Plate Collectors + Standard Solar Panels

Figure E.27 shows the input for the NPV calculation for combination 14.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	20		
		Electric boiler	30		
El. saved [kWh]	95361	Solar panel	25		
Benefits [NOK]	93130	Solar thermal	25		
Water-to-water hp	25	**Maintenance cost [NOK]**			
Hardware	-997803	Heat pump		-19956.1	
Installation	0	Saved on electric boiler		5264	
Enova	40000	Total		-14691.9	
Investment [NOK]	-957803				
		Residual value			
Flat			**Rrep**	**Rrem**	**S**
m2	144	heat pump	40	10	498901
costs	-2860	El boiler	30	10	-87735
Enova	28944	Total			411166
Investment [NOK]	-382896				
Solar shingle					
m2	38	Enova hp	1600		
costs	-3000	Enova solar th.	201		
Investment [NOK]	-114000				
Saved costs on reduced size of					
electric boiler [NOK]	263206				

Figure E.27: Input for the NPV calculation for combination 14.

Figure E.28 shows the NPV calculation for combination 14 completed in Excel.

Combination 14		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-1191493				-1191493					-1191493
1	0.952			-14692				-13992		88695	74702
2	0.907			-14692				-13326		84471	71145
3	0.864			-14692				-12691		80449	67757
4	0.823			-14692				-12087		76618	64531
5	0.784			-14692				-11512		72969	61458
6	0.746			-14692				-10963		69495	58531
7	0.711			-14692				-10441		66185	55744
8	0.677			-14692				-9944		63034	53090
9	0.645			-14692				-9471		60032	50562
10	0.614			-14692				-9020		57173	48154
11	0.585			-14692				-8590		54451	45861
12	0.557			-14692				-8181		51858	43677
13	0.530			-14692				-7791		49389	41597
14	0.505			-14692				-7420		47037	39616
15	0.481			-14692				-7067		44797	37730
16	0.458			-14692				-6731		42664	35933
17	0.436			-14692				-6410		40632	34222
18	0.416			-14692				-6105		38697	32592
19	0.396			-14692				-5814		36855	31040
20	0.377		-997803	5264			-376061	1984		35100	-338978
21	0.359			-14692				-5274		33428	28155
22	0.342			-14692				-5022		31836	26814
23	0.326			-14692				-4783		30320	25537
24	0.310			-14692				-4556		28876	24321
25	0.295		-525840	-14692			-155282	-4339		27501	-132119
26	0.281			-14692				-4132		26192	22060
27	0.268			-14692				-3935		24945	21009
28	0.255			-14692				-3748		23757	20009
29	0.243			-14692				-3569		22625	19056
30	0.231		263206	-19956			60900	-4617		21548	77831
31	0.220			-14692				-3238		20522	17284
32	0.210			-14692				-3083		19545	16461
33	0.200			-14692				-2937		18614	15678
34	0.190			-14692				-2797		17728	14931
35	0.181			-14692				-2664		16883	14220
36	0.173			-14692				-2537		16080	13543
37	0.164			-14692				-2416		15314	12898
38	0.157			-14692				-2301		14585	12284
39	0.149			-14692				-2191		13890	11699
40	0.142		-997803	5264			-141734	748		13229	-127757
41	0.135			-14692				-1988		12599	10611
42	0.129			-14692				-1893		11999	10106
43	0.123			-14692				-1803		11427	9625
44	0.117			-14692				-1717		10883	9166
45	0.111			-14692				-1635		10365	8730
46	0.106			-14692				-1557		9871	8314
47	0.101			-14692				-1483		9401	7918
48	0.096			-14692				-1413		8954	7541
49	0.092			-14692				-1345		8527	7182
50	0.087			-14692	411166			-1281	35855	8121	42695
		-1191493	-2258240	-699949		-1191493	-612177	-259077		0	-326726

Figure E.28: NPV calculation for combination 14 completed in Excel.

Combination 15: Water-to-Water Heat Pump + Evacuated Tube Collectors + Standard Solar Panels

Figure E.29 shows the input for the NPV calculation for combination 15.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	15		
		Electric boiler	30		
El. saved [kWh]	94343	Solar panel	25		
Benefits [NOK]	92135	Solar thermal	25		
Air-to-water hp	25	**Maintenance cost [NOK]**			
Hardware	-143438	Heat pump		-3069	
Installation	-10000	Saved on electric boiler		5264	
Investment [NOK]	-153438	Total		2195	
Evacuated					
m2	104	**Residual value**			
costs	-13811		**Rrep**	**Rrem**	**S**
Enova	20904	heat pump	45	10	102292
Investment [NOK]	-1415440	El boiler	30	10	-87735
		Total			14557
Standard					
m2	78	Enova hp	1600		
costs	-2655	Enova solar th.	201		
Investment [NOK]	-207090				
Saved costs on reduced size of					
electric boiler [NOK]	263206				

Figure E.29: Input for the NPV calculation for combination 15.

Figure E.30 shows the NPV calculation for combination 15 completed in Excel.

Combination 15		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-1512762				-1512762					-1512762
1	0.952			2195				2091		87748	89839
2	0.907			2195				1991		83570	85561
3	0.864			2195				1896		79590	81486
4	0.823			2195				1806		75800	77606
5	0.784			2195				1720		72190	73911
6	0.746			2195				1638		68753	70391
7	0.711			2195				1560		65479	67039
8	0.677			2195				1486		62361	63847
9	0.645			2195				1415		59391	60806
10	0.614			2195				1348		56563	57911
11	0.585			2195				1284		53870	55153
12	0.557			2195				1222		51304	52527
13	0.530			2195				1164		48861	50026
14	0.505			2195				1109		46535	47643
15	0.481		-153438	5264			-73806	2532		44319	-26955
16	0.458			2195				1006		42208	43214
17	0.436			2195				958		40198	41156
18	0.416			2195				912		38284	39196
19	0.396			2195				869		36461	37330
20	0.377			2195				827		34725	35552
21	0.359			2195				788		33071	33859
22	0.342			2195				750		31496	32247
23	0.326			2195				715		29997	30711
24	0.310			2195				681		28568	29249
25	0.295		-1643434	2195			-485311	648		27208	-457454
26	0.281			2195				617		25912	26530
27	0.268			2195				588		24678	25266
28	0.255			2195				560		23503	24063
29	0.243			2195				533		22384	22917
30	0.231		109768	0			25398	0		21318	46716
31	0.220			2195				484		20303	20787
32	0.210			2195				461		19336	19797
33	0.200			2195				439		18415	18854
34	0.190			2195				418		17538	17956
35	0.181			2195				398		16703	17101
36	0.173			2195				379		15908	16287
37	0.164			2195				361		15150	15511
38	0.157			2195				344		14429	14773
39	0.149			2195				327		13742	14069
40	0.142			2195			-21795	312		13087	-8396
41	0.135			2195				297		12464	12761
42	0.129			2195				283		11871	12154
43	0.123			2195				269		11305	11575
44	0.117			2195				257		10767	11024
45	0.111		-153438	5264				586		10254	10840
46	0.106			2195				233		9766	9999
47	0.101			2195				222		9301	9523
48	0.096			2195				211		8858	9069
49	0.092			2195				201		8436	8637
50	0.087			2195	14557			191	1269	8035	9495
		-1512762	-1840542	113710		-1512762	-555514	41388		0	-343603

Figure E.30: NPV calculation for combination 15 completed in Excel.

Combination 16: Air-to-Water Heat Pump + Evacuated Tube Collectors + Solar Shingles

Figure E.31 shows the input for the NPV calculation for combination 16.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	15		
		Electric boiler	30		
El. saved [kWh]	92684	Solar panel	25		
Benefits [NOK]	90515	Solar thermal	25		
Air-to-water hp	25	**Maintenance cost [NOK]**			
Hardware	-143438	Heat pump		-3069	
Installation	-10000	Saved on electric boiler		5264	
Investment [NOK]	-153438	Total		2195	
Evacuated					
m2	104	**Residual value**			
costs	-13811		**Rrep**	**Rrem**	**S**
Enova	20904	heat pump	45	10	102292
Investment [NOK]	-1415440	El boiler	30	10	-87735
		Sum			14557
Solar shingle					
m2	78				
costs	-3000	Enova hp	1600		
Investment [NOK]	-234000	Enova solar th.	201		
Saved costs on reduced size of					
electric boiler [NOK]	263206				

Figure E.31: Input for the NPV calculation for combination 16.

Figure E.32 shows the NPV calculation for combination 16 completed in Excel.

Combination 16		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-1539672				-1539672					-1539672
1	0.952			2195				2091		86205	88296
2	0.907			2195				1991		82100	84091
3	0.864			2195				1896		78190	80087
4	0.823			2195				1806		74467	76273
5	0.784			2195				1720		70921	72641
6	0.746			2195				1638		67544	69182
7	0.711			2195				1560		64327	65888
8	0.677			2195				1486		61264	62750
9	0.645			2195				1415		58347	59762
10	0.614			2195				1348		55568	56916
11	0.585			2195				1284		52922	54206
12	0.557			2195				1222		50402	51625
13	0.530			2195				1164		48002	49166
14	0.505			2195				1109		45716	46825
15	0.481		-153438	5264			-73806	2532		43539	-27735
16	0.458			2195				1006		41466	42472
17	0.436			2195				958		39491	40449
18	0.416			2195				912		37611	38523
19	0.396			2195				869		35820	36689
20	0.377			2195				827		34114	34942
21	0.359			2195				788		32490	33278
22	0.342			2195				750		30943	31693
23	0.326			2195				715		29469	30184
24	0.310			2195				681		28066	28747
25	0.295		-1670344	2195			-493257	648		26729	-465880
26	0.281			2195				617		25457	26074
27	0.268			2195				588		24244	24832
28	0.255			2195				560		23090	23650
29	0.243			2195				533		21990	22524
30	0.231		109768	0			25398	0		20943	46341
31	0.220			2195				484		19946	20430
32	0.210			2195				461		18996	19457
33	0.200			2195				439		18092	18530
34	0.190			2195				418		17230	17648
35	0.181			2195				398		16410	16808
36	0.173			2195				379		15628	16007
37	0.164			2195				361		14884	15245
38	0.157			2195				344		14175	14519
39	0.149			2195				327		13500	13828
40	0.142			2195				312		12857	13169
41	0.135			2195				297		12245	12542
42	0.129			2195				283		11662	11945
43	0.123			2195				269		11107	11376
44	0.117			2195				257		10578	10834
45	0.111		-153438	5264			-17077	586		10074	-6417
46	0.106			2195				233		9594	9827
47	0.101			2195				222		9137	9359
48	0.096			2195				211		8702	8913
49	0.092			2195				201		8288	8489
50	0.087			2195	14557			191	1269	7893	9354
		-1539672	-1867452	113710		-1539672	-558743	41388		0	-403319

Figure E.32: NPV calculation for combination 16 completed in Excel.

Combination 17: Air-to-Water Heat Pump + Flat Plate Collectors + Standard Solar Panels

Figure E.13 shows the input for the NPV calculation for combination 17.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	**15**		
		Electric boiler	30		
El. saved [kWh]	90265	Solar panel	25		
Benefits [NOK]	88153	Solar thermal	25		
Air-to-water hp	25	**Maintenance cost [NOK]**			
Hardware	-143438	Heat pump		-3069	
Installation	-10000	Saved on electric boiler		5264	
Investment [NOK]	-153438	Total		2195	
Flat		**Residual value**			
m2	144		**Rrep**	**Rrem**	**S**
costs	-2860	heat pump	45	10	102292
Enova	28944	El boiler	30	10	-87735
Investment [NOK]	-382896	Sum			14557
Standard					
m2	38				
costs	-2655	Enova hp	1600		
Investment [NOK]	-100890	Enova solar th.	201		
Saved costs on reduced size of					
electric boiler [NOK]	263206				

Figure E.33: Input for the NPV calculation for combination 17.

Figure E.34 shows the NPV calculation for combination 17 completed in Excel.

Combination 17		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-374018				-374018					-374018
1	0.952			2195				2091		83955	86046
2	0.907			2195				1991		79957	81948
3	0.864			2195				1896		76150	78046
4	0.823			2195				1806		72524	74330
5	0.784			2195				1720		69070	70790
6	0.746			2195				1638		65781	67419
7	0.711			2195				1560		62649	64209
8	0.677			2195				1486		59665	61151
9	0.645			2195				1415		56824	58239
10	0.614			2195				1348		54118	55466
11	0.585			2195				1284		51541	52825
12	0.557			2195				1222		49087	50309
13	0.530			2195				1164		46749	47914
14	0.505			2195				1109		44523	45632
15	0.481		-153438	5264			-73806	2532		42403	-28871
16	0.458			2195				1006		40384	41390
17	0.436			2195				958		38461	39419
18	0.416			2195				912		36629	37542
19	0.396			2195				869		34885	35754
20	0.377			2195				827		33224	34051
21	0.359			2195				788		31642	32430
22	0.342			2195				750		30135	30886
23	0.326			2195				715		28700	29415
24	0.310			2195				681		27333	28014
25	0.295		-512730	2195			-151411	648		26032	-124731
26	0.281			2195				617		24792	25410
27	0.268			2195				588		23612	24200
28	0.255			2195				560		22487	23047
29	0.243			2195				533		21416	21950
30	0.231		109768	0			25398	0		20397	45794
31	0.220			2195				484		19425	19909
32	0.210			2195				461		18500	18961
33	0.200			2195				439		17619	18058
34	0.190			2195				418		16780	17198
35	0.181			2195				398		15981	16379
36	0.173			2195				379		15220	15599
37	0.164			2195				361		14495	14856
38	0.157			2195				344		13805	14149
39	0.149			2195				327		13148	13475
40	0.142			2195				312		12522	12834
41	0.135			2195				297		11925	12222
42	0.129			2195				283		11358	11640
43	0.123			2195				269		10817	11086
44	0.117			2195				257		10302	10558
45	0.111		-153438	5264			-17077	586		9811	-6680
46	0.106			2195				233		9344	9577
47	0.101			2195				222		8899	9121
48	0.096			2195				211		8475	8686
49	0.092			2195				201		8072	8273
50	0.087			2195	14557			191	1269	7687	9148
		-374018	-709838	113710		-374018	-216896	41388		0	1061054

Figure E.34: NPV calculation for combination 17 completed in Excel.

Combination 18: Air-to-Water Heat Pump + Flat Plate Collectors + Solar Shingles

Figure E.35 shows the input for the NPV calculation for combination 18.

El. price [NOK/kWh]	0.9766	**Lifetime**			
Real discount rate	0.05	Heat pump	15		
		Electric boiler	30		
El. saved [kWh]	89457	Solar panel	25		
Benefits [NOK]	87364	Solar thermal	25		
Air-to-water hp	25	**Maintenance cost [NOK]**			
Hardware	-143438	Heat pump		-3069	
Installation	-10000	Saved on electric boiler		5264	
Investment [NOK]	-153438	Total		2195	
Flat					
m2	144	**Residual value**			
costs	-2860		**Rrep**	**Rrem**	**S**
Enova	28944	heat pump	45	10	102292
Investment [NOK]	-382896	El boiler	30	10	-87735
		Total			14557
Solar shingle					
m2	38	Enova hp	1600		
costs	-3000	Enova solar th.	201		
Investment [NOK]	-114000				
Saved costs on reduced size of					
electric boiler [NOK]	263206				

Figure E.35: Input for the NPV calculation for combination 18.

Figure E.36 shows the NPV calculation for combination 18 completed in Excel.

Combination 18		Nominal cash flows				Discounted cash flows					
Years	Discount factor	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Investment cost [NOK]	Replacement cost [NOK]	Maintenance cost [NOK]	Residual value [NOK]	Benefits per year [NOK]	Total cost [NOK]
0	1	-387128				-387128					-387128
1	0.952			2195				2091		83204	85294
2	0.907			2195				1991		79241	81233
3	0.864			2195				1896		75468	77364
4	0.823			2195				1806		71874	73680
5	0.784			2195				1720		68452	70172
6	0.746			2195				1638		65192	66830
7	0.711			2195				1560		62088	63648
8	0.677			2195				1486		59131	60617
9	0.645			2195				1415		56315	57731
10	0.614			2195				1348		53634	54981
11	0.585			2195				1284		51080	52363
12	0.557			2195				1222		48647	49870
13	0.530			2195				1164		46331	47495
14	0.505			2195				1109		44125	45233
15	0.481		-153438	5264			-73806	2532		42023	-29251
16	0.458			2195				1006		40022	41028
17	0.436			2195				958		38116	39074
18	0.416			2195				912		36301	37214
19	0.396			2195				869		34573	35442
20	0.377			2195				827		32926	33754
21	0.359			2195				788		31359	32147
22	0.342			2195				750		29865	30616
23	0.326			2195				715		28443	29158
24	0.310			2195				681		27089	27769
25	0.295		-525840	2195			-155282	648		25799	-128835
26	0.281			2195				617		24570	25188
27	0.268			2195				588		23400	23988
28	0.255			2195				560		22286	22846
29	0.243			2195				533		21225	21758
30	0.231		109768	0			25398	0		20214	45612
31	0.220			2195				484		19251	19735
32	0.210			2195				461		18335	18795
33	0.200			2195				439		17462	17900
34	0.190			2195				418		16630	17048
35	0.181			2195				398		15838	16236
36	0.173			2195				379		15084	15463
37	0.164			2195				361		14366	14727
38	0.157			2195				344		13682	14025
39	0.149			2195				327		13030	13358
40	0.142			5264				748		12410	13157
41	0.135			2195				297		11819	12116
42	0.129			2195				283		11256	11539
43	0.123			2195				269		10720	10989
44	0.117			2195				257		10209	10466
45	0.111		-153438	5264			-17077	586		9723	-6768
46	0.106			2195				233		9260	9493
47	0.101			2195				222		8819	9041
48	0.096			2195				211		8399	8610
49	0.092			2195				201		7999	8200
50	0.087			2195	14557			191	1269	7618	9079
		-387128	-722948	116778		-387128	-220768	41824		0	1030102

Figure E.36: NPV calculation for combination 18 completed in Excel.