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Enhancing Sustainability in Cabin Construction: A Case Study of Åneggagranda in Oppdal, Norway

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Master thesis
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Abstract

This thesis aims to provide solutions to enhance the sustainability of cabin construction in Norway with a focus on a case study named Åneggagranda, which is a pilot cabin project built in Oppdal, Norway by Nasjonalparken Næringshage. It also examines the individual emissions budget for Norwegians until 2030 in line with the Paris Agreement's target to reduce emissions by 43% as part of a larger goal of achieving zero emissions by 2050. Additionally, it assesses the contribution of cabin ownership to this budget, exploring whether cabins adhere to low-emission standards such as FutureBuilt ZERO and align with broader goals, such as the Paris Agreement. Using a mixed methods approach, data for the Ånegga cabin case study were obtained from Nasjonalparken, and in instances where data were unavailable, certain assumptions were made based on Sintef prefabricated construction systems for cabins. The study involved a site visit, an interview with the constructor, and the utilization of Reduzer software for main Life Cycle Assessment (LCA) calculations, while Rhino software and its Grasshopper plugin were used for energy analysis. This study underscores the substantial influence of occupancy patterns on building energy demand and operational emissions, particularly emphasizing the impact of shorter occupancy periods during colder seasons. Managing the frequency and duration of cabin use emerges as a crucial factor in enhancing energy efficiency and reducing building emissions. The research also highlights the potential of adjusting standby temperatures, proposing a practical recommendation for maintaining user comfort while minimizing heating loads. Additionally, the study emphasizes the importance of considering grid emissions during the design phase and explores the benefits of material reuse, solar panel integration, and individual choices in achieving sustainable construction practices. The Ånegga case study, while showing emissions below FutureBuilt Zero benchmarks, raises questions about their adequacy in meeting global reduction targets, emphasizing the importance of individual decisions on the generated GWP and fostering a collective commitment to practical and technological solutions for a more sustainable future.

Keywords: sustainable cabin construction, Norway, Individual emissions budget, Paris Agreement, FutureBuilt ZERO, Life Cycle Assessment, Occupancy patterns, Standby temperatures, Grid emissions, Material reuse, Solar panel integration, Paris Agreement

Preface

This study represents the master thesis study for graduation in sustainable architecture faculty at the Architecture and Technology department of the Norwegian University of Science and Technology. The focal point of this study is to investigate and propose strategies for reducing GWP in the Norwegian cabin construction sector with particular emphasis on the Ånegga cabin case study in Oppdal. Completing this master's thesis has been a challenging yet rewarding journey, and I am delighted to share the outcome of my efforts in these pages.

I would like to express my gratitude to my supervisor, Pasi Aalto, for his unwavering support and guidance during the development of this thesis. His expertise and insightful feedback have played a crucial role in shaping this work. His positive energy and encouragement have been constant sources of inspiration, rendering the exploration of the topic even more exciting and rewarding.

I extend my sincere appreciation to my co-supervisor, Patricia Eva Patricia Schneider-Marin, whose expertise has substantially enriched the depth and quality of this thesis. She has been an invaluable source of support, providing insightful feedback and thoughtful direction throughout the research process.

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List of Abbreviations

EPD Environmental Product Declaration

EPW Energy Plus Weather Files

GHG Greenhouse Gas

GWP Global Warming Potential

LCA Life Cycle Assessment

NFRC National Fenestration Rating Council

PV Photovoltaic

SHGC Solar Heat Gain Coefficient

VT or Tvis Visible light transmittance

ZEB Zero Emission Building

Chapter 1

Introduction

Before the average temperature of Earth increases by 2 degrees Celsius, it is predicted that the world can release 2,900 gigatons of emissions. 1900 gigatons of this amount is generated in advance and only 1000 Gt is left. This is the climate budget that remains as the CO2 equivalents which is produced before will not disappear. This is the reason that humans must be climate-neutral by 2050. If not, the temperature will rise more than 2 degrees which its fatal consequences affecting all people on Earth [2]. The EU is raising quota prices and according to that, building products which are the cause of massive production of greenhouse gas emissions will be more expensive. This affects the selection of building products to be used[2]. The reason that it is essential to limit global warming to 1.5°C by the end of this century is that surpassing the 1.5°C limit poses the danger of experiencing significantly more severe consequences of climate change, such as more and extreme droughts, rainfall, and heatwaves.[1]. To prevent the earth‘s temperature increase more than 1.5°C, based on the Paris Agreement, emissions need to be decreased by 45% by 2030 and reach net zero by 2050[35].

The ecosystem can store a large amount of carbon emissions. Alpine habitats and wetlands have significant potential in this way. Nature in Norway is diverse and consists of forest, mountain, open lowland, wetland, and aquatic ecosystems. All of these together store approximately 7 billion tons of co2, approximately. Of these, 33% are stored in mountains [3]. Large conservation areas in Norway are in the mountains and more than 30% of them are protected areas. The construction of holiday homes is the biggest threat to these areas. In low-alpine areas, physical disturbances caused by cabins lead the mountains to release more carbon emissions than they absorb [4]. In addition, construction in nature can change the ecosystem such as hydrology, snow conditions, and nutrient circulation. These can lead to changes in the rate of decomposition of organic materials, primary production, and species composition of soil-living organisms and plants [4].

In general, the construction sector is one of the largest waste generators in the world. Additionally, the production of construction materials is resource-intensive and generates a huge amount of greenhouse gas emissions. Construction, demolition, and rehabilitation generate plenty of waste. Only in Norway, the construction sector is responsible for producing close to two million waste annually, of which more than half a million tonnes are landfilled [8]. This illustrates the central role of the industry sector in the transition towards a more circular economy. To achieve the overall climate goals in the Paris Agreement, the UN's sustainability goals, and Norway's environmental goals, a transition from a linear to a circular economy is an essential part of the effort. "Norwegians are cabin people. 40-50% of the population own or dispose of holiday homes, but the demand for holiday homes is still high" [10]. A cabin is a place to unplug the TV shows and get closer to nature, and beloved ones. The ownership of cabins in Norway and other Nordic countries is higher than in other areas of the world [11].

Oppdal which is located in the west of Norway is a skiing and hiking spot and a large number of cabins are annually being built in this area. This growing trend results in a substantial release of GHG emissions into the atmosphere and it is incumbent upon construction companies to seek solutions to mitigate these adverse effects. The Ånegga cabin, investigated in this thesis, is a pilot project undertaken by Nasjonalparken AS with the purpose of diminishing emissions linked to cabin construction. The focus of this study is on the Ånegga pilot project, suggesting solutions to decrease its emissions. The findings benefit future projects of Nasjonalparken and other companies involved in cabin construction. It also analyzes the individual emissions budget for Norwegians until 2030 in accordance with the Paris Agreement's objective of reducing emissions by 43%, as part of the overarching aim of achieving zero emissions by 2050. Furthermore, the thesis evaluates the role of cabin ownership in this budget, investigating whether the cabin adheres to low-emission standards like FutureBuilt ZERO and aligns with broader objectives outlined in the Paris Agreement. Several solutions are advocated in this study, including the reuse of materials and heating systems, design adjustments, the utilization of solar panels, and changes in cultural practices associated with cabin usage. Through the examination of the case study and the provision of solutions for reducing GHG emissions, this analysis provides practical insights that can be implemented in future projects, thereby enhancing their overall quality.

Background and review
This chapter contains the background and review of previous works, an overview of the Norwegian context, problem definition, research questions, and objectives.

Existing Ånegga cabin
This chapter provides an introduction to the case study, presenting its context situated in the Oppdal area of Norway.

Methods
This chapter outlines the primary methods employed in the analysis of the case study, encompassing aspects such as the selection of the software, definition of parameters, and establishment of various scenarios for examination.

Results
This chapter contains all the analysis results.

Discussion
This chapter contains the results, answers the research questions, and discusses different options.

Conclusion and future works
This chapter contains the conclusion of the results of this study and suggests future works.

Chapter 2

Background and review

This chapter includes a review of past studies, offers insight into the Norwegian context, articulates the problem definition, outlines the research questions, and establishes the objectives of the study.

2.1 Circular economy

"In our current economy, we take materials from the Earth, make products from them, and eventually throw them away as waste – the process is linear. In a circular economy, by contrast, we stop waste being produced in the first place". This is the definition introduced by The Ellen Macarthur Foundation which developed the idea of circular economy[7]. The foundation of a circular economy lies in the utilization and restoration of products through reusing and repairing, which has the potential to make a significant contribution to the mitigation of climate change by preventing resource depletion, the diversion of materials and products from being landfilled and subjected to incineration (therefore preventing associated emissions), and decreasing energy demand[6].

2.2 Paris Agreement

The Paris Agreement, established in 2015 under the United Nations, is a momentous global pact involving almost 200 countries. It aims to tackle climate change by limiting the increase in global temperatures to below 2 degrees Celsius, with an ambition to keep it even lower at 1.5 degrees Celsius. Each country outlines its specific commitments, known as Nationally Determined Contributions (NDCs), to reduce greenhouse gas emissions. This agreement provides a crucial framework for worldwide collaboration to combat climate change and encourages sustainable development efforts [35]. Based on the Paris Agreement, global emissions need to be decreased by 45% by 2030 and reach net zero by 2050 [35]. Norway has started to decrease its produced emissions from the year 1990 and it is a reference for the years after it to calculate changes in GHG emissions. Norway's contribution to reaching Paris Agreement goals is reducing the emissions by 55% by 2030 [72] and 90% - 95% by 2050, compared to the generated emissions in 1990 [38]. For instance, emissions were reduced by 2020 by 4.7% [36].

2.3 LCA

Life cycle assessment is a methodology that is based on scientific foundations for measuring the environmental impacts of a building during its lifespan. A significant amount of these impacts originates from embodied carbon which includes the manufacturing of construction products (A1-A3), the construction process (A4-A5), material replacement (B4), and the end-of-life phase (C1-C4)[12]. Figure 2.1 shows the stages of the life cycle of the building. To get the details about a material and its emissions, EPDs are being used. Increasing the use of environmental product declarations (EPDs) which are being used for evaluation of the environmental performance of buildings and comparing products for procurement decisions in the advanced phases of building design is helpful. The lack of data quality and the transparency of EPDs can lead to making wrong decisions in recognizing and purchasing lower embodied carbon products [12].

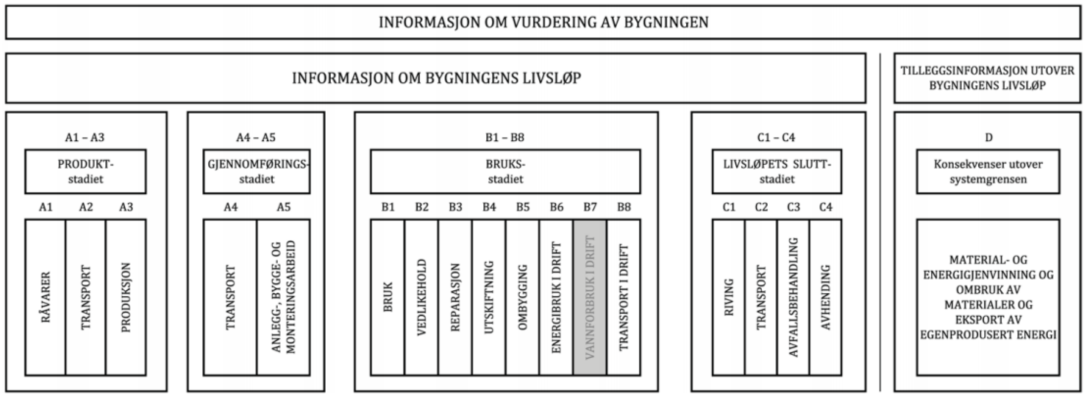


Figure 2.1: Life cycle stages according to FutureBuiltZero [19]

2.3.1 Embodied emissions

Embodied carbon represents emissions generated throughout the manufacturing, transportation, installation, maintenance, and disposal of building materials at the end of life [70].

2.3.2 Operational emissions

Operational emissions encompass the emissions connected to the energy utilized for operating a building or infrastructure. This operational energy refers to the energy used in the building during its operational stage, including activities such as heating, cooling, ventilation, hot water provision, lighting, and the utilization of various electrical appliances [66].

2.3.3 Building LCA

Whole Building Life Cycle Assessment or Building LCA, thoroughly assesses a building's environmental impact throughout its entire life. This evaluation considers embodied carbon, operational emissions, and various impact categories [66].

2.4 FutureBuilt

Since its inception in 2010, FutureBuilt has employed pilot projects as a strategic approach to transform the development of buildings and urban areas, emphasizing the significance of exemplary models in effecting change. The main objective is to successfully execute 100 pilot projects that achieve a minimum 50% reduction in carbon emissions compared to prevailing regulations and conventional practices. This reduction is assessed through a greenhouse gas accounting tool, with the criteria encompassing improvements in the realms of transportation, energy, and materials. By June 2023 FutureBuilt included 71 pilot projects – both public and commercial – dealing with neighborhoods, housing, schools, kindergartens, office buildings, cultural centers, and cycling projects [30].

2.4.1 FutureBuilt ZERO

FutureBuilt ZERO consists of standards for low-emission buildings and areas. These standards are intended to support both national and international goals for achieving a low-emission society by 2050. The criteria need to be ambitious, providing guidance while remaining easily understandable and applicable. Additionally, the objective is to align these criteria with existing Norwegian standards and guidelines [31]. Norway has set targets to decrease greenhouse gas emissions by 50-55% by 2030 and 90-95% by 2050 compared to 1990 levels. The construction sector is expected to contribute to these reductions. This involves adjusting the "current practice," including emissions from manufacturing, construction, operation, and disposal of Norwegian buildings. FutureBuilt model projects are envisioned as innovation-focused initiatives, demonstrating the feasibility of achieving such reductions. Consequently, they are required to consistently operate at approximately 50% below and 10 years ahead of the established "current practice" [31].

The FutureBuilt Zero approach considers changes in technology and policy, incorporating various adjustment factors like biogenic carbon, time- and technology-dependent characterization factors, carbonization of concrete, and carbon uptake through forest regrowth. The amount of carbon in materials determines how much biogenic and fossil carbon is released into the atmosphere during end-of-life incineration. The method includes straightforward circularity accounting, accounting for the advantages of product reuse during construction and promoting future reusability. FutureBuilt Zero tackles these challenges by utilizing sophisticated methodological concepts from dynamic life cycle assessment (LCA) in a simplified and practical manner designed for industry professionals [29].

Waste Incineration(B2-5 and C3): Emissions are to be calculated for the disposal of all combustible/organic materials without documented arrangements for reuse. Incineration occurs both during replacements and in the final phase at the end of the lifespan of the product [29].

Facilitation for reuse (D-Reuse): Materials with proven reusability in Module D for Reuse allow for a deduction of up to 10% from the greenhouse gas emissions of modules A1-A3. The factor for adjustment in this module is -0.1. There is a reduction of 80% in GHG emissions of reused materials as compared to an equivalent new product [29].

Biogenic Carbon (B2-5): The factor for adjustment (-1.27) is used to calculate the carbon absorption in the building based on the amount of wood-based materials (in kilograms). However, this compensation can only offset emissions from material production (A1-A3) and waste treatment, excluding emissions from transportation. Additionally, it is essential that the wood originates from sustainable forest management [29].

Carbonation of Cement-Based Products (B2-5): The weighting factor specified as -0.06 is used to calculate the carbon absorption in kilograms of Co2 equivalent per kilogram of concrete or other cement-based products in the building. This calculation involves multiplying the factor by the proportion of cement in the product [29].

2.5 Energy requirements

The key considerations in energy provision involve the manner in which energy is generated and the energy source itself, encompassing choices such as gas, biofuel, district heating, direct electricity, and heat pumps. It affects the operational emissions of the building. In cases where electricity serves as the energy source, the pivotal factor is the reliability and quality of the electricity grid. In countries where the emission intensity of the electricity grid is more than 300-400 gCO2eq/kWh, the emissions that come from the operational phase are considerably high. However, in countries with lower electricity grid emissions, the focus is more on the embodied emissions of the materials. Norway is one of the top countries in renewable energy production and has a low emission intensity of the grid [14]. This amount was 17 gCO2eq/kWh queried 26.10.2023 [15]. It is used in the calculation part of this thesis study. In 2022 the average emissions were 30 gCO2eq/kWh. Renewable sources generated 99% of the energy with the main source of the energy being Hydro (87.5%). Figure 2.2 shows the carbon intensity of electricity in 2022 for different countries [15]. As well as this, the Co2 factor of 136 g/kWh is an average amount between the electricity emissions of Norway and Europe which is also used in the calculations in this thesis [78]

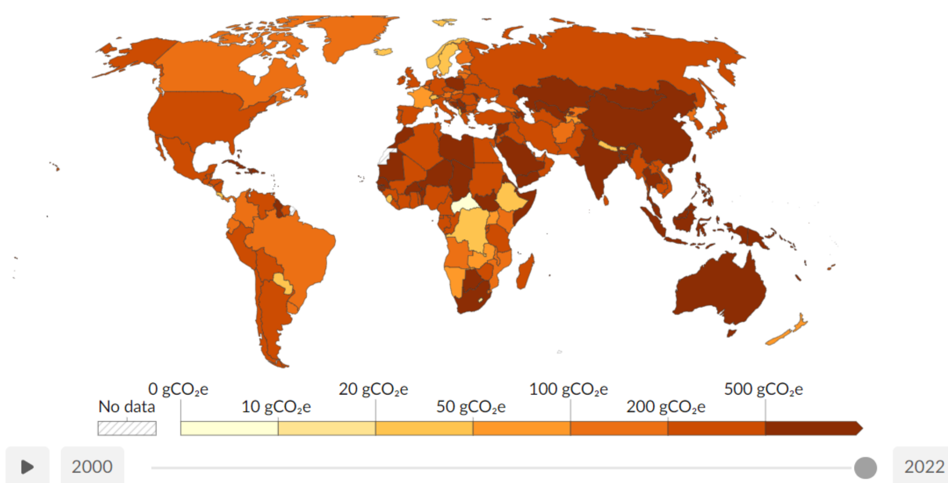


Figure 2.2: Carbon intensity of electricity, 2022 [18]

2.6 Emission reduction targets

Various sectors contribute to the production of carbon emissions, including agriculture, transportation, aquaculture and fishing, industry and energy, as well as petroleum. While individuals can directly reduce emissions in certain sectors, others necessitate government intervention for effective mitigation. The reduction of carbon emissions in industrial activities, such as the production of construction materials and waste incineration, significantly contributes to lowering the overall Global Warming Potential (GWP) and achieving carbon emission reduction objectives [90]. For instance, in the new targets set by Norway's government to reduce emissions by 60% by 2035, the share of carbon capture and storage in waste incineration plants, and carbon capture and storage at industrial facilities are 1025 tonne Co2eq and 3378 tonne Co2eq respectively in the total GWP reduction. This highlights the substantial emissions from these processes, indicating a necessity for decarbonization [90]. Regarding transportation emissions reduction, one of the strategies is to decrease travel times as well as switch from personal cars to public transportation [90].

2.7 Holiday house requirements

Holiday homes or cabins in Norway have their own regulations. Cabins that are 150 m2 or larger, as well as cabins between 70 m2 and 150 m2 have specific energy requirements. For small cabins less than 70 m2, there are no energy requirements [5]. In this study, the minimum requirement is also investigated. Table 2.1 presents the minimum energy efficiency criteria based on Tek17 for holiday and residential homes with lathed outer walls. Cabins below 70 m2 are exempt from these energy requirements [13].

Outer wall dimension	U-value roof [W/(m 2 K)]	U-value floor on the ground and facing the outside [W/(m 2 K)]	U-value window and door, [W/(m 2 K)]
$\geq 6inch/15.24cm$	0.18≥	0.18≥	1.2≥

Table 2.1: Requirements for holiday homes[13]

2.7.1 Holiday house development in Norway

There is not a clear difference between holiday homes and cabins. Cabins refer to the smaller houses intended for short-term accommodation with no or few modern conveniences, which are located in the mountains, fields, by the sea, or forests. However, a holiday home has a more comprehensive meaning, which has a higher degree of comfort [16]. Hytter, fritidsboliger, and fritidshus are three words for cabin and holiday homes in the Norwegian language. In this study, the three of them are used interchangeably.

The history of the Norwegian cabin started in the latter half of the 19th century. Norwegian Tourist Association opened up the countryside as a destination for holidays and motivated farmers to welcome the city people to their farms and homes by marketing "authentic Norway" and building the nation. The concept of owning a cabin was about something other than home. As well as this, a large number of people dreamed of a small place to own for themselves [17]. After the Second World War and because of the material shortage as a result, the cabins were built mostly simple and small, and people needed to use public transport to get to the cabins [17]. However, in 1960 people had more affordability and it was easier for them to build and get to the cabin by their own car, so cabins had become a mass phenomenon. in 1965 the first building law came in Norway and after that municipalities had the authority to supervise the construction and distribution of cabins [3].

Classic Norwegian cabins had a medium size between 30-40 m2. However, this size is growing so that newly built cabins in 2020 were on average 96 m2 and there are also cabins with the size of 120-150 m2 and more [16]. The traditional cabin was often located in remote areas but today a typical cabin is located in an organized cabin field that has good infrastructure and is close proximity to sports facilities and services. There are certain municipalities, especially in the mountains which have a large number of cabins, and they are referred to as «hyttekommune» or cabin municipality. In 2020, approximately 440,000 cabins/holiday homes were registered in Norway, and around 5,000 new cabins are built in the country each year [16].

2.7.2 Cabin construction in Oppdal, Norway

The most popular locations for building holiday homes are mountainous areas. In Trøndelag 44% of the registered cabins in 2015 were in the mountains. Half of the construction of holiday homes is in the inland municipalities where the mountain villages extend further and further up into the mountains [22]. Inland municipalities have most of the cabins in Trøndelag municipality. Oppdal is the second municipality with the most holiday homes in Trøndelag with 4,234 cabins as of 1 January 2023. It also had the largest growth in cabins in the county measured in numbers [23]. 2022 was a record year as there were a total of 7,472 start-up permits to build the cabin in comparison with the past few years with an average of 5,000 cabins annually [3]. (Statistics for completed buildings are based on the date on which the municipality registers the building as completed. The holiday home may therefore have been completed several years before the completion date is recorded so this figure could possibly be higher.) A survey was conducted by Nasjonalparken Næringshage AS in 2015 in Oppdal, in which all the cabin owners were invited and 689 respondents answered it. Two other surveys were conducted in 2008 and 1999. The comparison between these years shows an increase in remarkable variables such as the size of the cabins, the number of the cabins, and the days of use Table 2.2. It shows that the demand for cabins is gradually increasing in the area.

Development key tacts	1999	2008	2015	Change
Size of the cabin	73.2 m2	89.6 m2	93.8 m2	+28.10%
Number of days of use	51	58	57	+11.80%
More future use	29.40%	24.60%	22.00%	-7.40%
Number of people	3.7	3.4	3.3	-10.80%
Yes to settlement	16.50%	20.50%	14%	-2.50%
Number of cabins	1,737	2,917	3,386	+94.90%

Table 2.2: Development of Key Facts 1999 - 2015 [21]

It is shown in Table 2.2 that the cabins are used about 60 days a year by about 4 people on average. Most of the cottage owners are happy with having a cabin in Oppdal (average 5.2 of 6) but a considerable percentage of them (64%) do not like to settle there. Generally, most of the people answered that they go to Oppdal only for their leisure time and others mostly go there for their jobs.[21].

2.8 Location and size

Furthermore, the conducted survey by Nasjonalparken shows that most of the cabins are located in Gjevilvatnet/Skarvatnet and are more than 23 years old, however, the largest use of the cabins is in the Rønningslia area. The size of the cabins varies but it is popular to be between 71 and 100 m2. People under twenty and between 51–60 years old are the most interested group in the cabins respectively and they think they will use their cabins the same way in the future [21].

2.9 Attractions and unsatisfactions

Three features that are important for the cabin users in Oppdal are nature and the mountain areas, prepared ski slopes, and marked hiking trails respectively. They are satisfied with nature and the mountain areas, prepared ski slopes, and peace and tranquility. However, they are not satisfied with the property tax, densification of cottage areas, and the renovation fee. It is noteworthy that a large number of people who have cabins in Oppdal live in Trondheim [21]. The average cost per person/day is 526 NOK which is on a moderate rise each year due to the economic changes and inflation [21].

2.10 Occupancy and thermal requirement

In an occupied building the temperature should align with the occupant's comfort zone. Thermal comfort can be defined as 'the state of mind, which expresses satisfaction with the thermal environment' [57]. Throughout history, people have always aimed to create a comfortable environment. It is still a key consideration in the process of the building design. The indoor environment encompasses all physical, chemical, and biological factors of a building affecting the well-being and health of the occupants [54]. In addition, the thermal requirements of the building cover aspects such as health, thermal comfort, addressing process needs, and setting criteria to prevent issues such as freezing water pipes, mold, mildew, and damage to building materials or furnishings. In standard operating conditions, buildings following code guidelines are expected to be protected from mold and mildew problems. If such issues arise, they are considered matters requiring operations and maintenance intervention [55]. According to the Humidity Control Design Guide for Commercial and Institutional Buildings, recommended Dew Point (DP) limits, aligning with both health and mold prevention criteria, are $< 14°C$ during summer and $> 2°C$ in winter [56].

2.11 Transportation

The transportation sector is responsible for about 25% of greenhouse gas emissions related to energy [61]. Currently, most transportation relies on burning fossil fuels, leading to significant air pollution in both urban and regional areas. The UN environment program advocates for the advantages of 'mode shifting,' encouraging a transition from private motor vehicle usage to public transport and non-motorized alternatives like walking and cycling [61]. Electric vehicles contribute to a reduction in greenhouse gas emissions due to their higher energy efficiency, being four to five times more efficient than traditional fossil fuel vehicles. As well as this, the electricity powering electric vehicles can be sourced from renewable options like hydropower in Norway. However, it is important to note that the production phase of electric vehicles releases more GHG emissions compared to the production of internal combustion engine vehicles. Additionally, this life cycle stage results in significantly higher toxicity impacts compared to conventional vehicles [62].

2.12 Relevant studies

This section presents past scientific research on factors contributing to lower building emissions. It also includes instances of cabins constructed using reused/recycled and environmentally friendly materials. Additionally, a local database for reusing materials and two reports are discussed, focusing on assessing buildings for the potential reuse of materials in their construction.

An open-source and modular dynamic material flow analysis model of the transformation of passenger residential, and non-residential buildings as well as vehicles in Germany (all together stand for about 50% of national greenhouse gases) to a material-efficient system, was applied by Pauliuk, S. and Heeren, N. This analysis covered the time span 2016–2060 and focused on a material-efficient system. The assessment was conducted to see how material efficiency strategies (mentioned) affect climate-relevant materials such as concrete, steel, timber, aluminum, and plastics. The results show that for all three sectors, 2-degree compatible use of more efficient materials, transitioning energy sources to electricity, energy supply transformation, and building renovation will result in a significant reduction in emissions during the direct use phase. Specifically in buildings, replacing materials with wood, more intense use of the materials, prolonging the lifetime, and higher yields are especially relevant. These strategies will have a notably strong effect on the reduction of GHG within the material cycle industries. This impact could potentially lead to additional emission reductions up to 93% for residential buildings, 67% for non-residential buildings, and 56% for vehicles by the year 2050 [20].

Gjenbrukshuset in Trondheim is two identical houses, one of them was built in an ordinary way and with new materials while the other one was made with a focus on reusing the materials. The project was built in 2003. In this project, 85 percent of the trusses and cladding are from reused and resized wood, as well as, all interior doors, about 50% of the kitchen fittings, all roof tiles and brickwork, 16 of 24 windows, and toilets and sinks. The recycled building at the end varied a bit in appearance from the new one. The whole recycled materials were processed and procured through work training because there were no regular commercial suppliers of reused materials [58].

An Energy-efficient timber cabin made from all-natural materials was built in Bymarka, Trondheim. The name of the cabin is Dikehaugen 12 which is a modern timber cabin made from recyclable and environmentally friendly materials. The cladding is in pine shingles, also left unpainted, that will develop a patina over time. A noticeable part of this project is its insulation which is 35 cm thick paper, as well as this, the construction of a two-wall "climate shield" system is implemented. It means the outer cool wall is separated from the inner wall which is warm by a 1.4-wide-meter open air gap. with this method, the embodied emission of insulation is removed. The cabin is large,120 m2 area, and has an open plan in which a single air-based heat pump heats the whole house. In addition, it has a wood-burning fireplace with a chimney [52].

There are two reports conducted by Asplan Viak and Multiconsult in which they mapped the building materials that can be reused in other projects. These donor buildings are going to be demolished or rehabilitated. The results from the reports show that the largest amount of reusable materials are non-load-bearing parts. Interior equipment and furniture, as well as windows, doors, heat pumps, ceramic tiles, pipes, and electricity cables, are among the reusable materials [50] [59]. In the Stabbursmoen school's reuse mapping conducted by Asplan Viak, the possible reused materials prevent the generation of 197 tonnes of waste and 121 tonnes of CO2, leading to savings of 8,800,000 NOK. Generally, in the mapping process with the purpose of reusing materials, the building components should be easily disassembled and reassembled, possess a prolonged lifespan, offer cost savings, and contribute significantly to environmental conservation when repurposed[50].

In the Trondheim area, the companies doing the mapping reports for reuse of materials input their identified building elements into Loopfront, a local material database facilitating the reuse of materials in various projects. Loopfront, located in Trondheim, maintains an inventory containing diverse items. The majority of these items consist of non-load-bearing building components and furniture. This resource proves valuable for individuals in the construction field, aiding them in finding suitable matches for their projects and simplifying material reuse. Additionally, Loopfront offers practical information such as weight, CO2 emissions, prices, and the presence of hazardous materials for the items, although not all materials are thoroughly documented in this regard [53].

2.13 Problem definition

Åneggagrenda developed by Nasjonalparken AS is a pilot project with the objective of lowering greenhouse gas production in cabin construction. During a meeting with Nasjonalparken, challenges and goals were discussed in relation to the design and construction of the cabins for the Ånegga project, with the aim of enhancing their environmental friendliness. They have a project currently underway in Oppdal that will be constructed in the near future. They aim to draw upon the experience gained from their pilot project for the upcoming project and for others in the future. In this study, the Ånegga project will be analyzed, the issues and the goals that they had toward reusing materials and making their cabins more environmentally friendly will be discussed and solutions will be introduced. In addition, The cabin culture in Norway is a growing trend and needs to be decarbonized, therefore such studies need to be conducted to find solutions for reducing emissions.

2.14 Implementing reused materials

One of the primary emphases for emission reduction is material reuse. Nasjonalparken is keen on integrating reused materials into their projects. While aiming to utilize reused materials in their pilot project, Ånegga, faced challenges due to the absence of a material exchange system. Consequently, the project was built of new materials. This thesis will explore the possibilities and methods of material reuse, including the use of a database system.

2.14.1 Windows

Windows are accountable for a significant amount of undesired heat loss and heat gain between structures and the surroundings, globally. More than 3% of energy usage in the USA and 7% in Sweden is lost via windows. This amount is 6% in Britain and only for residential buildings [48]. The window system is an essential part of exterior envelopes, which affects the energy demand of the building. Heat transfers from the window more easily than the wall system because its thermal performance is worse. Window thermal parameters such as U-value (heat transfer coefficient), SHGC (the solar heat gain coefficient), and the window-to-wall ratio are important factors in selecting a window [44]. When a window is new its properties are easy to get from the company. However, When reusing an old window, it is difficult to realize its thermal parameters. It is still possible to find their parameters in labs and by getting help from simulation tools such as the NFRC simulation tool from Lawrence Berkeley National Laboratory [47]. As well as this, the window should not contain hazardous materials otherwise it cannot be reused in another project. In Loopfront inventory which is a database for reusable materials, the windows are marked with and without hazardous materials.

U-Value and window-to-wall ratio

A smaller U-value can result in reduced energy demand but although a lower U-value results in less heat loss through windows during winter and lowers heat gain in summer, its effect is limited and depends on the WWR (window-to-wall ratio). In buildings with a low WWR, the role of the insulation thickness is more prominent. A study conducted by Hou, J. shows that in a building with WWR of 7.5%, even if the amount of U-value is high (7 W/m2K), only by increasing the thickness of insulation the energy demand decreases by 63% [44]. SHGC and light transmittance (Tvis/VT) are other parameters in the specifications of windows. The ratio of Tvis to WWR is a factor that affects the lighting energy consumption of the building. A higher ratio leads to an increase in the total building energy load for lighting. The SHGC value quantifies the amount of solar heat that penetrates through the window. In a cold climate such as Norway, it is more desirable for the windows to have a lower U-value and higher SHGC. A higher SHGC is beneficial in the winter because the building gets a considerable amount of heat gain and it reduces heating energy. It is disadvantageous in the summer for the cooling energy reduction [49]. However, in climates such as Oppdal in which the winter is dominant and the summer is cool, it is still beneficial. It is expected that the windows with higher SHGC be utilized towards the sun, which in Norway and Oppdal is to the south. This side of the building is the one with the largest amount of glazing [47].

Orientation

The orientation of the windows is another factor that affects the energy load of the building. In a cold climate such as Oppdal, the orientation to the south can decrease the heating load [49]. In addition, in different climates from warm to cold, the north facade is less affected by SHGC, WWR, and Tvis, however, these specifications play a more significant role on windows on the west and east faces of the building [80].

2.14.2 Heating system

Traditional heating systems, such as pellet and oil boilers, exhibit low efficiency. In contrast, modern heating systems like Air Source Heat Pumps (ASHP) and Ground Source Heat Pumps (GSHP) are highly efficient. Implementing these advanced heating systems in buildings can yield a positive impact on operational emissions. Reuse is not only for the construction materials of the building, the heating system which is responsible for the operational emissions and has its own embodied emissions is also an option for being reused. In the Ånegga project, the heating system is electricity. Another two heating systems that are explored to be used in this study are GSHP and ASHP.

A Ground Source Heat Pump (GSHP) heating system is a sustainable and energy-efficient technology that harnesses the stable temperature of the earth to provide heating for buildings. GSHPs are known for their high efficiency, as they can provide both heating and cooling, making them versatile for various climates. Additionally, GSHPs contribute to reducing greenhouse gas emissions by relying on the stable thermal energy stored beneath the Earth's surface. The efficiency of the system is 367% [76] and the GHG impact with 30 years of lifetime is 896.5 kgCO2eq/kW [40].

ASHPs (Air Source Heat Pumps) extract heat from the outdoor air, even in cold temperatures, and amplify it for indoor heating purposes. They provide a greener alternative to traditional heating methods, as they require less electricity to produce heat. The efficiency of the system is 230% [76] and the GHG impact of it with 20 years of lifetime is 363.8 kgCO2eq/kW [40].

Electric heating system: This system transforms electricity directly into heat using radiators or coils, achieving a 100% efficiency rate [76]. More details are included in the methods chapter.

2.14.3 PV panels

A PV system generates electricity by converting solar energy directly into electricity using PV cells (solar panels/modules), which are the system's most important components [69]. PV power generation systems receive acclaim for their cheap operational cost, minimal maintenance needs, and environmentally friendly characteristics [67]. Despite the benefits, the primary challenge in gaining public acceptance for PV systems is the significant initial cost [68]. Although solar panels come with a substantial initial expense, photovoltaic (PV) systems, particularly those connected to the grid, have been promoted in numerous countries due to their potential economic advantages over the medium and long term [67]. By 2024, solar panels are expected to generate nearly 57% of all renewable energy [68]. The majority of electricity in Oppdal is generated through hydropower in Norway, with a small portion also originating from nuclear sources due to energy exchange between Sweden and Norway. In addition, a small portion of the electricity is imported from Europe, where it is produced with emissions from non-renewable fuels in this particular region [65]. A renewable source of energy such as PV panels can help to reduce the GWP of the cabin by providing emissions-free electricity. Therefore, they compensate for the produced emissions in the embodied and operational phases depending on the electricity produced by them. Nasjonalparken is willing to make their cabins off-grid but their concern about the PV panels is the costs and the days that PV panels can receive radiation from the sun because of the cold climate [65].

2.15 Objectives and research questions

The goal of this thesis study is to get an understanding of what the Nasjonalparken can do in its future cabin constructions to be more environmentally friendly. The results gained from this study may prove valuable for companies sharing similar environmental goals with Nasjonalparken. In addition, this thesis investigates the emissions budget that each Norwegian person has until 2030 based on the Paris Agreement goals to decrease emissions by 43%, as well as, the share of the emissions generated by owning a cabin in this budget. The study aims to explore if a cabin is low emission based on the regulations and standards such as FutureBuilt ZERO, then how it is aligned with the bigger goals such as the Paris Agreement.

RQ1 - What factors contribute to increased GHG (greenhouse gas) emissions at various stages of cabin development?

RQ2 - How can material reuse be effectively employed to mitigate Global Warming Potential (GWP), and what are the methodologies and contributions to environmental sustainability associated with these practices?

RQ3 - To achieve a 43% reduction in GHG emissions by 2030, aligning with the objectives outlined in the Paris Agreement, of which Norway is committed to a 55% reduction, what impact does owning a leisure house have on this objective? what is the individual carbon budget for each Norwegian? Additionally, what portion of this budget is allocated exclusively for cabin ownership?

RQ4 - What guidelines can be developed to minimize Global Warming Potential (GWP) in future cabin construction projects, with a specific focus on the locality of Oppdal?

Chapter 3

Existing Ånegga cabin design - Scenario 1

This chapter introduces the case study, outlining its structure and providing information about its context in the Oppdal area of Norway.

3.1 Background

The holiday home industry is central in Oppdal and Rennebu, which is central Norway's largest "cottage region". The construction and use of holiday homes are a significant basis for value creation in the region. At the same time, the development of holiday homes also requires large resources, in the form of natural interventions, material use, and greenhouse gas emissions. Åneggagrenda was a pilot in the Sustainable Leisure Project, with the aim of realizing a more sustainable holiday home concept using a methodology for more comprehensive area development. The aim of the project Sustainable Leisure or Grønn Fritid in Norwegian is to facilitate and form the basis for more sustainable solutions for people's leisure through increased expertise, introducing new solutions, and greater participation. The project has been ongoing since 2017 (including the pre-project Grønn Fjellhageby), which is led by the Nationalparken Næringshage in collaboration with NTNU and financed by Trøndelag County Municipality. In the Sustainable Leisure Project, a cabin development strategy was developed. The strategy was built upon a comprehensive range of themes and measures required for achieving sustainable area development for vacation homes [25].

3.2 Nationalparken Næringshage

A Næringshage serves as an operator within Siva's commercial garden initiative, which aims to promote sustainable growth in industry and business. Functioning as a business community, Næringshagen actively contributes to the development of businesses within its regional context. The overarching goal of Nasjonalparken is to establish an appealing environment for development and expertise in Oppdal and Rennebu. They actively promote and support initiatives and projects initiated by local businesses. Collaborating closely with Oppdal and Rennebu municipalities, they strive for the collective welfare of the entire region. The foundation for their endeavors lies in regional plans from Trøndelag County Council and national initiatives from the Ministry of Local and Regional Affairs, SIVA, and the Ministry of Business and Industry.

3.3 Oppdal climate

Different areas in Norway have relatively different climate models. It is essential to know about the climate of the area before any type of construction happens. The climate of Oppdal based on Koppen Geiger climate classification is Dfc which is a subarctic climate. In which, Df stands for snow climate, fully humid, and c stands for cool summer and cold winter [24]. The following graph shows the average monthly temperature of Oppdal Figure 3.1. As the temperature is low most of the year, the heating demand is considerably higher than the cooling demand in the area. Climate graphs were generated using the Ladybug tool in Grasshopper and Climate Consultant software.

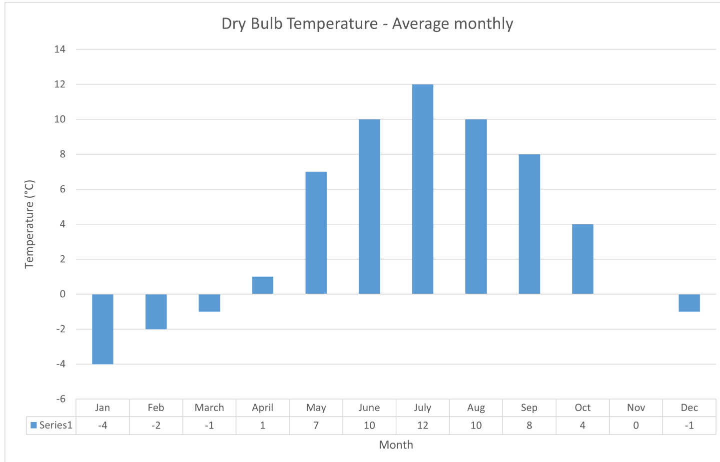


Figure 3.1: Average monthly temperature in Oppdal[26]

3.4 Annual sun path analysis

The analysis shows the location of the sun during the year in Oppdal. As it is shown in the graph, Figure 3.2, the low solar elevation angle of the sun is dominant during the year. As well as this, the temperature of the sun is mostly low which is shown with blue color in the graph and means less than 10 degrees Celsius. The annual sun path analysis is important to understand from which directions a building can get more daylight and heat from the sun. The radiation analysis gives more information about the heat gained from the sun.

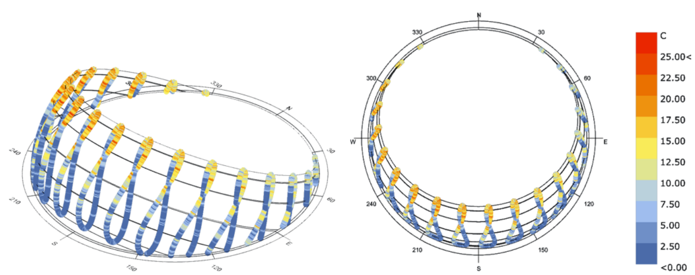


Figure 3.2: Oppdal annual sun path analysis[26]

3.5 Annual radiation analysis

The analysis shows the total radiation in Oppdal annually (kWh/m2). It shows that the most amount of radiation is coming from the south and at higher altitudes, a higher amount of heat can be gained. Annual radiation analysis affects the orientation of the windows, inclined roof angle, and potential PV panel's direction and angle.

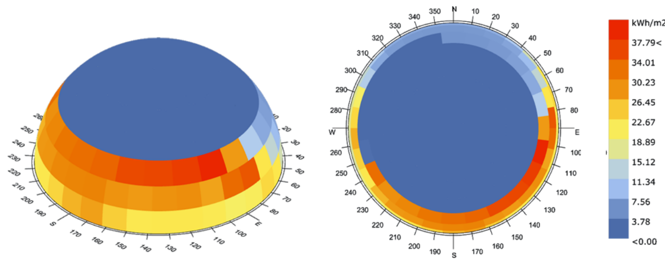


Figure 3.3: Oppdal annual radiation analysis, 1 Jan 1:00 - 31 Dec 24:00 [26]

3.6 Annual wind rose analysis

This analysis was done using the Ladybug tool in Grasshopper which is a plugin for Rhino software. As is shown in the graph most portion of the wind blows from the west and northwest. The information from the analysis shows that the area is calm for 1.03% of the time which is equal to 90 hours in a year. This amount demonstrates that Oppdal is a considerably windy area. In addition, the speed of the wind reaches about 14.5 m/s, which is a greatly high speed. Figure 3.4. It is essential that the cabin be shielded from the wind to prevent energy loss and decrease the heating load. Buildings that are wind-shielded consume 10% less energy compared to wind-exposed buildings [27].

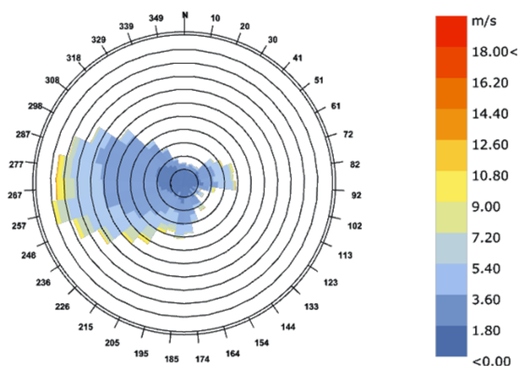


Figure 3.4: Oppdal Annual wind rose analysis, 1 Jan 1:00 - 31 Dec 24:00 [26]

3.7 Site plan

As it is shown in the site plan Figure 3.5, the cabins are oriented towards the southeast with different angles. Since the plan of all 8 cabins is identical, one of them, cabin H6 with a 45° orientation to the southeast, is chosen to be studied Figure 3.6.

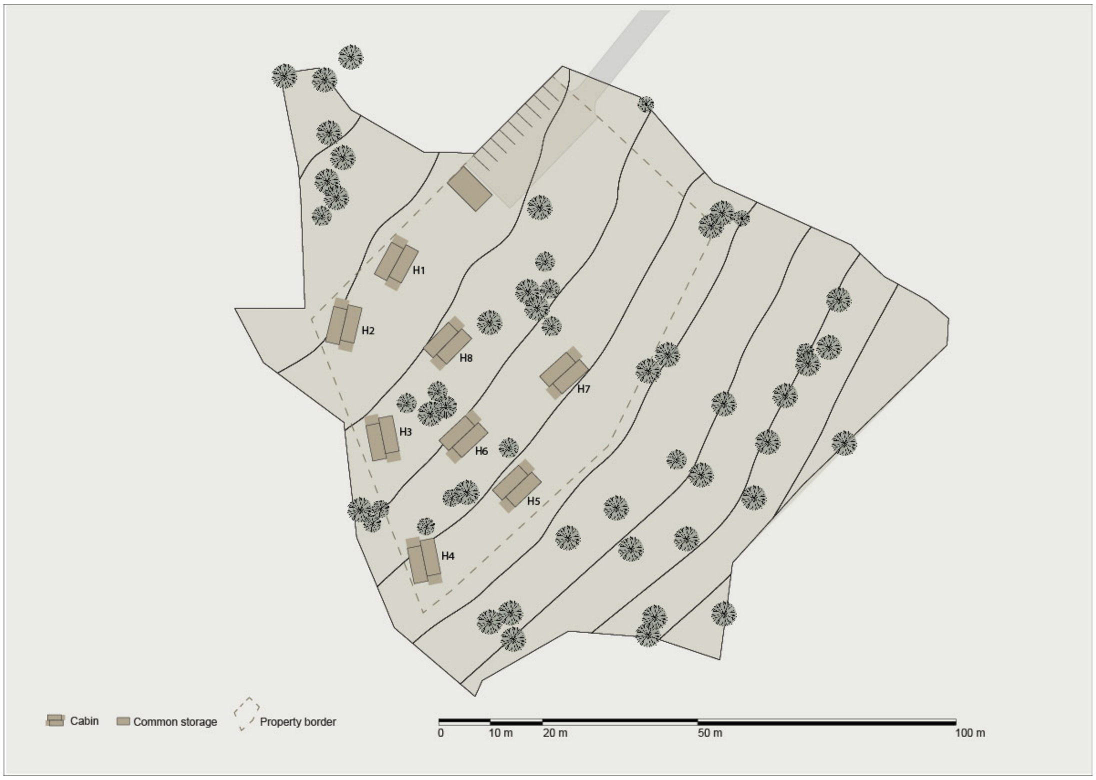


Figure 3.5: Site plan

3.8 Climate influence on Ånegga cabin design

The climate analysis was conducted to investigate the factors influencing the design of the Ånegga cabin and to inform decisions regarding changes in design and the installation of photovoltaic (PV) panels. Windows are predominantly positioned on the southeast and southwest facades. The southeast receives more sun radiation Figure 3.3 as well as sunlight Figure 3.2, leading to a larger facade in that direction with sizable windows. This side of the building is allocated to the wall of the living room and kitchen in which people spend more time during the day. Despite receiving considerable radiation, the southwest also experiences some winds, resulting in a smaller facade on this side. Notably, the prevailing northwest winds, which constitute the main wind direction, prompted the cabin to have the fewest openings on this side to act as a wind barrier Figure 3.4.

3.9 Plan

The cabin is with an area of 37 m2. The dimensions of the plans and the section A-A section are as follows Figure 3.8 Figure 3.10 Figure 3.12. The cabin has one floor with an attic. On the ground floor, it has an open plan that includes a kitchen, living room, and dining room. There is a bedroom and a bathroom on this floor as well. The Cabin has two entrance doors that open to the porches and the outside area. Figure 3.7 shows the first-floor plan. The attic floor is used as a sleeping area. Its plan is shown in Figure 3.9. The foundation of the cabin is with steel piles which have a 2-meter depth in the ground and keep the cabin 0.5 meters above the ground Figure 3.11.

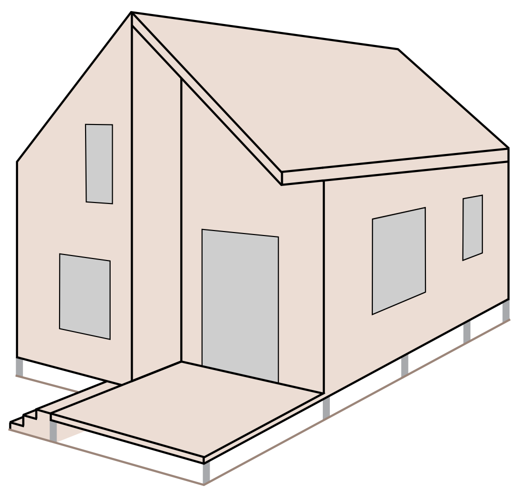


Figure 3.6: A sketch of Ånegga cabin, H6, South-east facade

3.9.1 First floor

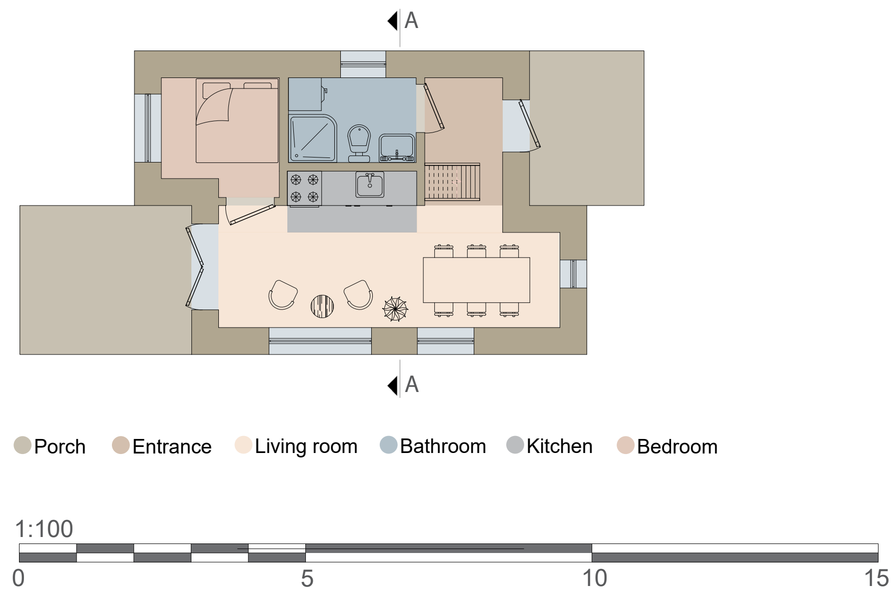


Figure 3.7: first floor plan

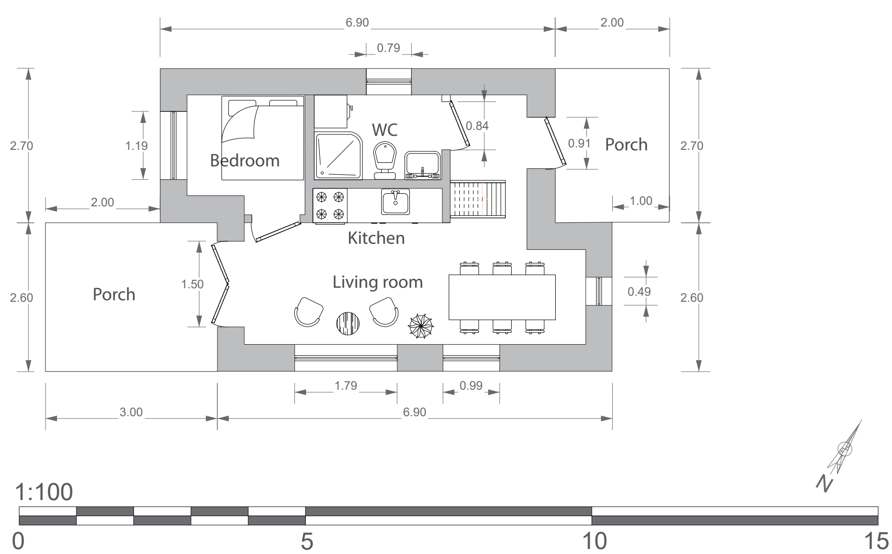


Figure 3.8: First floor dimensions

3.9.2 Attic

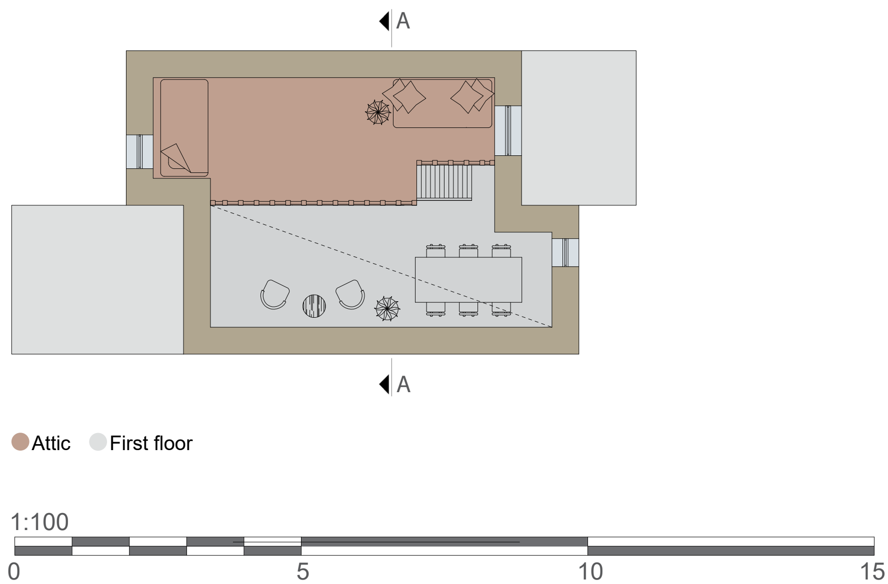


Figure 3.9: Attic floor plan

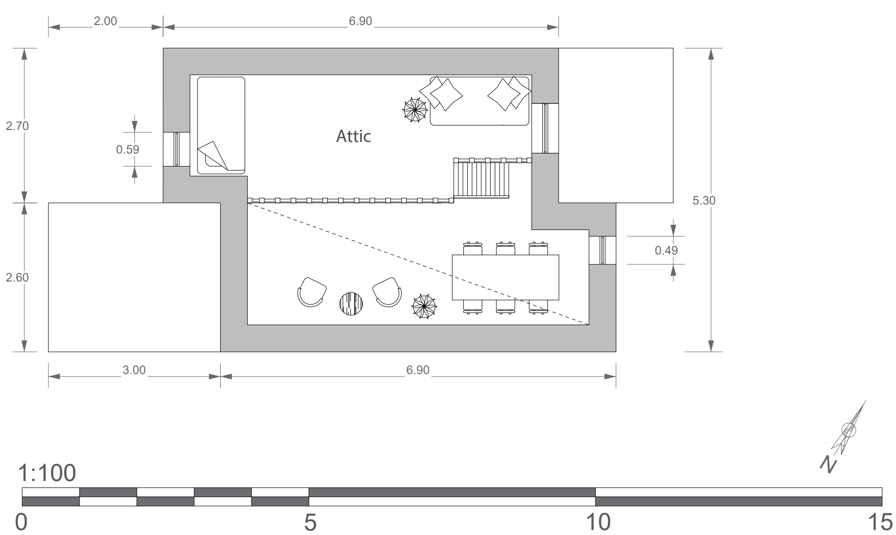


Figure 3.10: Attic floor dimensions

3.9.3 Section A-A

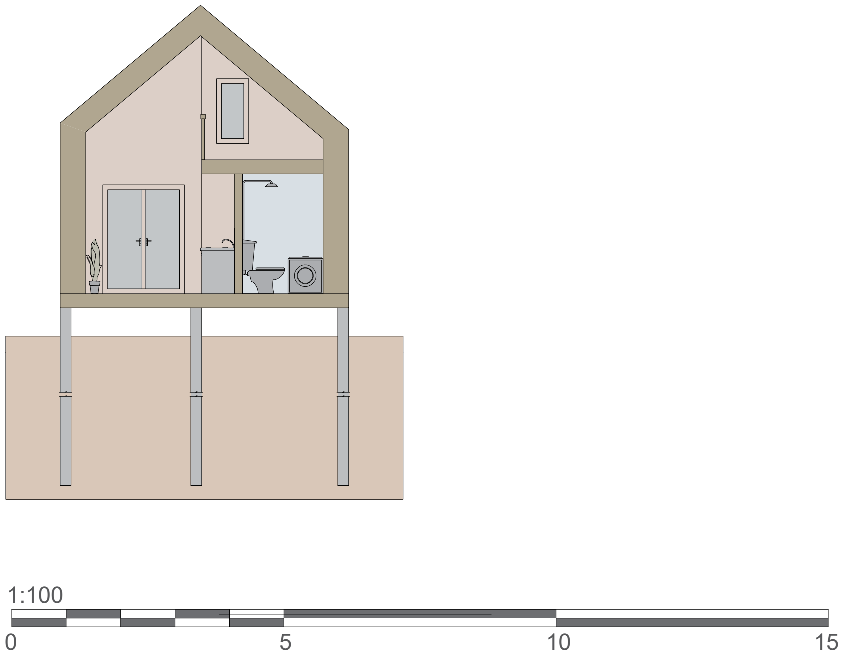


Figure 3.11: Section A-A

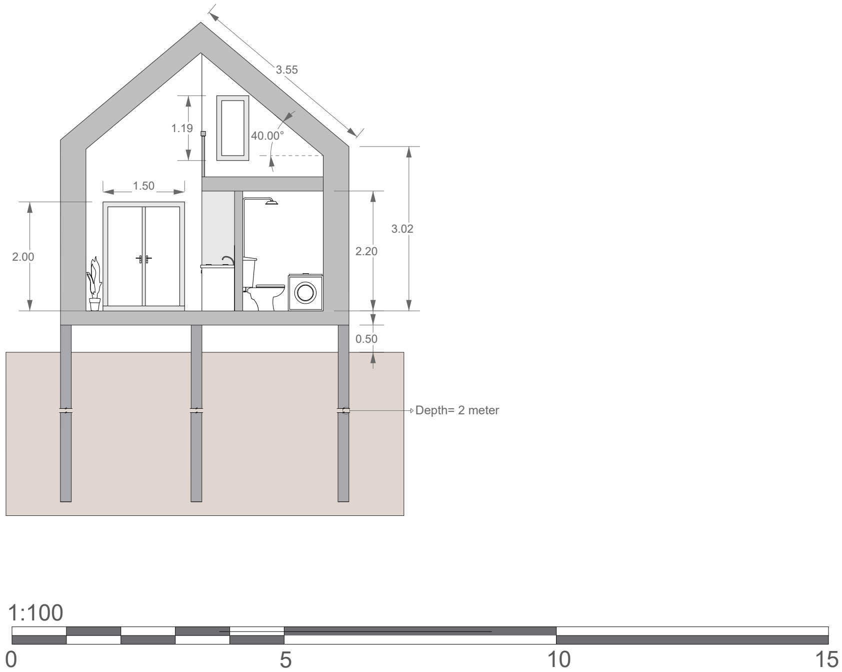


Figure 3.12: Section A-A dimensions

3.9.4 Steel piles in the foundation

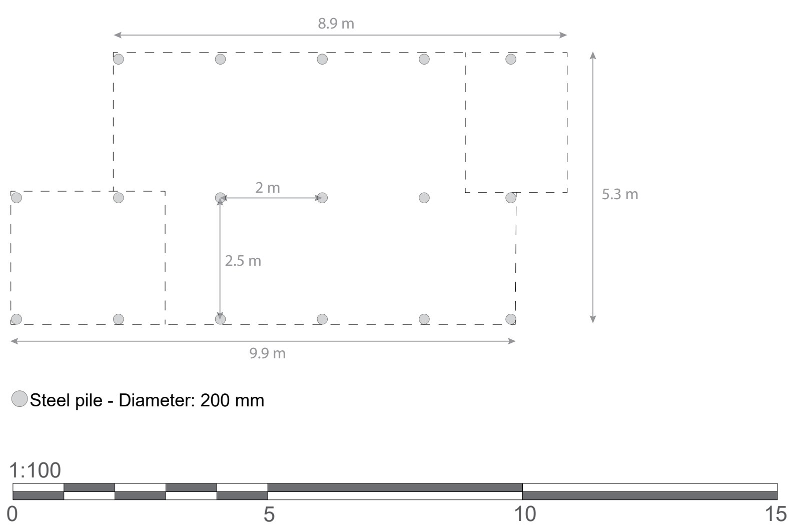


Figure 3.13: Steel piles in the foundation

3.10 Physical properties of the case study

The physical properties of the cabin such as the size, U-values of the building envelope, and the type of the heating system are important for analyzing a building. The U-value is a measure that signifies the speed of heat transfer through building envelopes in an optimal stationary condition. This variable plays a significant role in performing thorough energy audits for buildings [71]. The materials and their properties affect the U-value of the building envelope.

There was a lack of structural details for the Ånegga cabin. Nasjonalparken confirmed that the cabin possesses a prefabricated structure during a meeting with them [65]. They provided a list of materials for the entire project but it was not possible to extract which material is used for which part of the building. As well as this, the list was unclear on some points. For example, it listed quantities as packages for some products, and it was unclear how many products were in each package. Therefore, the provided inventory was taken as a reference in this study during the material selection and it was tried to choose the materials close to the inventory. The Nasjonalparken inventory is available in the Appendix from Figure A.1 to Figure A.7. As there were no structural drawings available from the project, assumptions based on the Sintef prefabricated construction systems , [60] [63], were utilized to formulate a structural framework for the Ånegga cabin.

3.11 Structure and materials

The structural details of the cabin are as follows.

3.11.1 Internal wall

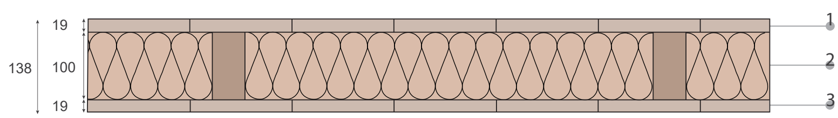


Figure 3.14: Internal wall structural detail scale 1:20 [63].

1	Inner cladding
2	48 × 98 mm studs – c/c 600 mm + 100 mm wood fiber insulation
3	Inner cladding

Table 3.1: Structural detail of internal wall

3.11.2 External wall

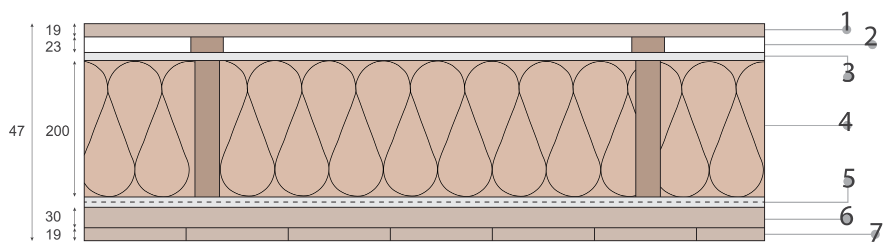


Figure 3.15: External wall structural detail scale 1:20 [63].

1	Outside cladding
2	23 × 48 mm lath
3	Wind barrier 12 mm
4	36 × 198 mm stud c/c 600 mm + 200 mm wood fiber insulation
5	Vapor barrier
6	30 × 48 mm lath c/c 600 mm
7	Inner cladding

Table 3.2: Structural detail of the external wall

3.11.3 Ground floor and foundation

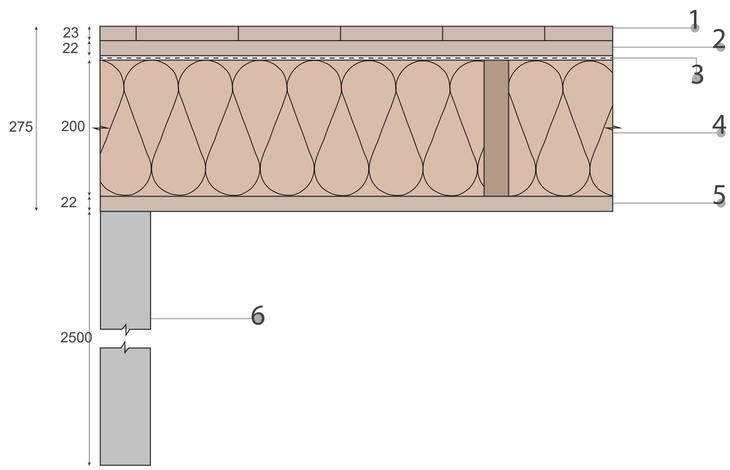


Figure 3.16: Structural detail of the ground floor and foundation scale 1:20

1	Flooring 23 mm
2	Chipboard 22 mm
3	Vapor barrier
4	Beam 48 x 198 mm c/c 600 mm + Insulation 200 mm
5	Chipboard 22 mm
6	Steel piles 200 mm diameter and 2500 mm height

Table 3.3: Structural detail of the ground floor and foundation

3.11.4 Roof

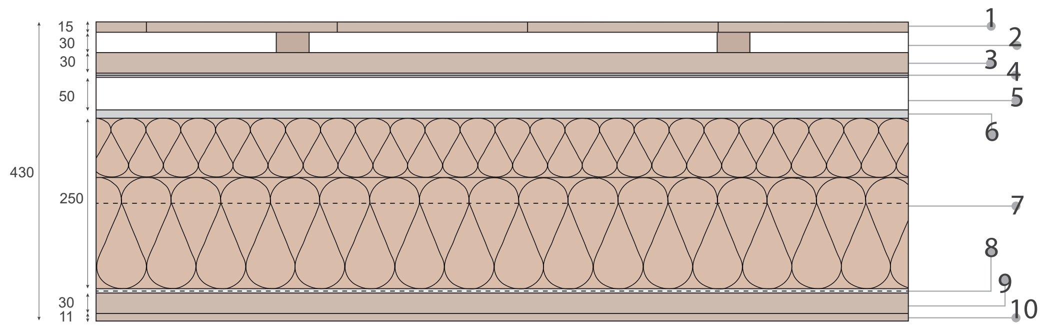


Figure 3.17: Structural detail of the roof scale 1:20 [60] [64]

1	Clay roof tiles 15 mm
2	Lath 30 x 48 mm c/c 600 mm
3	Lath 30x48 mm c/c 600 mm
4	Simplified suspended ceiling (Forenklet undertak)
5	Ventilation carton with 50 mm air gap
6	Wind barrier
7	Timber rafters 48x98 mm c/c 600 mm + Insulation 250 mm
8	vapor barrier
9	Lath 30x48 mm c/c 600 mm
10	Chipboard 11 mm

Table 3.4: Structural detail of the roof

3.11.5 Building materials

As it is shown in the structural details, the Ånegga cabin is constructed using wood. Noteworthy materials of the building include the following.

Windows: The cabin has 8 windows and 2 glass entrance doors. The U-values of the windows in the case study are 1.4 W/m2K for two of them and 1.3 W/m2K for the rest of the windows. The U-value of the entrance glass doors that are in the outer wall is 1.3 W/m2K.

Steel piles: To have the least intervention in the landscape, the steel piles are used for the foundation of the cabin. They have a 2-meter depth in the ground and it is the first time that the NasjonalParken has used this type of foundation. They were using concrete for the foundation in the past cabin projects. The advantage of this method is that in the future the cabins can be dismantled and the piles be removed without leaving a negative effect on the soil and the nature around. The steel piles used in the Ånegga cabin are made of recycled steel and this is one of the reasons that their embodied emissions are lower than new steel piles. It is 0.83 kgCO2e/kg with the life span of 60 years.

Insulation: The insulation used in the Ånegga cabin is with wood fiber boards with a Lambda value of 0.04 W/mK and a low amount of emission (A1-A3) which is 0.566 kgCO2e/ m2. The life span of the insulation is 60 years. Recently, there has been a significant surge in interest regarding the utilization of different natural fibers for thermal insulation and sound absorption purposes. Wood fibers are renewable materials and are widely used because of their favorable mechanical characteristics and low cost. Due to the growing emphasis on sustainability, the emergence of recycling and recovery practices for industrial wastes, including those from the textile sector, are significant [81]. Wood fiber insulation has a higher moisture capacity compared to for instance mineral wool. This improves the overall moisture conditions within a wooden frame wall [84]. A higher moisture capacity decreases the risk of mold growth in the building [84], especially for a holiday house that is not occupied on a daily basis.

Generally, synthetic and mineral materials outperform natural fibers regarding thermal insulation, sound absorption, and fire resistance. However, most of these synthetic and polymeric materials are predominantly manufactured from petroleum resources, thereby contributing negatively to the environment [82]. Natural fibers are cost-effective, biodegradable, readily accessible, environmentally friendly, and possess favorable thermal insulation and sound absorption properties [83].

3.11.6 U-values of windows and walls

Based on the structure and materials of the cabin U-value of the building elements such as walls, Roof, and floor were calculated in Ubakus [32]. The following table compares the U-values of the cabin and the general requirements based on the regulations in Tek17. Although this requirement is a minimum amount and the Ånegga cabin which is under 70 m2 is exempted from it, the U-value of the Ånegga cabin envelope meets these energy requirements [33].

Component	U-value (W/m2k)	Tek17 Requirement for holiday homes
External wall	0.18	6 inch / 15.24 cm
Roof	0.18	0.18
Ground floor	0.18	0.18

Table 3.5: Requirements for holiday homes [33]

3.12 Occupancy

As it was mentioned before, a survey conducted by NasjonalParken before starting the Ånegga project to gather information about the culture of using the cabins as well as having an overview of the current situation of the cabins in the Oppdal area and use it for future projects [39]. Based on the survey the duration of using the cabins by their owners was about 60 days a year in 2015 which was the highest amount compared to the previous statistics in 1999 and 2008 Table 2.2. It shows a gradual rise trend in cabin usage which can be continued in the future. The average amount of users was a family of 4 people. Regarding the culture of using the cabins, the collected information showed that most of the cabin users (73%) were using their cabins throughout the year. As well as this, the Easter holiday (34%), Weekends in Autumn (27%), winter holidays (26%), summer holidays (23%), and weekends of winter with 21% interest to use the cabins were popular periods during the year respectively [39]. Most of the cottage owners are happy with having a cabin in Oppdal (average 5.2 of 6), however, 64% of the cabin users do not like to settle there. Generally, most of the people answered that they go to Oppdal only for their leisure time and most of the rest go there for their jobs [21]. In general, Oppdal is a tourist spot where people stay temporarily. Cabin owners use their cabins at specific times of the year and the rest of the year they are unoccupied. However, these buildings still need to be heated to prevent freezing the water pipes and damaging the materials.

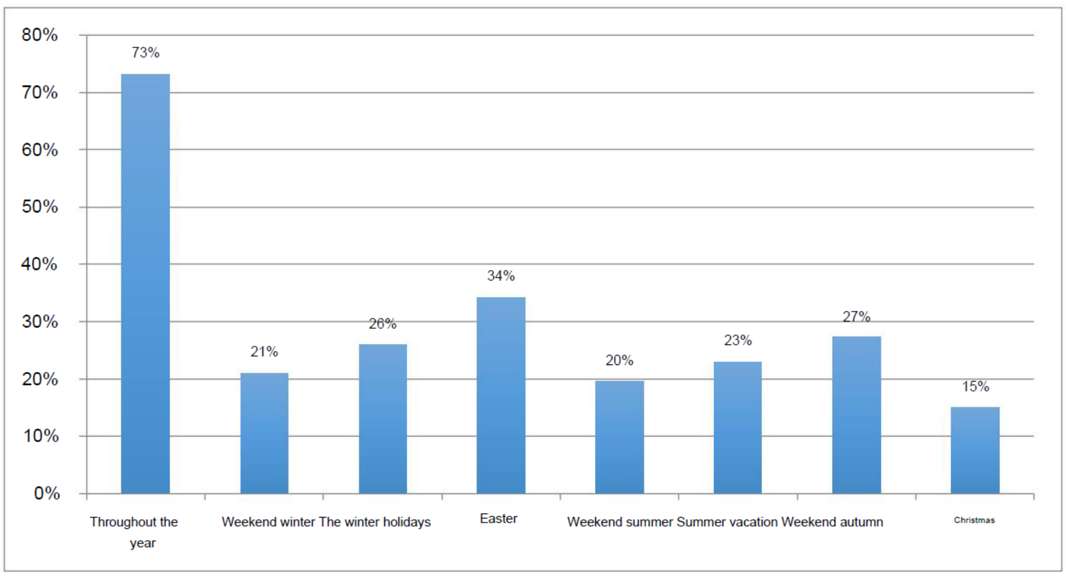


Figure 3.18: What time of year is the cabin in use? [21]

Chapter 4

Methods

This chapter explains the main techniques used to analyze the case study. It covers choosing the software, defining parameters, and setting up different scenarios for examination.

4.1 Scenarios

Three different scenarios are defined in this thesis to understand the changes in GWP and the factors involved in it. The aim is to analyze the case study give solutions to reduce GWP, and define guidelines that can be used in future projects. These scenarios are as follows:

Scenario 1: This scenario is the Ånegga cabin with its current new materials and structure.

Scenario 2 (Reused scenario): In this scenario, Ånegga cabin with specific reused materials is studied in terms of changes in GWP. The materials in this scenario are the same as the new ones but are considered reused. The reused heating system and PV panels are included in this scenario as well.

Scenario 3: In this scenario, specific materials are replaced with different types of materials. As well as this, the plan is explored to be more optimized in the design.

In this chapter, after defining each scenario, the LCA and energy analysis are calculated to explore the involved factors in emissions production and suggest solutions to decrease them. In the end and in the following chapters, the results of all scenarios are compared and guidelines for future projects are suggested with the aim of GWP reduction that is in line with the goals of the Paris Agreement.

4.1.1 Ånegga case study - Scenario 1

This scenario is introduced in Chapter 3 as existing Ånegga cabin design.

4.1.2 Reused - Scenario 2

It is tried to explore the possibility of the reuse of materials on a smaller scale in the region of Trøndelog county. Therefore, mapping reports and the local database of Loopfront are used in this study. Mapping reports done by Asplan Viak and NorConsult for Trondheim municipality contain information about the parts of the buildings that are possible to be reused [50] [59]. As well as this, Loopfront as a database for reused material which has storage in Trondheim was explored and an interview was conducted with them [74] [75]. The results show that the most reusable parts of the building are non-load-bearing parts and in Loopfront the most available materials are furniture and then non-load-bearing materials such as windows. In addition, in the case study cabin, the foundation is with steel piles as a load-bearing element. It is a highly reusable product [79]. Another reusable item in the cabin is its insulation which is with wood fiber and reusable material [81]. More details are in the following sections about the reused materials in this scenario.

Reused materials

It is considered that the reused materials maintain their original properties and values after being reused. The decision to choose the reused materials involved seeking assistance from two mapping reports from Asplan and Multiconsult which were mentioned before, along with a review of the Loopfront inventory and a meeting with them. Exploring the emission intensity of the materials in Reduzer and checking their EPDs for factors such as their composition were also taken into account during the decision-making process. This also included comparing how the reuse of materials could influence the GWP of the building in Reduzer. The materials that are replaced with reused ones are ceramic tiles, windows, glass doors, clay roof tiles, steel piles, wooden interior doors, and wood-fiber insulation.

Ceramic tiles: Tiles are possible to be reused. However, from the tiles that are used in a building, a small portion of them are possible to be reused. This is because the cement-based glue which is used to keep the tiles on the walls and floors has great adhesive properties that make gentle disassembly difficult. It is a manual and time-consuming process. However, it is still possible to reuse them, especially for small cabins [50] [59].

Windows and entrance glass doors: Windows are the products that are easy to remove and reuse in another project. Generally, The value should be checked when taking the window or doors out from a donor project and if it meets the minimum construction standards such as Tek17 then can be reused [50] [59].

Roof tiles: The roof covering in this project is clay tiles that is replaced with reused same tiles. However, most of the tiles and coverings that are used outside are damaged by the harsh weather and are not aesthetically pleasant to be reused as they are [50] [59]. However, the amount of the roof tiles that is needed for a small leisure house is less than a residential house in the city and it has lower requirements to be aesthetically pleasant.

Steel piles: Steel is a material with the potential to be reused. It is an expensive material with high GWP and it needs higher energy to be produced. The lifespan of steel is high which is another factor that makes it suitable for reuse purposes [50] [59].

Insulation: Wood fiber insulation can be reused in some cases, and it depends on the specific type of wood fiber insulation, its condition after removal, and the intended reuse. With cautious removal from a structure and minimal damage, wood fiber insulation potentially can be reused in another location or for its original purpose. Nevertheless, various considerations must be taken into account.

4.1.3 Redesign - Scenario 3

In this scenario, it is investigated if it is possible to reduce emissions by making changes in the current design of the cabin. The aim of this scenario is to find the possible solutions in the case study design and give solutions for future projects. Making changes in the amount of the glazing as well as altering the design, are parts of this scenario. The area of the Ånegga cabin is 37 m2 for four people but it is explored if it is possible to reduce this area. Although holiday houses should be comfortable for the users in terms of the temperature, and the function of the space, the plan should be designed to use the space optimally. In addition, a considerable amount of energy loss is from windows which is taken into account in redesigning the building.

Replacing glazings

By decreasing WWR (window-to-wall ratio) in the building, the total heating load is decreased. However, the heating demand depends on the size of the windows, as well. The wider size of windows leads to a greater amount of energy consumption. It is worth noting that solar heat gain through the window and conduction loss are in conflict. With wider windows more heat is gained inside the building but the heat loss is increased as well [80]. In the Ånegga case study, the ratio of windows to external walls varied in different directions which will be explored. The entrance doors in the cabin are glass doors and they are considered as windows for the calculation of window-to-wall ratio. The window-to-wall ratio in the case study is 14.05%. The total area of external walls is 98.06 m2 and it is 13.78 m2 for windows and glass doors. In Ånegga cabin, a higher percentage of glass is used in the south facade which is beneficial regarding getting more sun radiation in the winter. However, by implementing more glass, the impact of window specifications on the energy demand of the cabin increases.

Changing the plan

In this scenario, the bedroom is removed and the attic floor is used as the sleeping area for four people. There is a partition to divide it into two separate spaces when needed. The initial plan had a pair of glass entrance doors, with one of them being a double door. In the redesigned layout, one entrance was eliminated, resulting in the cabin having a single wooden door as its entry. One of the porches was eliminated, and the other porch was reduced in size. The temporary staircase to the attic, resembling a ladder for easy mobility, remained unchanged but was repositioned to create additional space in the attic for the sleeping area. Moreover, due to the reduced floor area (21.62 m2) in the redesigned layout, two windows on the first floor were removed, reflecting the diminished space requirement for allowing sunlight and radiation into the cabin.

4.2 LCA stages

In the context of the Life Cycle Assessment, the study includes stages A1-A3 which refer to the production of the materials, A4-A5 for the transport and construction, B1 (use), B4 (replacement of the material), B6 (operational energy use), C3 (waste procession), and D (reusability). The covered stages are based on the FutureBuilt ZERO standard and in the Reduzer software. The embodied emissions are calculated in Reduzer, therefore, there are limitations related to the software. The system boundary with more details is included in Figure B.2 and Figure B.3. The operational emissions related to stage B6 are calculated separately through energy analysis and then manual calculations. The embodied emissions of the heating systems and PV panels are calculated manually.

FutureBuilt ZERO is used as a standard for sustainability in this study. Its total, material, and energy benchmarks are used to compare the emissions generated by the case study.

Web-based software, Reduzer, is an LCA calculator that can be used for LCA calculations within different standards such as FutureBuilt Zero and NS 3720.

The material inventory received from Nasjonalparken included all the materials used in the 8 cabins of the Ånegga pilot project. Since it was not clear how much of which material was used in each cabin and also because structural drawings were not available, a new material inventory was defined and it was tried to be close to the original materials.

4.3 Embodied emissions of electric heating system

The heating system in the Ånegga project is electricity. In this type of system, the electricity is converted to heating directly using radiators or coils. In this case study electric heaters are used which have an efficiency of 100% [89]. The Electric heater used in Ånegga has 20 years of lifetime and its emission is 51 kgCO2eq/kW [40]. For the living room, 13.58 m2, the power of the heater is 1.92 kW. For the bedroom, 4 m2, and bathroom, 3.30 m2, it is 1.4 kW [73].

Honeybee tool

Energy analysis in this thesis is done using the Honeybee tool. It is a tool for thermodynamic and daylight modeling that generates visualized results for energy models using Open Studio and Energy Plus. It runs in Grasshopper, a plugin in Rhino software [42].

EPW weather file

The EPW weather file to use in the energy analysis was downloaded from the Climat One Building website [28]. The EPW file format which is the Energy Plus weather file is standard weather data and includes information such as time zone, latitude, longitude, temperature, sun position, etc.

4.3.1 Heating demand

The heating demand in both scenarios 1 and 2 remains consistent, as scenario 2 involves the reuse of identical materials. For analytical purposes, their properties are treated as equivalent. However, the operational emissions exhibit variations for different heating systems with/without photovoltaic systems, depending on the specific types employed. The amount of thermal energy produced in relation to the input energy, reflecting the system's effectiveness in converting fuel or power into useful heat is termed heating energy. In scenario 3, due to alterations in the design and the removal of materials, the heating demand differs from that of scenarios 1 and 2.

4.4 Occupancy and standby mode

In this study, different periods of occupancy are explored to calculate the energy demand of the building and the emissions produced in the operational phase. With this aim, different scenarios of occupancy are defined as follows for the Ånegga cabin.

1- Throughout the year as a normal residential housing unit

2- weekends and holidays in the year (127 days)

3- Weekends during the year (96 days)

4- Weekends and holidays in the winter (44 days)

5- Weekends during the winter (32 days)

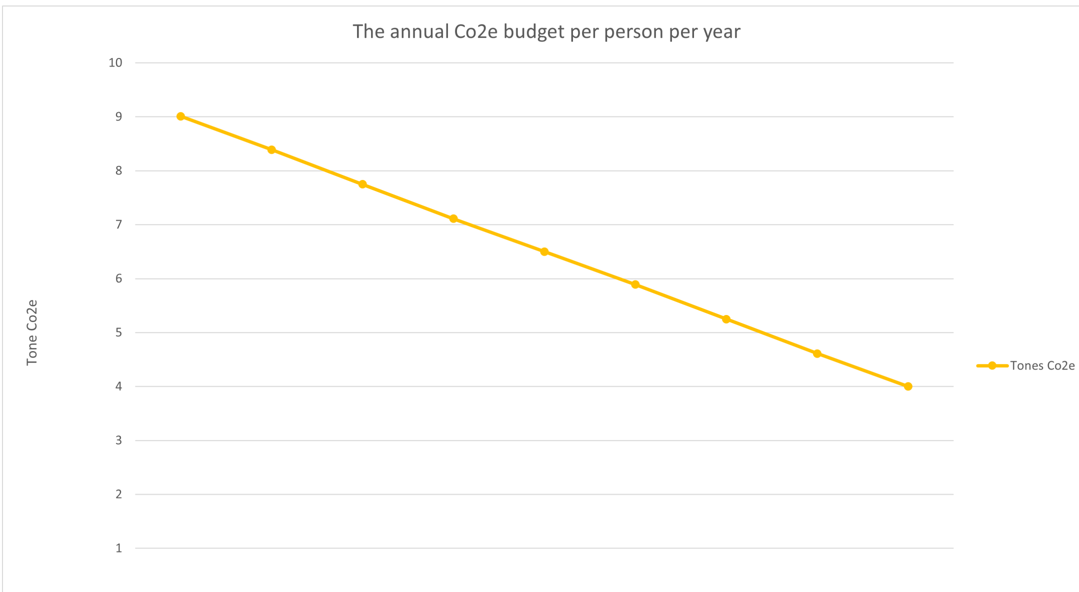
6- Weekends and holidays during the summer (75 days)

The designated standby temperature for this research in the energy analysis is set at 16°C. The analysis and findings are derived from this specific temperature. This temperature is considered higher than the minimum temperature that is needed to prevent pipes from freezing. This is to analyze the worst-case scenario in terms of energy demand and assume that the users use the cabin more regularly, as well as this, because of considering different scenarios of occupancy to be comparable to one another. Certain occupancy scenarios follow a more consistent pattern, while others involve more frequent periods of being unoccupied. Nevertheless, it is crucial to explore how adjusting the standby temperature impacts the heating load. By examining variations at 5°C and 10°C and conducting repeated energy analyses, notable changes in results have been observed.

Based on ASHRAE Standard 55–2013, assuming slow air movement and 50% indoor relative humidity, the heating setpoint temperature should be between 20.28 °C – 23.89 °C [45]. As well as this, based on EN15251 a minimum temperature of 20°C for bedrooms is recommended during the heating season [46]. In this study, during the occupancy period, the temperature of the cabin is defined as 20°C during the day, and from 10 pm until 7 am when people are sleeping, it is 18°C.

4.5 Carbon emission budget

As mentioned before, the share of Norway based on the Paris Agreement is to achieve a reduction in emissions by 55% by 2030 [72] and 90% - 95% by 2050, compared to the generated emissions in 1990 [38]. in the year 2022 Norway reached 4.7% reduction of GWP [36]. By knowing the goal of reduction by 55% by 2030 and having it for the year 2022 as 4.7% [36], as well as the population of each year in Norway [37], the GWP budget of each person per year can be calculated. In the following linear graph, Figure 4.1, it is considered that the amount of GWP is decreasing gradually. The first point is 2022 and the endpoint is 2025 with 9 and 4 tonneCo2eq respectively as the total annual emission budget per person.



	2022	2023	2024	2025	2026	2027	2028	2029	2030
Tones Co2e	9.01	8.39	7.75	7.11	6.5	5.89	5.25	4.61	4

Figure 4.1: Emission budget graph

4.6 Reused heating system

Two different types of heat pumps which are ASHP and GSHP are analyzed in this study as reused systems, as well as, a reused electric heating system. The aim is to understand which system is more optimized and produces lower GHG emissions to be implemented in the cabin. Testing the Ånegga case study with different reused heating systems can provide solutions for future cabin construction projects. In the following steps to calculate the emissions of the heating systems, it is considered that they keep their efficiency as a new one, but the embodied emissions of them are decreased by 80% based on the FutureBuilt ZERO standard. The efficiency of the heating system used in this study for electricity is 100% and it is 367% and 230% for the GSHP and ASHP respectively.

4.7 Reused PVs + Reused heating system

Photovoltaic panels (PVs) are installed on the 30 m2 of the roof with the direction to the south-east. In the third scenario, the installation area for PVs is 20 m2, reflecting a reduction in cabin size. For the PV panels as well as the heating systems to be implemented as reused, 80% of the embodied emissions is decreased based on the FutureBuild Zero standard. The embodied emissions of the reused PV panel in this study is 0.52 kgCO2e/m2/year and the life span is 30 years. The study calculated the total Global Warming Potential (GWP) of the cabin using two CO2 factors: 17 gCO2eq/kWh and 136 gCO2eq/kWh. It also assessed the GWP of the cabin in different scenarios, considering the presence or absence of photovoltaic panels (PVs).

The reason to do the calculations for both Co2 factors is that the current emissions of Norway (26.10.2023) is 17 gCO2eq/kWh [41]. However, the electricity of Oppdal is provided mostly by hydropower energy in Norway but some of it comes from Europe which has emissions from fossil fuels with it. As well as this, Norway in different seasons has varied Co2 factors, which are higher during the winter. The Co2 factor of 136 g/kWh is the average amount between the electricity emissions of Norway and Europe [78]. In the following sections, to calculate the total GWP of the cabin with PVs the following parameters are summed up: Embodied emissions of the materials + Operational emissions + Embodied emissions of the heating system + (Production of PVs - Embodied emission)

Chapter 5

Results

In this section, the outcomes of the Life Cycle Assessment calculations and energy analysis, conducted as outlined in the methodology chapter, will be presented. A comparative discussion of the results from the three specified scenarios will follow in the subsequent discussion chapter.

5.1 Ånegga case study - Scenario 1

The results of scenario 1 which is the existing Ånegga cabin, are as follows in the next sections. The duration of the winter in the energy analysis is considered as from November 1st at 1:00 until February 28th at 24:00. It is from May 1st at 1:00 until August 31st at 24:00 for the summer. As was mentioned before, different scenarios are defined for the occupancy to calculate the energy demand of the building. The standby temperature in Table 5.7 and Figure 5.7 is 16°C.

5.2 Energy analysis

Scenario 1) Occupancy as a residential housing during the whole year

For this scenario, it is considered that the cabin is used as normal residential housing which is occupied during the whole year. Table 5.1 shows the heating and cooling load amount and Figure 5.1 is the visualization of the energy analysis in different zones of the building. The amount of the cooling load is very low and does not even get to 1 kWh/m2 because Oppdal has cool summers.

Annual energy analysis - 365 days	
Heating load	59.45 kWh/m2
Cooling load	0.91 kWh/m2

Table 5.1: Annual energy analysis. Occupancy: one year

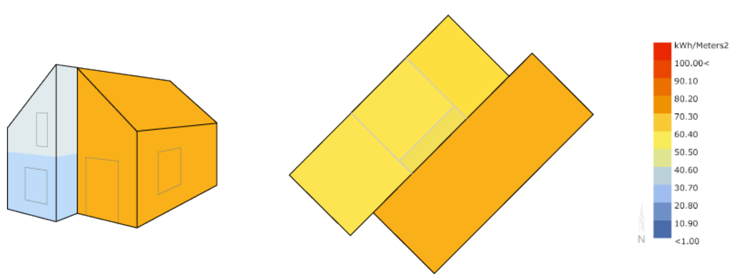


Figure 5.1: Heating load kWh/m2 Jan 1 1:00 - Dec 31 24:00

Scenario 2) Occupancy as weekends and holidays during the year

In this scenario, occupancy is distributed as all the weekends and holidays during the year which means 127 days per year. Table 5.2 shows the heating and cooling load amount for the specified period and Figure 5.2 is the visualization of the analysis and shows the heating load in different zones of the building.

Annual energy analysis - 127 days	
Heating load	31.16 kWh/m2
Cooling load	0.55 kWh/m2

Table 5.2: Annual energy analysis, Occupancy: weekends and holidays 127 days

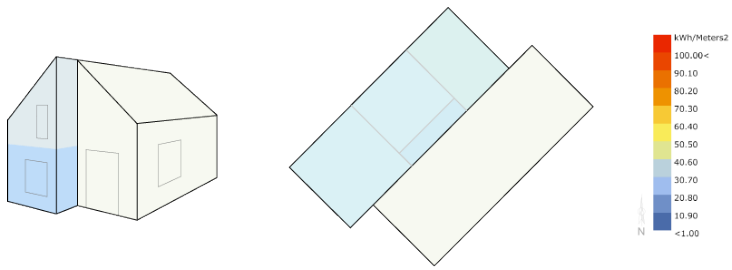


Figure 5.2: Annual heating load kWh/m2 Jan 1 1:00 - Dec 31 24:00

Scenario 3) Occupancy as weekends during the year

Occupancy is defined as the weekends during the year which is 96 days. Following Table 5.3 and Figure 5.3 show the heating and cooling load amount and the energy analysis visualization respectively.

Annual energy analysis - 96 days	
Heating load	24.51 kWh/m2
Cooling load	0.63 kWh/m2

Table 5.3: Annual energy analysis, Occupancy: weekends 96 days

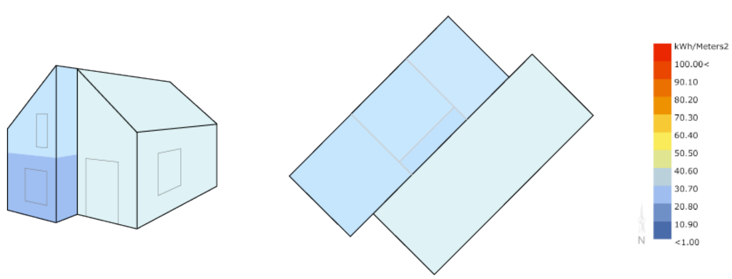


Figure 5.3: Annual heating load kWh/m2 Jan 1 1:00 - Dec 31 24:00

Scenario 4) Occupancy as weekends and holidays in winter

Occupancy as weekends and holidays in the winter (44 days). Following Table 5.4 and Figure 5.4 show the heating and cooling load amount and the energy analysis visualization respectively.

Winter energy analysis - 44 days	
Heating load	27.35 kWh/m2
Cooling load	0.00 kWh/m2

Table 5.4: Winter energy analysis. Occupancy: weekends and holidays 44 days.

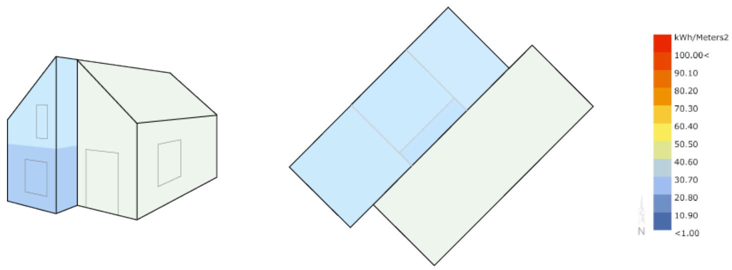


Figure 5.4: Winter heating load kWh/m2 Nov 1 1:00 - Feb 28 24:00

Scenario 5) Occupancy as weekends in winter

Occupancy is defined for the weekends during the winter (32 days). It is from November 1st until February 28th. Following Table 5.5 and Figure 5.5 shows the heating load amount and its visualization respectively.

Winter energy analysis - 32 days	
Heating load	22.04 kWh/m2
Cooling load	0.00 kWh/m2

Table 5.5: Winter energy analysis. Occupancy: weekends 32 days.

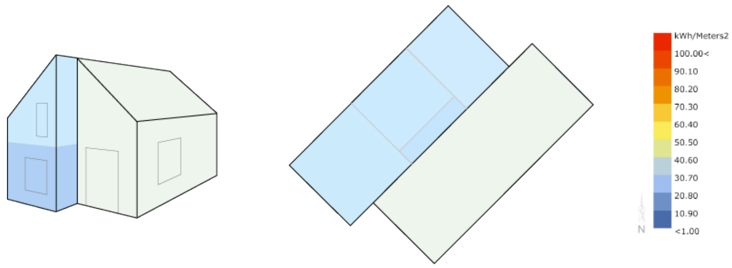


Figure 5.5: Heating load kWh/m2 Nov 1 1:00 - Feb 28 24:00

Scenario 6) weekends and holidays in summer

In this scenario, occupancy is defined as weekends and holidays in summer from May 1st until August 31st. Following Table 5.6 and Figure 5.6 show the heating load amount and its visualization respectively. The heating load and cooling load of the summer are very low and neglectable. The dominant heating load is during winter.

Summer energy analysis 75 days	
Heating load	0.00 kWh/m2
Cooling load	0.49 kWh/m2

Table 5.6: Summer energy analysis. Occupancy: 75 days.

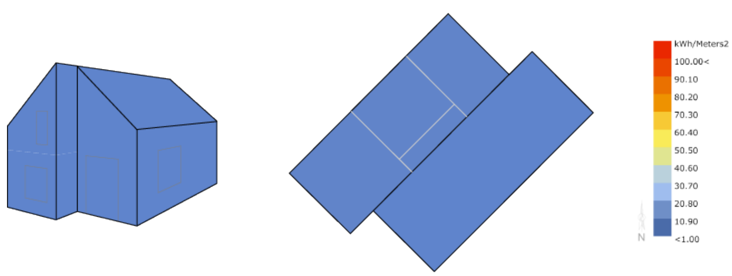


Figure 5.6: Summer heating load kWh/m2 May 1 1:00 - August 31 24:00

Comparison of the results

Scenario	Occupancy	Heating load kWh/m2
1	Annual energy analysis - 365 days	59.45
2	Annual energy analysis - 127 days	31.16
3	Annual energy analysis - 96 days	24.51
4	Winter energy analysis - 44 days	27.35
5	Winter energy analysis - 32 days	22.04
6	Summer energy analysis 75 days	00.00

Table 5.7: Summary of heating load scenarios

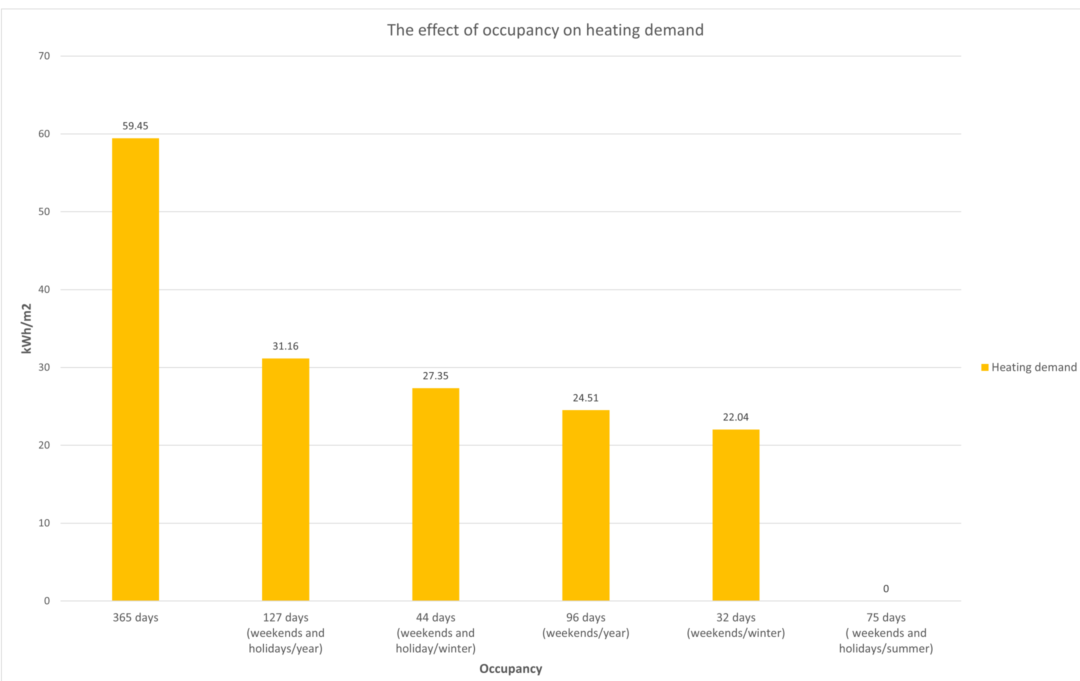


Figure 5.7: The effect of occupancy on heating demand

5.3 Altering the standby mode

As mentioned before, the standby temperature in this study is considered 16 degrees Celcius. However, the way altering standby temperature affects the heating load is worth discussing. By considering 5 and 10 degrees Celcius and repeating the energy analysis, the results changed and they are as follows in Table 5.8 and Figure 5.8.

Occupancy	Standby temperature (°C)	Heating load (kWh/m2)
Annual (weekends and holidays, 127 days)	16 °C	31.16
Annual (weekends and holidays, 127 days)	10 °C	24.51
Annual (weekends and holidays, 127 days)	5 °C	20.16
Annual (weekends, 96 days)	16 °C	24.51
Annual (weekends, 96 days)	10 °C	20.17
Annual (weekends, 96 days)	5 °C	19.04
Winter (weekends and holidays, 44 days)	16 °C	27.35
Winter (weekends and holidays, 44 days)	10 °C	22.03
Winter (weekends and holidays, 44 days)	5 °C	17.87

Table 5.8: Standby temperature and its effect on heating load

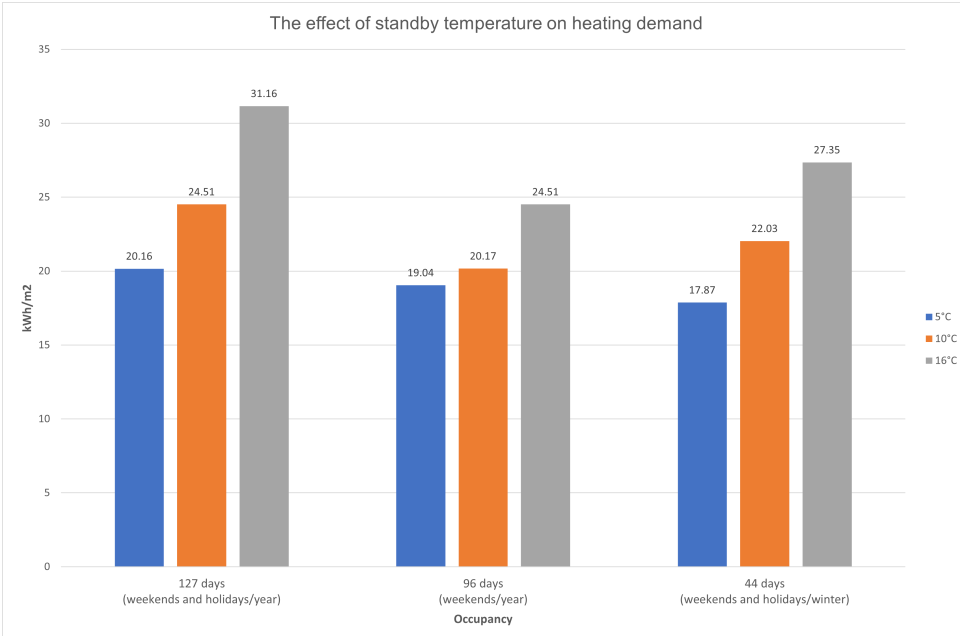


Figure 5.8: The effect of standby temperature on heating demand

5.3.1 Heating load selection

Based on the results from the energy analysis and the popular periods of using the cabins during the year [39], it is concluded that there is a range for the heating load of the cabin as follows Table 5.9. One of them will be chosen to continue the analysis and LCA calculations.

Occupied period	Heating load kWh/m2	Selection
Occupied during weekends and holidays throughout the year (127 days)	31.16	
Occupied during weekends throughout the year (96 days)	24.51	×
Occupied during summer + winter, holidays and weekends, (119 days)	27.35	
Occupied during summer + winter, weekends (64 days)	22.4	

Table 5.9: The range of energy analysis results

The chosen heating load is 24.51 kWh/m2 which is for the occupation during weekends throughout the year (96 days). The reason for choosing this heating load is because the amount of the heating load in this scenario is in the middle of the range and also the days are distributed throughout the year. In addition, as the number of occupied days was considered on the rise in the Nasjonalparken survey, 96 days of occupancy can be a choice. Other options can be correct as well based on different cultures of using the cabin.

5.4 Operational phase emissions

There are two Co2 factors used in this study to calculate the operational emissions. One is the Co2 factor of Norway which is 17 gCO2eq/kWh retrieved on 26.10.2023 [41]. The other factor is a combination of the emissions from Europe and Norway on electricity supply and based on the standard NS03720, which is 136 gCO2eq/kWh [78]. The calculations regarding the operational phase emissions are added to Appendix 3.

Operational phase emissions, Co2 factor=17 gCO2eq/kWh

operational emissions for 60 years = 24.6 kgCo2/m2 = 0.41 kgCo2/m2/year, section C.1.

Operational phase emissions, Co2 factor=136 gCO2eq/kWh

operational emissions for 60 years = 200 kgCo2/m2 = 3.33 0.41 kgCo2/m2/year, section C.2

5.5 Embodied emissions of the electric heating system

Embodied emissions of the heating system is as follows in the Table 5.11 and detailed calculation is in Appendix section C.3.

5.6 Embodied emissions of the materials

The embodied emissions results for the case study which was calculated in Reduzer are as follows Table 5.10. The results are presented per square meter to be more understandable and comparable to one another and to the emissions of other projects.

Building	Total mass	Total GWP	Total GWP
Ånegga cabin	12 tonne	7.4 tonne Co2eq	201 kgCo2eq/m2

Table 5.10: Embodied emissions of the materials

Total embodied emissions

Total embodied emissions = Material embodied emissions + Embodied emissions of the electrical heating system. For the Ånegga cabin, the total embodied emission is 220.5 kgCo2eq/m2 Table 5.11.

Embodied emissions of materials	201 kgCo2eq/m2
Embodied emissions of the heating system	19.50 kgCo2eq/m2
Total embodied emissions	220.5 kgCo2eq/m2

Table 5.11: Total embodied emissions

5.7 Total GWP (embodied + operational)

The total GWP which is a result of embodied and operational emissions is demonstrated in the following Table 5.12 and Table 5.13. It is calculated with the Co2 factor of 17 gCO2eq/kWh and 136 gCO2eq/kWh.

Total embodied emissions	220.5 kgCo2eq/m2
Operational emissions	24.60 kgCo2eq/m2
Total emissions of the Cabin	245.10 kgCo2eq/m2

Table 5.12: Total emissions of the Cabin, Co2 factor = 17 gCO2eq/kWh

Total embodied emissions	220.5 kgCo2eq/m2
Operational emissions	200 kgCo2eq/m2
Total emissions of the Cabin	420.5

Table 5.13: Total emissions of the Cabin, Co2 factor = 136 gCO2eq/kWh

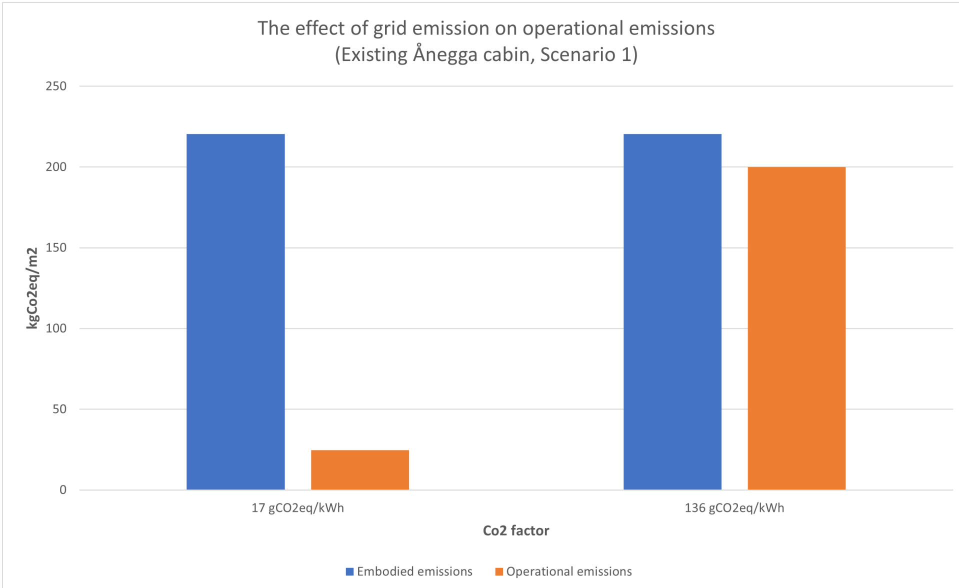


Figure 5.9: The effect of grid emission on operational emissions, scenario 1

5.8 FutureBuilt ZERO benchmarks

The following figures show the comparison between the GWP produced by the cabin and the benchmarks from the FutureBuilt ZERO standard. The GHG emissions are decreased by 35.16% compared to the total benchmark, 8.71% compared to the material benchmark, and 84.14% compared to the energy emissions benchmark.

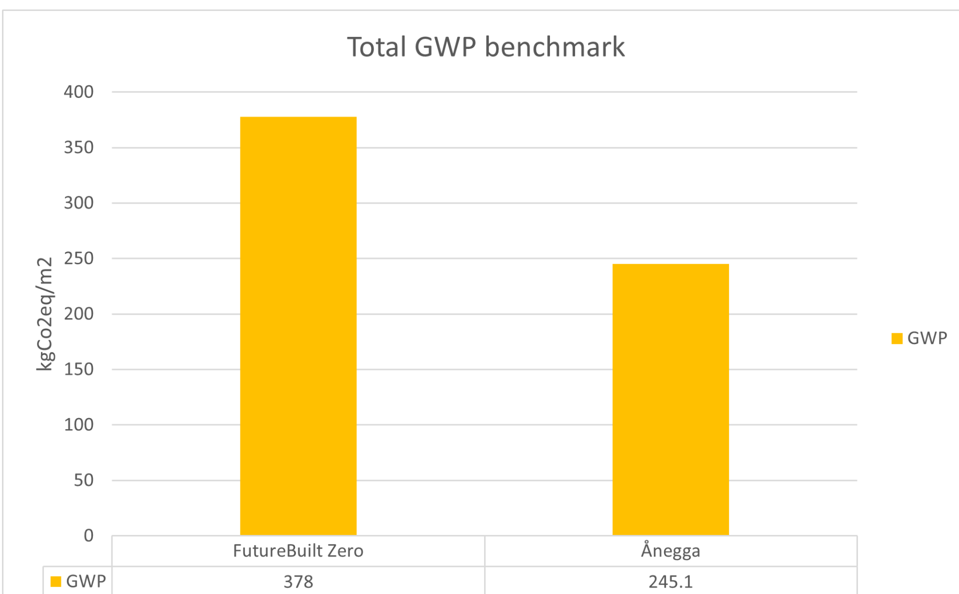


Figure 5.10: Total benchmark comparison, 35.16% reduction

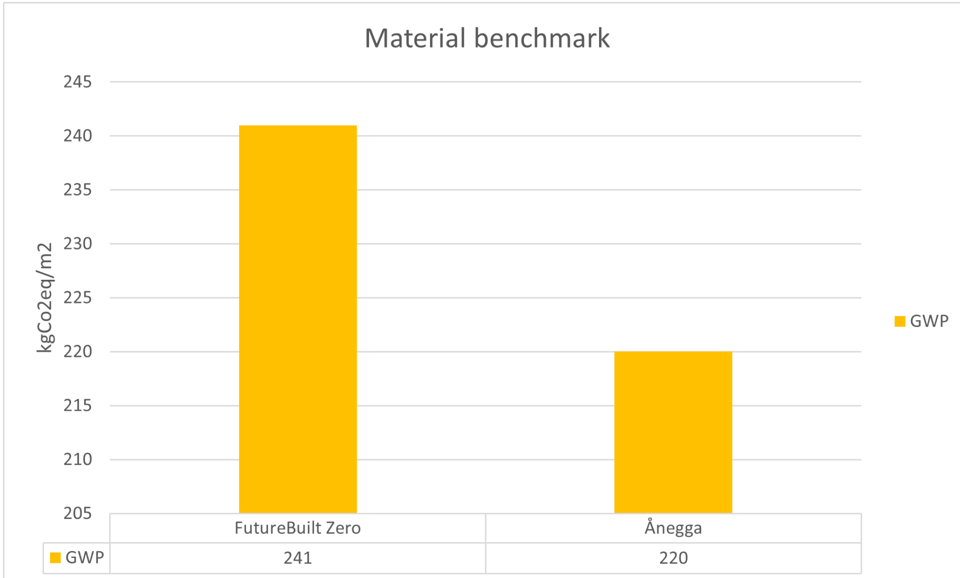


Figure 5.11: Material benchmark, 8.71% reduction

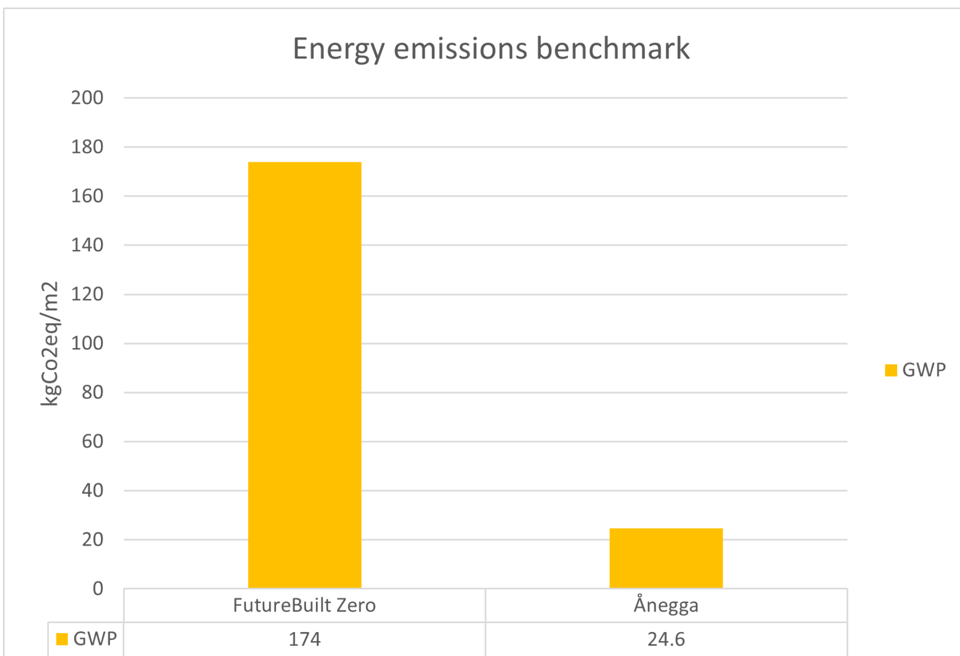


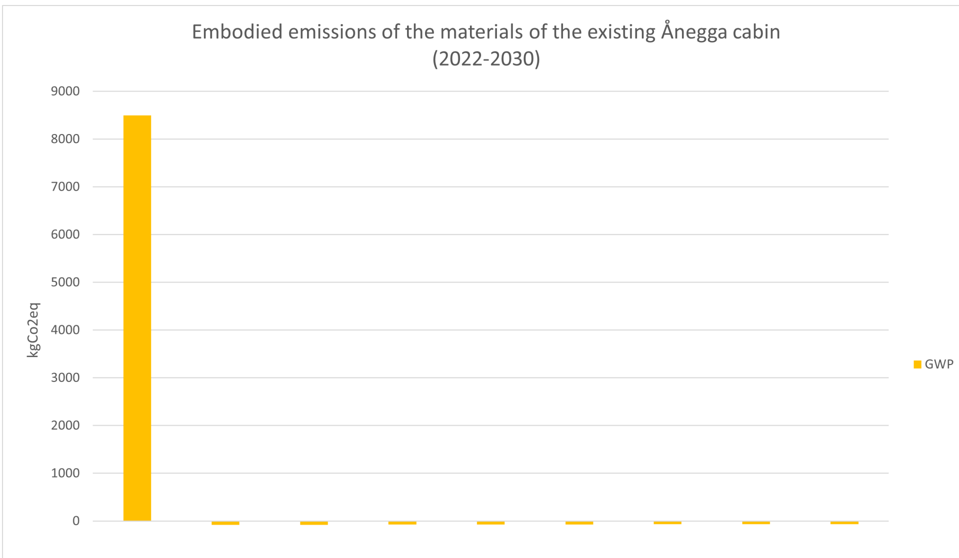
Figure 5.12: Energy emissions benchmark, 84.14% reduction

5.9 Emission budget

Based on Figure 4.1, the GHG emission budget for each person from 2022 (the year the cabin was built) until 2030 is 58.51 tonneCo2eq. This number is the amount of emission that each person can use by 2030 in line with the goals of the Paris Agreement. This amount for each person in 2022 is 9.34 tonneCo2eq.

5.9.1 Emission budget considering existing Ånegga cabin

The embodied emissions of the existing Ånegga cabin in the year 2022 is 9215 kgCo2eq. This amount includes the embodied emissions of the materials in the same year (8494 kgCo2eq), Figure 5.13, and the embodied emissions of the electric heating system (722 kgCo2eq). The annual operational emissions considering the Co2 factor of 136 gCo2eq/kWh is 123.33 kgCo2eq/year. With four owners, each person's share of the cabin's total GWP is 2.34 tonnesCO2eq Figure 5.15. Emissions beyond 2022 until 2030 and subsequently in 2050 are influenced by operational emissions, biogenic carbon uptake, and cement carbonation each year Figure 5.14. The end-of-life phase in 2082 generates 347.82 kgCO2eq.



	2022	2023	2024	2025	2026	2027	2028	2029	2030
GWP	8493.81	-78.78	-76.82	-74.89	-72.63	-70.74	-68.87	-66.95	-65.12

Figure 5.13: Yearly embodied emissions of the materials of the existing Ånegga cabin Figure C.1

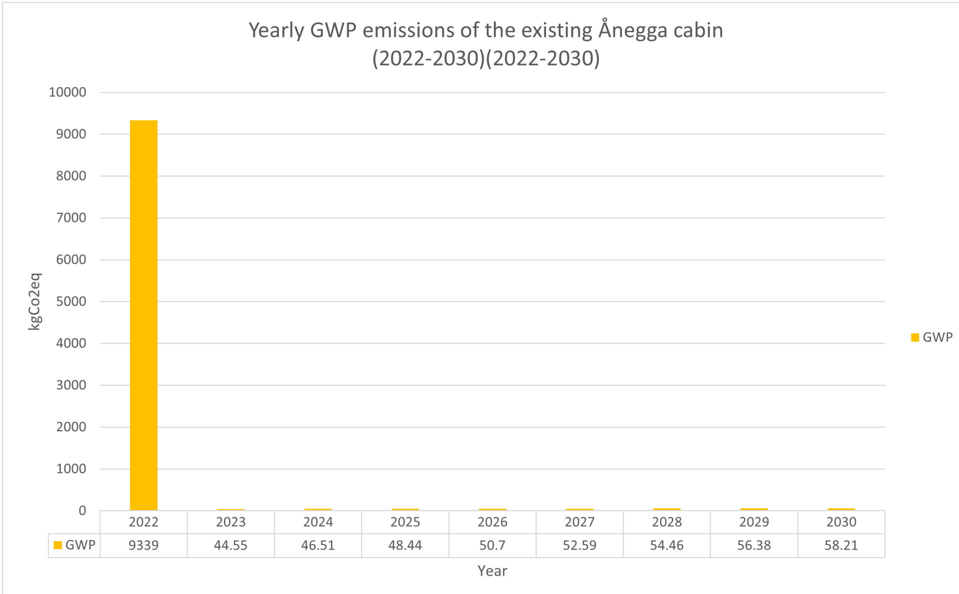


Figure 5.14: Yearly GHG emissions of the existing Ånegga cabin (2022-2030)

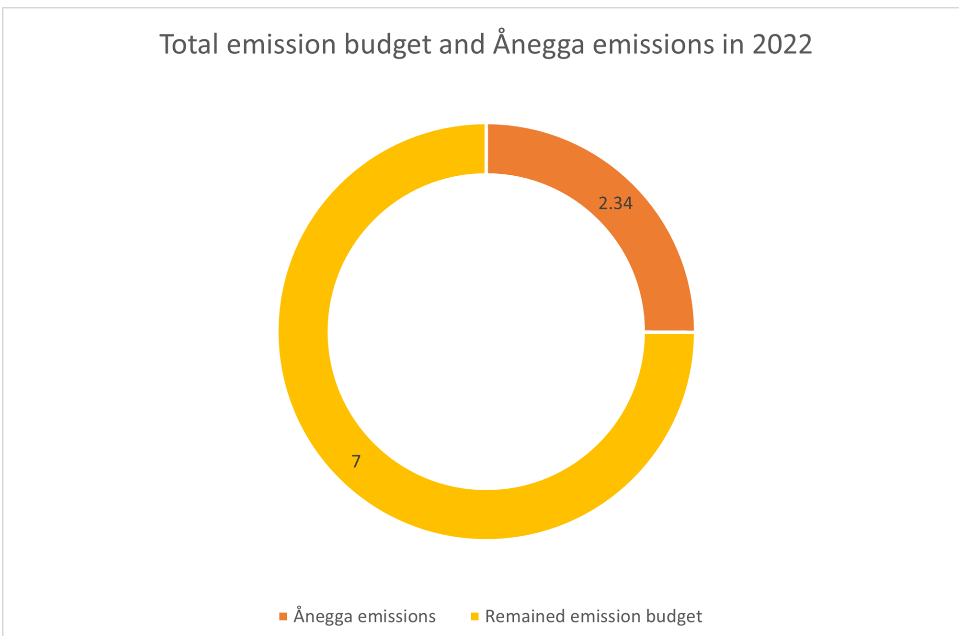


Figure 5.15: Total emission budget and emissions of the Ånegga cabin in 2022

5.10 Scenario 2 - Reuse scenario

In this scenario, the parts of the building that are considered reused materials have the same properties as the new ones in scenario 1. Windows, glass doors, interior doors, roof tiles, steel piles, and insulation are the reused items. The total mass of the cabin is 12000 kg and from this, 7069.4 kg is new and 4930.6 kg is reused materials Figure 5.16. The mass of each reused part of the cabin is shown in Figure 5.17

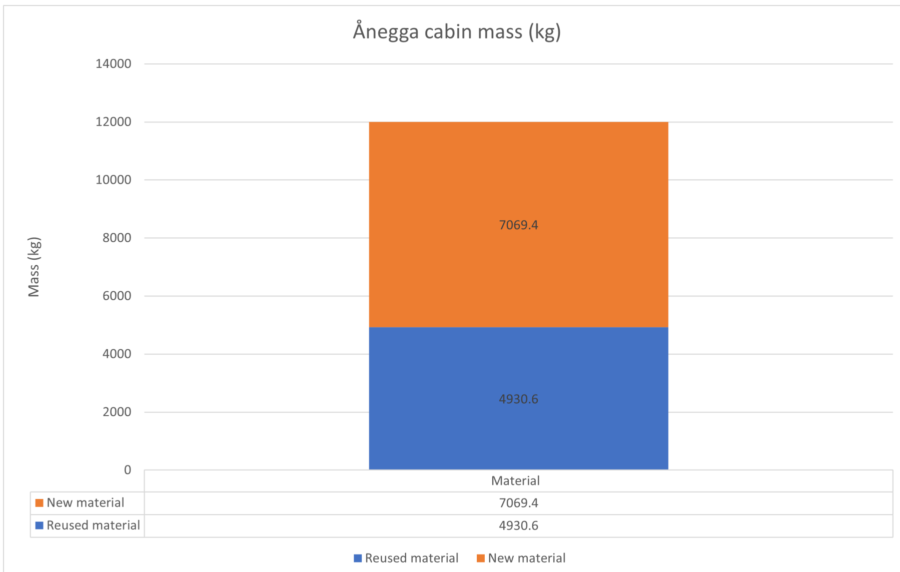


Figure 5.16: Total Mass of Ånegga cabin divided into new and reused materials

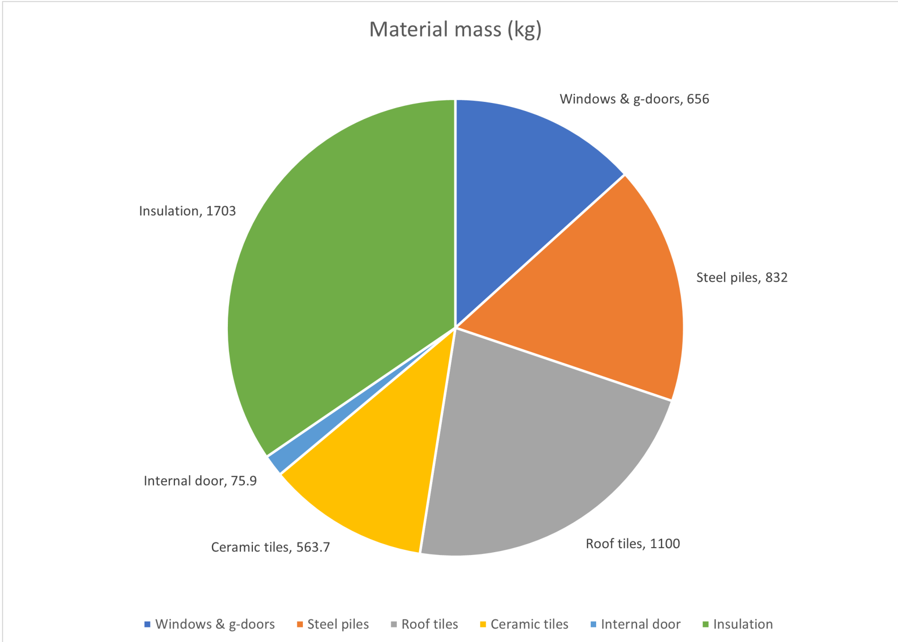
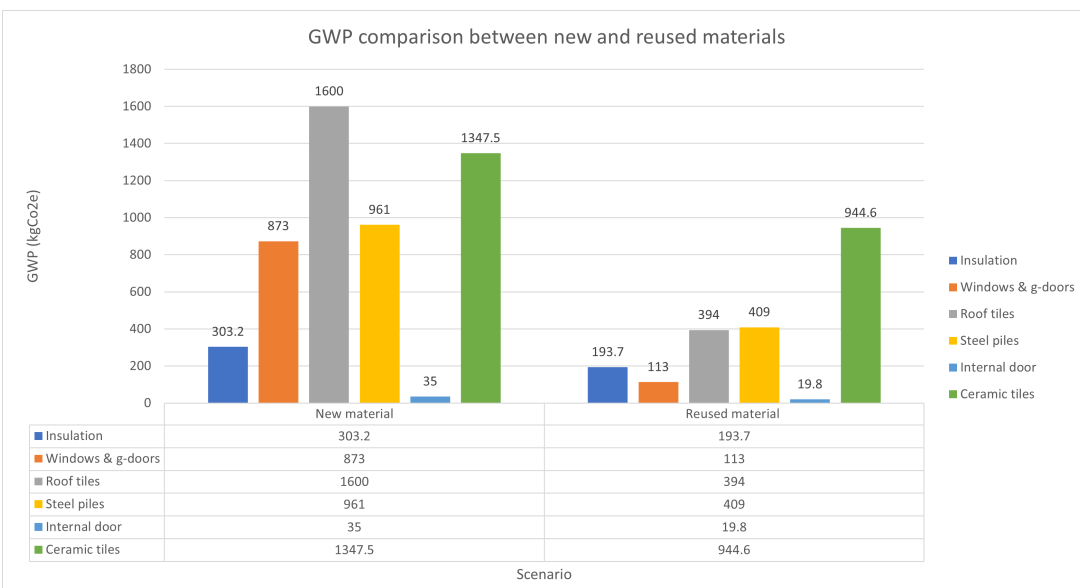


Figure 5.17: Mass (A1-A3) of the reused materials

5.11 Comparison between embodied emissions in scenario 1 and 2

Figure 5.18 shows a reduction in GWP in scenario 2 compared to scenario 1.



	New material	Reused material
Insulation	303.2	193.7
Windows & g-doors	873	113
Roof tiles	1600	394
Steel piles	961	409
Internal door	35	19.8
Ceramic tiles	1347.5	944.6

Figure 5.18: Embodied emissions comparison between scenario 1 and 2

5.12 Total embodied emissions reduction, scenario 1 and 2

By considering 41.08% of the materials in Ånegga cabin as reused in scenario 2, the embodied emissions are reduced by 40% Figure 5.19.

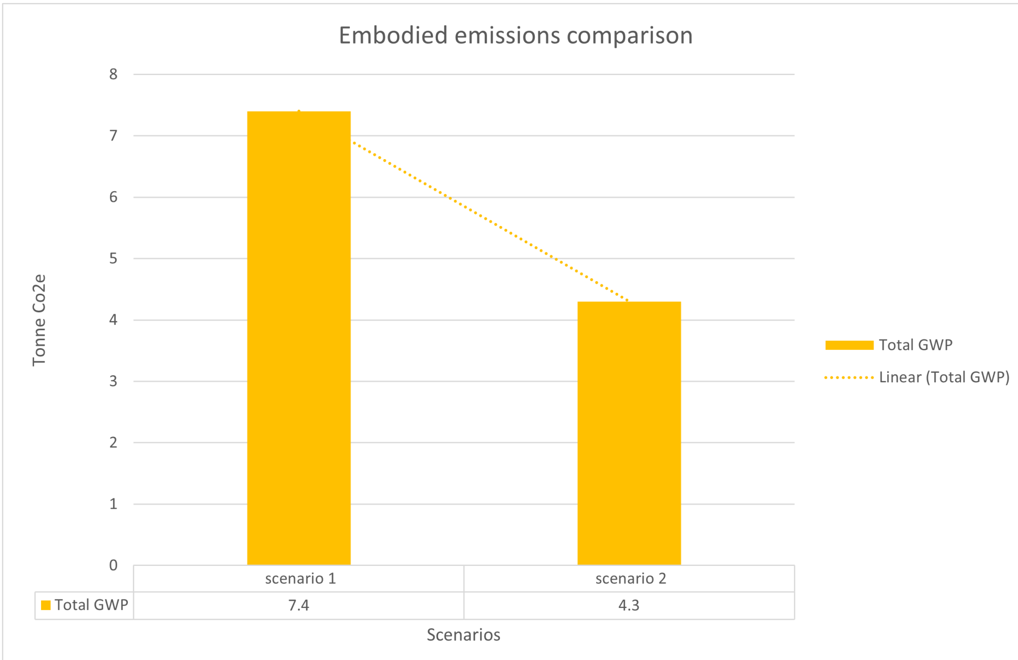


Figure 5.19: Total embodied emissions comparison between scenario 1 and 2

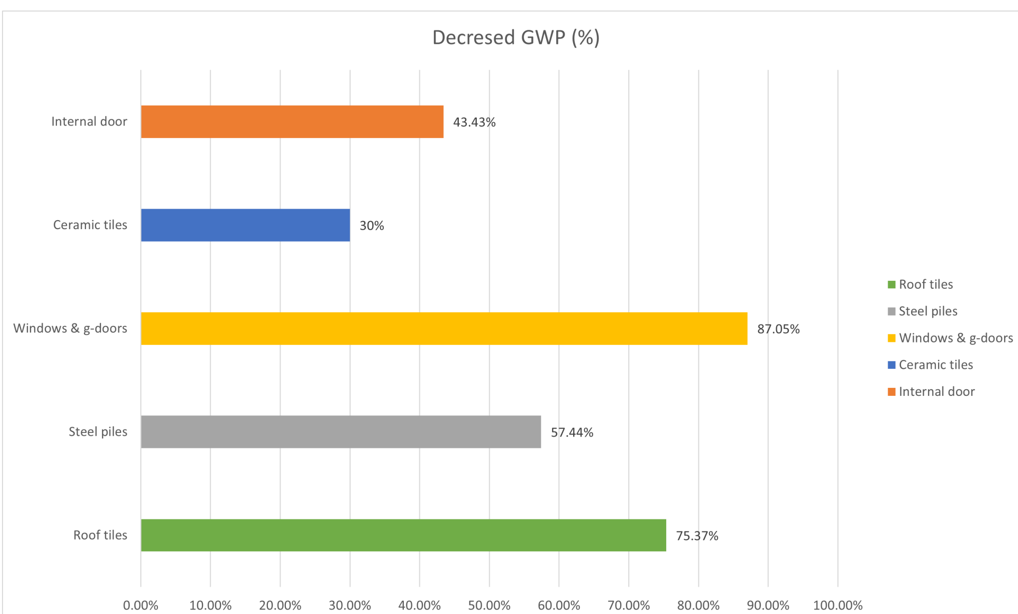


Figure 5.20: GWP reduction per each reused material

5.13 Embodied emissions

Embodied emissions of the materials are as follows in Table 5.14. (The embodied emissions of the heating system are not included in Table 5.14.)

Embodied emissions of scenario 1	Embodied emissions of scenario 2
3.35 kgCo2/m2/year	2.01 kgCo2/m2/year

Table 5.14: Embodied emissions of the cabin in scenario 1 and 2

5.13.1 Embodied emissions of the heating system

The environmental impact of various heating systems, whether newly installed or reused, is presented in Table 5.15. Detailed calculations are attached in Appendix3 section C.5

Heating system	Electric system	GSHP	ASHP
Embodied emissions kgCo2/year/m2 New heating system	0.32	2.42	1.47
Embodied emissions kgCo2/year/m2 Reused heating system	0.06	0.48	0.3

Table 5.15: Embodied emissions of the heating systems

5.14 Reused PVs + Reused heating system

The results of the total GWP for both scenario 2 and scenario 1 (existing Ånegga cabin) are presented in the Table 5.16 and Table 5.17. These figures consider two different Co2 factors: 17 gCO2eq/kWh and 136 gCO2eq/kWh. The presentation includes variations with and without the incorporation of reused photovoltaic panels.

5.15 Total GWP

Scenario 1 = The Ånegga cabin with current new materials

scenario 2 = The Ånegga cabin with 41.08% reused materials.

kgCo2/m2/year	Reused electric system	Reused GSHP	Reused ASHP
GWP of scenario 1 with PV	2.09	2.21	2.10
GWP of scenario 1 without PV	3.83	3.94	3.84
GWP of scenario 2 with PV	0.75	0.86	0.76
GWP of scenario 2 without PV	2.49	2.60	2.50

Table 5.16: Total GWP of the cabin with and without PVs - Co2 factor = 17 g/kWh [15]

kgCo2/m2/year	Reused electric system	Reused GSHP	Reused ASHP
GWP of scenario 1 with PV	-10.10	-12.11	-11.70
GWP of scenario 1 without PV	6.74	4.74	5.14
GWP of scenario 2 with PV	-11.44	-13.45	-13.04
GWP of scenario 2 without PV	5.40	3.40	3.80

Table 5.17: Total GWP of the cabin with and without PVs - Co2 factor = 136 g/kWh [78]

5.15.1 Results comparison

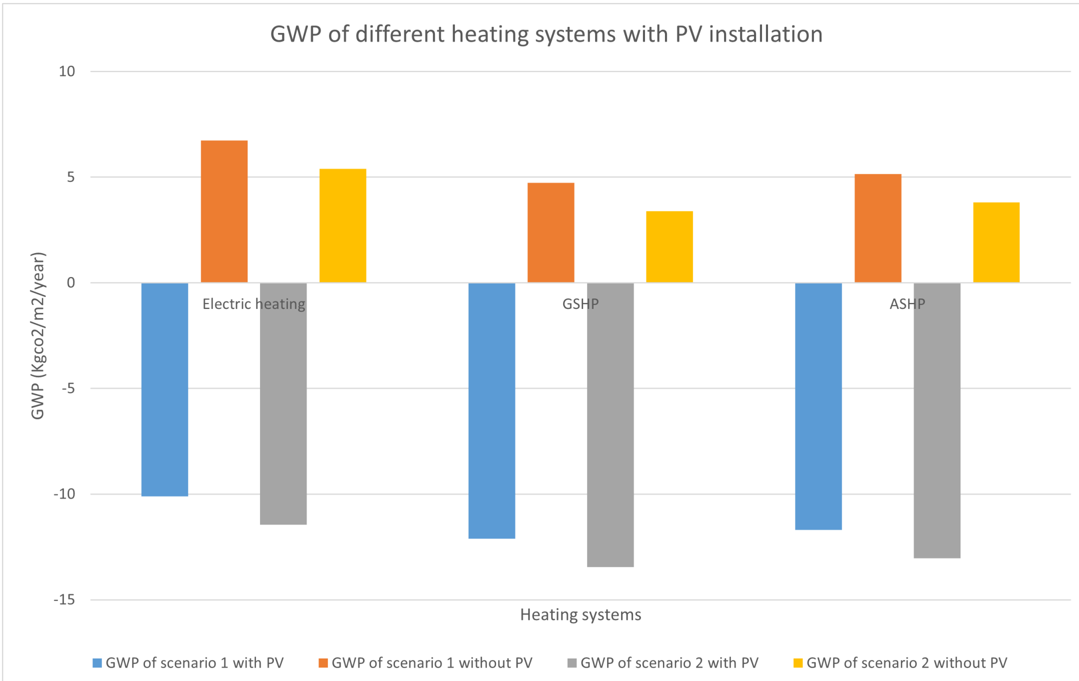


Figure 5.21: GWP of reused heating systems with/without reused PV installation, Co2 factor = 136 g/kWh

5.16 Redesign - Scenario 3

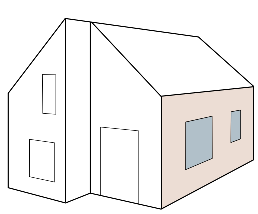
5.17 Replacing windows and entrance doors

Table 5.18 illustrates the window-to-wall ratio of the existing Ånegga cabin, while Figure 5.22 and Figure 5.23 depict the building's facades with windows in different directions. Following the cabin redesign, the glass entrance doors were substituted with recycled wooden doors, leading to a reduction in cabin size from 37 m2 to 21.62 m2. Consequently, the demand for windows decreased, resulting in a decline in the total window-to-wall ratio from 14.05% to 9.19%. This adjustment contributed to a slight decrease in the heating load from 24.51 kWh/m2 to 22.91 kWh/m2.

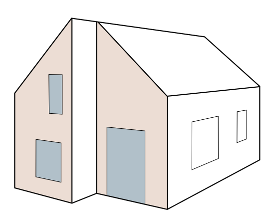
5.17.1 Window-to-wall ratio of existing Ånegga cabin

Direction	WWR	Reference figure
South-East	17.99%	Figure 5.22a
South-West	22.94%	Figure 5.22b
North-East	13.34%	Figure 5.23a
North-West	4.39%	Figure 5.23b

Table 5.18: Window-to-wall ratio of existing Ånegga cabin



(a) South-east facade



(b) South-west facade

Figure 5.22: Existing Ånegga cabin - South facade windows

(a) North-east facade

(b) North-west facade

Figure 5.23: Existing Ånegga cabin - North facade windows

5.17.2 Window-to-wall ratio after redesign

Direction	WWR	Reference figure
South-East	14.60%	Figure 5.22a
South-West	3.14%	Figure 5.22b
North-East	9.40%	Figure 5.23a
North-West	4.39%	Figure 5.23b

Table 5.19: Window-to-wall ratio of scenario 3

5.18 Redesign-plans

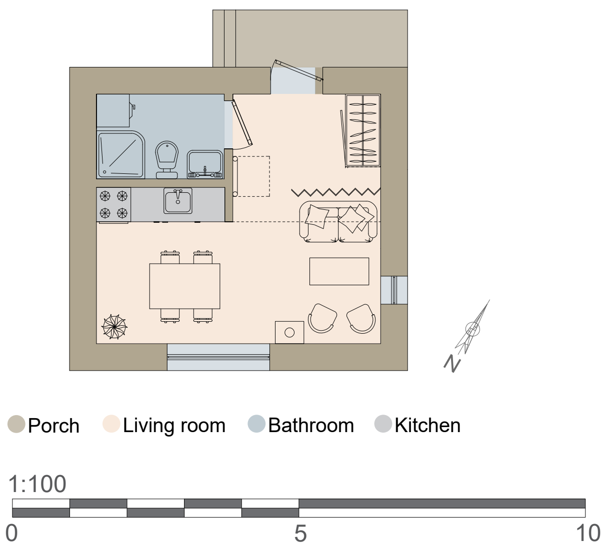


Figure 5.24: First floor plan - Scenario 3

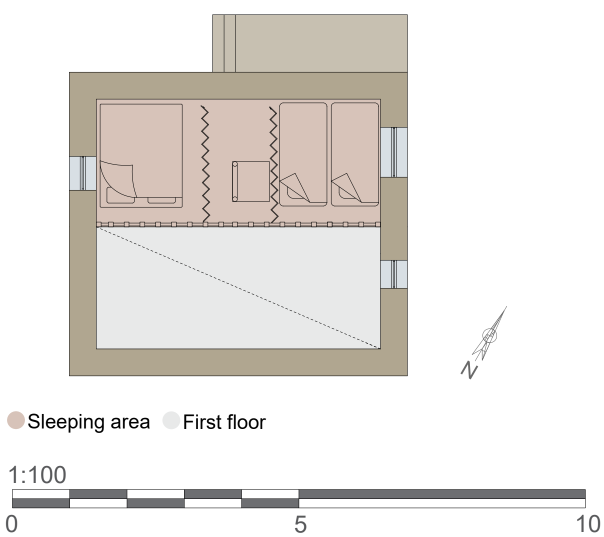


Figure 5.25: Attic - Scenario 3

5.19 Embodied emissions

Redesign scenario leads to a reduction in the embodied emissions of the materials Figure 5.26.

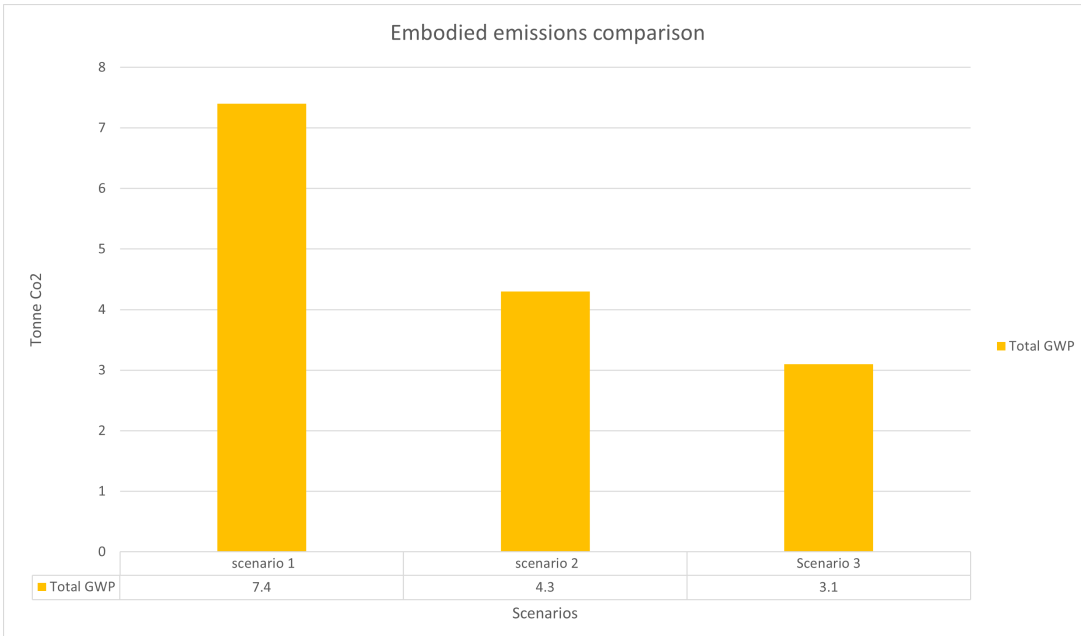


Figure 5.26: Embodied emissions of the material

5.20 Heating load

In scenarios 1 and 2 the properties of the materials were the same and the design was not changed. This is why both of them have the same heating load. In scenario 3, the properties of the materials are the same as in the two other scenarios but the design is changed. In the redesign scenario, the heating load is decreased slightly Figure 5.27.

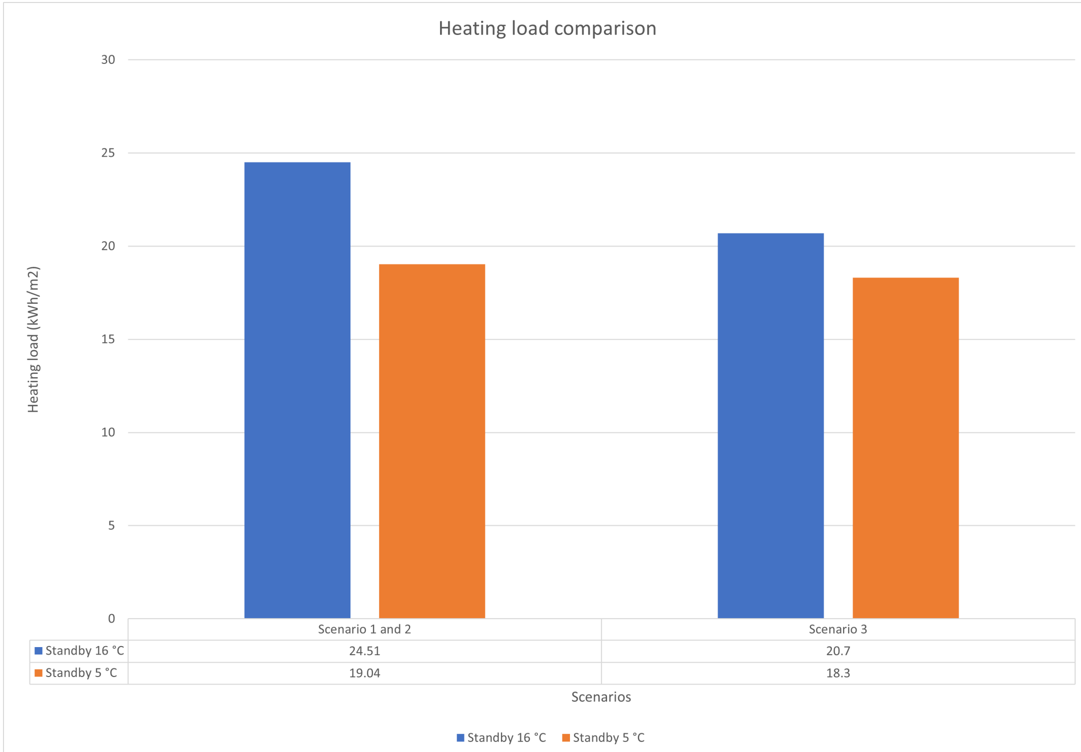


Figure 5.27: Heating load comparison

5.21 Total GWP of scenario 3

Roof area = 40.79 m2 . PV = 30 m2

kgCo2/m2/year	Reused electric system	Reused GSHP	Reused ASHP
GWP of scenario 3 with PV	0.77	0.96	0.84
GWP of scenario 3 without PV	2.75	2.94	2.81

Table 5.20: Total GWP of the scenario 3 with/without PVs - Co2 factor = 17 gCo2/kWh [41]

kgCo2/m2/year	Reused electric system	Reused GSHP	Reused ASHP
GWP of scenario 3 with PV	-14.29	-15.68	-15.42
GWP of scenario 3 without PV	4.93	3.54	3.80

Table 5.21: Total GWP of the scenario 3 with/without PVs - Co2 factor = 136 gCo2/kWh [78]

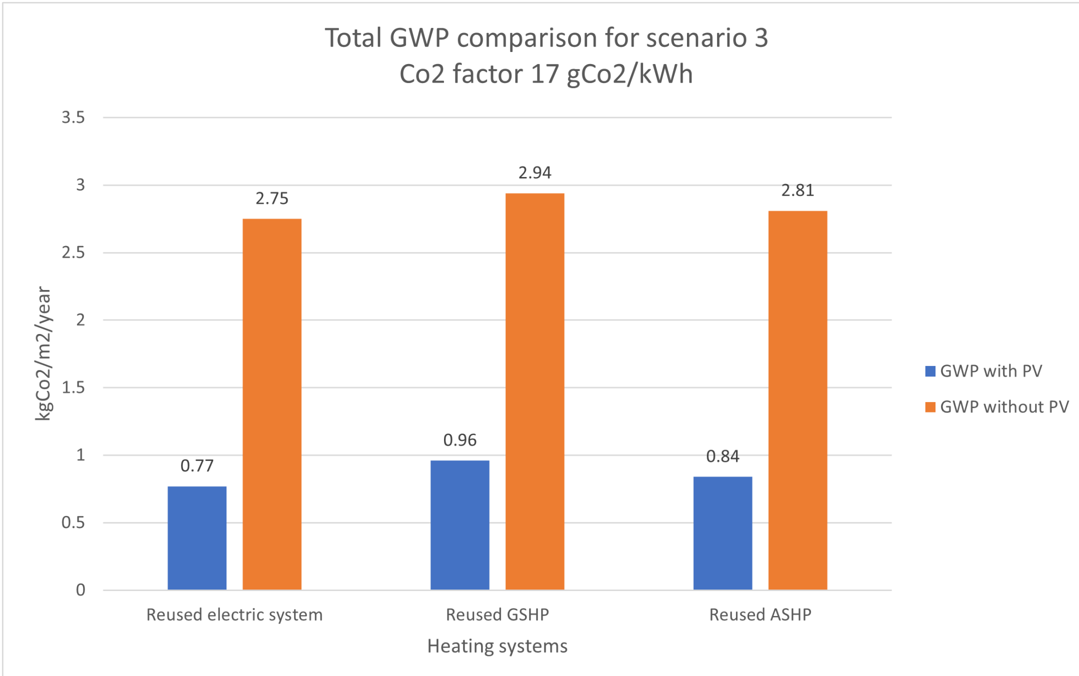


Figure 5.28: Total GWP comparison in scenario 3 with the Co2 factor of 17 gCo2/kWh

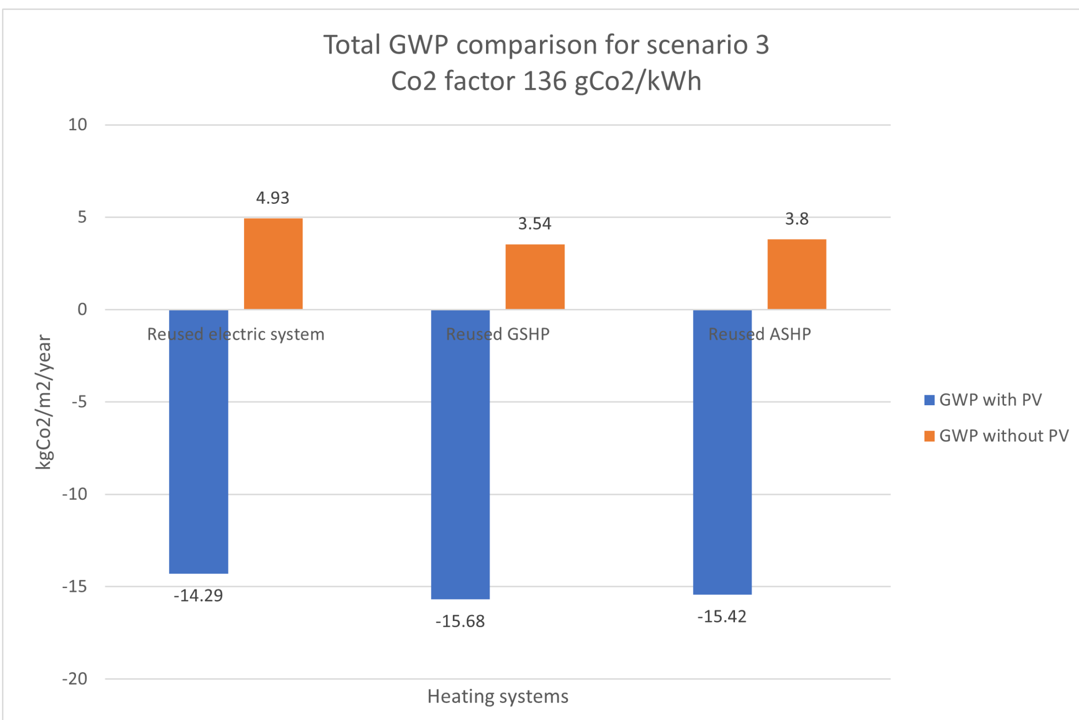


Figure 5.29: Total GWP comparison in scenario 3 with the Co2 factor of 136 gCo2/kWh

5.22 Results comparison for three scenarios

The optimal outcome is chosen from scenarios 1 and 2, where both involve the reuse of Ground Source Heat Pump (GSHP) with PV panels. Scenario 1 is maintained as the existing Ånegga cabin. The Co2 factor considered 136 gCo2/kWh for the comparisons.

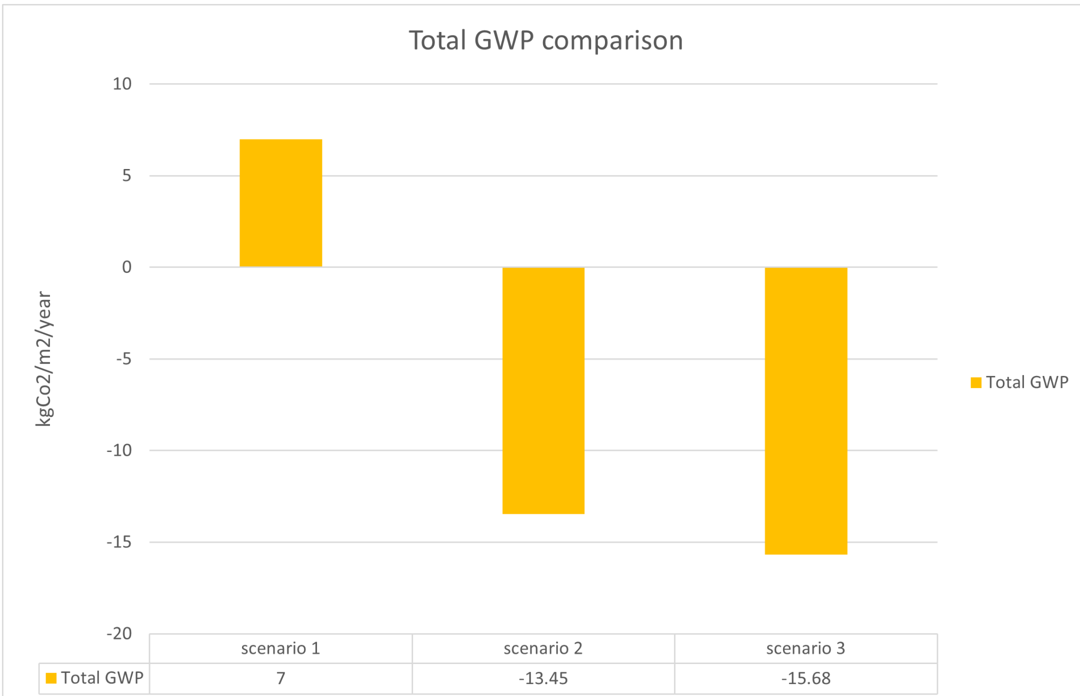


Figure 5.30: Comparison of the total GWP in three scenarios

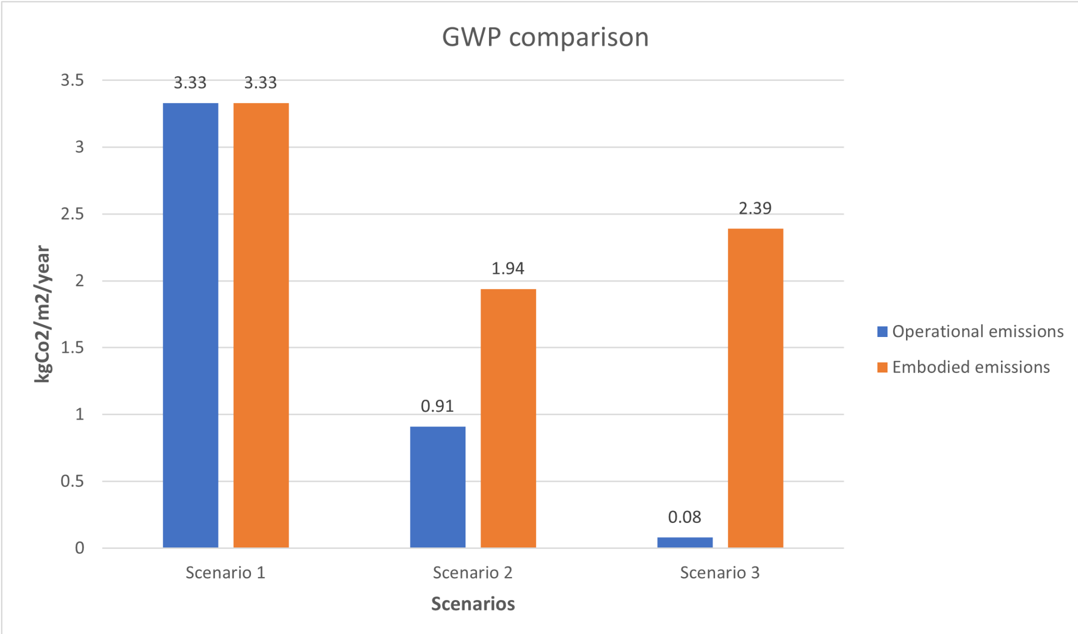


Figure 5.31: Comparison of the total embodied and operational emissions in three scenarios

kgCo2/m2/year	Scenario 1	Scenario 2	Scenario 3
Operational emissions	3.33	0.91	0.08
Embodied emissions	3.33	1.94	2.39
Total GWP	7	-13.45	-15.68

Table 5.22: GWP comparison by separation of operational and embodied emissions

5.23 Life cycle phases compensated by PV production

PV production - embodied pv = 16.85 kgCo2e/m2/year.

By knowing the PV production and the emissions produced by each phase, Table 5.23, it is shown that the PVs compensate for the embodied emissions plus operational emissions. In addition to this, they produce 13 kgCo2e/m2/year extra.

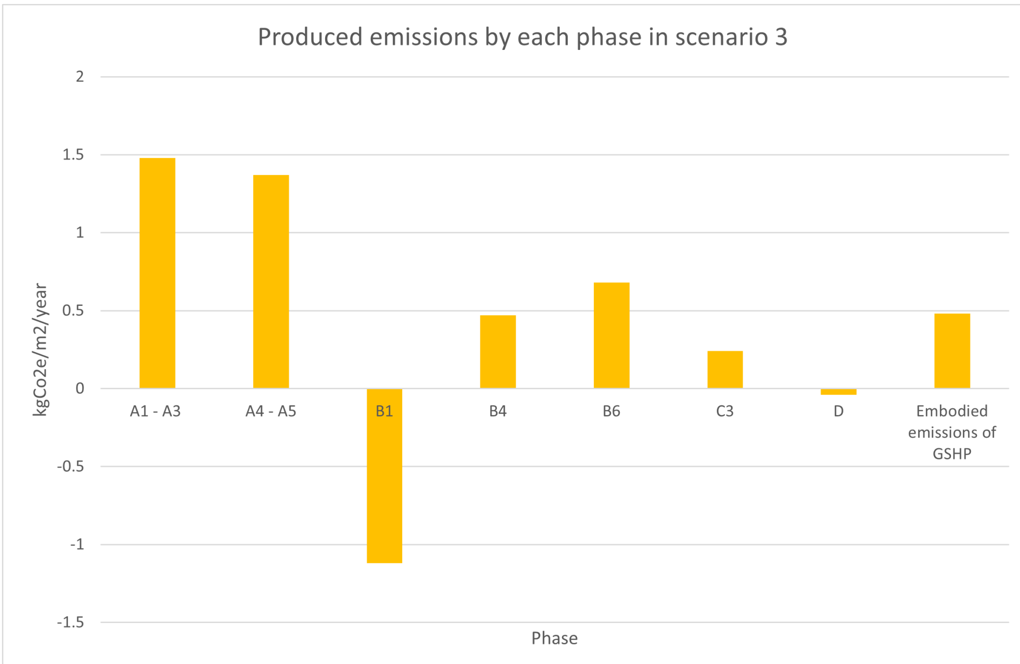


Figure 5.32: Produced emissions by each phase in scenario 3

LCA phase	kgCo2e/m2/year
A1 - A3	1.48
A4 - A5	1.37
B1	-1.12
B4	0.47
B6	0.68
C3	0.24
D	-0.04
Embodied emissions of GSHP	0.48
Sum	3.55

Table 5.23: Emissions of life cycle phases compensated by PV production

Chapter 6

Discussion

In this chapter, the results and analysis are discussed to achieve a better understanding of the suggested design and lead to a well-structured approach to cabin construction.

6.1 Influence of occupancy patterns on energy demand and operational emissions

A constant number cannot be determined for the energy demand of the cabin, as it varies depending on the usage culture of the owners. However, it is clear that cabins in Oppdal are likely to be occupied during the winter, particularly for winter sports. The results from the energy analysis show the significant role of occupancy in the energy demand and accordingly the operational emissions of a building. The difference between a residential housing unit and a holiday house of the same size and properties is in their occupancy. If the building is occupied as a normal residential house, the heating demand is considerably higher compared to a cabin which is used partially for instance only during the holidays and weekends, 127 days a year (Table 5.1 and Table 5.2). This amount decreases more by reducing the number of occupied days in the year. In addition, the season of occupancy is an essential factor. The heating demand in the summer is close to zero in the results Figure 5.6, therefore, the summer occupancy does not affect the heating load of the cabin. The focus is on the winter usage of the holiday house because the heating demand in winter is close to the heating demand of one year. It shows that occupancy in a shorter period of time (winter) can have a considerable effect on the energy demand compared to occupancy in a longer period. As a comparison, the annual heating load with an occupancy of 127 days is 31.16 kWh/m2 (Table 5.2) and it is comparable with the winter heating load which is 27.35 kWh/m2 for 44 days shown in Table 5.4. As well as this, The heating load with the occupancy of 96 days in a year (Table 5.3) is comparable with the winter heating load with the occupancy of weekends (Table 5.5) which is 24.51 kWh/m2 and 22.04 kWh/m2 respectively. The comparisons remark that the winter energy demand correlated directly with the energy demand of the cabin for the whole year. The energy demand remains constant in scenario number 2 because there is no change in the materials properties but it reduces in the third scenario.

6.2 Altering the standby mode

The standby mode, set at 16°C to account for the worst-case scenario, is applicable for situations where the cabin is occupied every weekend. However, two alternative temperatures were also explored. The results show that when the cabin is run at a lower temperature of 10°C and 5°C instead of 16°C, the heating load is reduced gradually in each scenario Table 5.8. The lowest heating demand is when the standby temperature is at 5°C. Therefore, it is beneficial to use a heating system that keeps the temperature at the minimum temperature and can be remotely controlled to prepare the interior area at a comfortable temperature of around 20°C when the users arrive in the cold season.

6.3 Cultural change

Obtained results from energy analysis demonstrate that the operational emissions of the building are correlated directly with the duration of the occupancy, season of occupancy, and standby mode temperature. Analyzing the results allows for defining a cultural change in the utilization patterns of the cabin. Given the negligible energy demand during the summer, operational emissions similarly remain at a low level Figure 5.6. Due to this, the concept of summer cabins serves as a viable solution in particular regions. The southern and western coasts of Norway experience an oceanic climate (Cfb and Cfc), characterized by the absence of dry seasons and warm summers [85]. These regions are favorable locations for the concept of summer cabins. For instance, Stavanger on the south coast has a Cfb climate based on Köppen climate classification [86] which stands for warm temperature climate with no dry seasons and with warm summers [24]. Using the cabin exclusively during the summer in popular vacation spots leads to substantial energy savings and a comparative reduction in operational emissions. This is attributed to the absence of heating requirements when the cabin is occupied, while the cooling load is negligible. When the cabin is unoccupied it is adjustable to be on standby mode at the minimum degree of 5 °C with the least need for heating.

In areas such as Oppdal which are ski and winter sports spots, people are more interested in using their cabins in the winter. As it is obtained from the results Table 5.7, the winter has the most effect on the annual heating demand of the cabin. In this case, the cultural shift in using the cabin is suggested as a limitation for staying in the cabins. As most of the cabin owners are living in neighboring areas, it is easy to reach their cabins every holiday or weekend. However, by limiting the days of using the holiday houses, the emissions from the operational emissions, as well as, transportation to and back from the cabin can be decreased.

6.4 Grid emission

The operational emissions of the cabin, and consequently its total emissions, are significantly influenced by the emissions from the power grid. In the current Ånega cabin scenario (scenario 1), the total emissions increased by approximately 40% when the grid emissions rose to 136 gCO2eq/kWh Table 5.13 compared to the CO2 factor of 17 gCO2eq/kWh Table 5.12. In the other two scenarios, a rise in the grid emissions leads the operational emissions to increase considerably, as well. Norway generally has low-emission electricity from the grid, as indicated by the recorded grid emission of 17 gCO2eq/kWh on October 26, 2023. However, because Oppdal partially sources electricity from Europe and the CO2 factor of Norway varies throughout the year, it is essential to explore the outcomes associated with other CO2 factors, particularly the higher value of 136 gCO2eq/kWh.

It is crucial to calculate grid emissions in the design phase since individuals cannot directly reduce them. Knowing grid emissions in the first steps allows for selecting materials with lower emissions, deciding on energy sources, and finding solutions to compensate for the operational emissions if needed and to minimize GHG emissions, aligning with emission reduction goals.

6.5 Transportation emissions

Although the number of occupied days does not matter in summer, the number of trips to the cabin and going back from it is an important factor in producing transportation emissions. Therefore, the users should still consider a longer stay in their cabins instead of going there every weekend which contains two trips for each trip by personal car. As well as this, during the cold season, it is more efficient to go to a cabin and stay there for a longer period instead of going there every weekend. It reduces the emissions generated from transportation. A scenario is to use the cabin only during one or two holidays in the cold seasons and stop using it on the weekends. In addition to this, people can still use their cabins in the warm season to take advantage of the hiking trails and nature in the area.

6.6 Emission budget

The total GWP produced by the Ånegga case study is lower than the benchmarks in FutureBuilt Zero but it is questioned if this amount of reduction is enough to meet the goal of GWP reduction by 55% by 2030 and 90-95% by 2050. As it is demonstrated in Figure 5.15, 25% of the 2022 emission budget of each person is allocated to the emissions produced from owning a small cabin such as Ånegga. This amount is 4% of the total emission budget that a person has until 2030. Every person has different needs, as well as, different interests which lead to carbon emissions production. As an example, having a house to live in is a necessity, while owning a cabin is considered a preference. In the current situation, every decision is crucial as it either contributes to a warmer planet with associated challenges or aids in its recovery. In the case study presented in this thesis, a small cabin alone consumes 4% of an individual's total carbon budget. This allocation could be redirected to more critical needs, such as the requirement for health and food.

Individuals with higher wealth levels often participate in more energy-intensive activities, such as frequent air travel or owning multiple vehicles and houses. This results in a larger carbon footprint when compared to individuals with more modest lifestyles. Environmental policies and initiatives should take into account the carbon footprint inequality to address the disproportionate impact of wealthier individuals on the environment. This includes promoting sustainable consumption, adopting green technologies, and advocating for the fair distribution of resources.

Efforts to meet the Paris Agreement goals focus on practical solutions using existing technology and encouraging behavioral changes. However, as we look towards 2030 and beyond 2050, advancements in technology, for instance in cleaner automotive options, and switching to electricity in more areas, may surpass current expectations. This suggests a possibility of achieving greater emission reductions. Material reuse is a practice that can be undertaken on a small scale by individuals and on a larger scale through governmental strategies. In the context of the construction sector, since industrial processes such as material production and waste incineration are significant sources of carbon emissions, utilizing strategies such as material reuse helps diminish the reliance on these emission-intensive processes, thereby keeping materials within a sustainable usage cycle.

6.7 Embodied emissions

By reusing the materials, they are kept in the cycle of being used and prevented from waste incineration and being landfilled (C3-C4). In addition, the production of the material phase (A1-A3) is removed. Removing these phases from the life cycle of the cabin leads the embodied emissions to decrease.

The results show that by implementing 41.08% reused materials in the case study cabin (scenario 2), the embodied emissions are reduced by 40% Figure 5.19. The graph shows that the GWP is reduced significantly from 7.4 tonneCo2e to 4.3 tonneCo2e. The roof tiles with 1100 kg and the internal doors with 75.9 kg constitute the highest and lowest mass among reused materials Figure 5.17. However, the mass of the material does not directly relate to a high or low amount of the embodied emissions. In this scenario windows and glass doors with 656 kg are responsible for the most amount of GWP reduction when reused (87.05%). Clay roof tiles (75.37%), steel piles (57.44%), internal wooden doors (43.43%), Insulation (36.11%), and ceramic tiles (30%) have the highest reduction respectively Figure 5.18 Figure 5.20.

The embodied emissions continue decreasing in scenario 3. This is attributed to the optimized use of space, resulting in a smaller cabin size with reduced material usage. Moreover, the decrease in cabin size reduces the demand for emission-intensive components like windows, necessary for sunlight and radiation. Additionally, the substitution of glass entrance doors with wooden ones further contributes to a reduction in overall glass usage.

6.8 Renewable energy

As previously noted, Nasjonalparken had concerns about installing solar panels due to the climate conditions that might result in insufficient sunlight for electricity generation. The tables illustrating total emissions in three scenarios reveal that when the grid emissions are elevated (136 gCO2/kWh), the impact of photovoltaic panels is more significant in terms of energy production. However, in scenarios with low grid emissions (17 gCO2/kWh), the presence of solar panels does not substantially offset the emissions. Due to the variability in Norway's grid emissions across seasons and the fact that Oppdal receives electricity partially from Europe, the actual emissions from the grid fall between the two CO2 factors discussed in this thesis. Consequently, the emissions that can be offset by photovoltaic panels are expected to be less than the values corresponding to the CO2 factor of 136 but greater than that of the CO2 factor of 17. Therefore, the installation of solar panels is still deemed advantageous. As demonstrated in scenario 3, through the reuse of materials, design optimization, and the incorporation of photovoltaic panels, the solar panels not only offset the operational and embodied emissions of the cabin but also generate additional electricity.

Furthermore, solar panels are suitable for leisure houses situated in distant or off-grid areas where obtaining electricity from conventional sources could be difficult or costly. Incorporating photovoltaic panels is in line with sustainable living practices, endorsing an environmentally friendly way of life and playing a role in the worldwide shift towards renewable energy sources. This aligns with the objectives of the Paris Agreement, aimed at reducing emissions and mitigating climate change on a global scale. Solar energy has the potential to result in decreased electricity expenses in the long run, as the cabin becomes partially or entirely self-reliant in generating power.

Chapter 7

Conclusion and future work

This chapter concludes the summarization of the primary research in this thesis and outlines potential future directions based on the analysis as well.

7.1 Conclusion

In conclusion, the study reveals that occupancy patterns significantly impact the energy demand and operational emissions of the building. Notably, shorter periods of occupancy, particularly in the cold season, can considerably affect energy demand compared to warmer longer periods. This insight suggests that managing the frequency and duration of cabin use can be a vital factor in energy efficiency and consequently the emissions of the building. While the number of occupied days may not significantly affect energy demand in summer, transportation emissions become a crucial factor. Encouraging longer stays in cabins and minimizing frequent trips can contribute to reducing transportation-related emissions. Secondly, Adjusting the standby temperature of cabins presents an opportunity to reduce heating loads. Results indicate that lowering the standby temperature leads to gradual reductions in heating demand. Recommending a heating system that maintains a minimal temperature while allowing remote control for user comfort upon arrival is a practical suggestion. As well as this, the study proposes a cultural shift in cabin utilization patterns, especially in regions like Oppdal with a focus on winter sports. Limiting the number of days cabins are used, can contribute to reduced operational emissions and transportation-related emissions. The research highlights the significant impact of grid emissions on cabin operational emissions. It emphasizes the importance of considering grid emissions during the design phase, enabling the selection of materials, energy sources, and solutions to mitigate total emissions, aligning with emission reduction goals. In addition, the study explores the potential of material reuse in reducing embodied emissions. Results indicate a substantial decrease in embodied emissions through the implementation of reused materials, highlighting the importance of sustainable material practices in construction. The integration of solar panels is identified as a viable strategy for offsetting operational and embodied emissions while contributing to energy generation. Despite concerns about sunlight availability in the Oppdal area, the study emphasizes the advantages of solar panels, especially in remote or off-grid areas. The Ånegga case study reveals emissions lower than FutureBuilt Zero benchmarks but prompts questions about their adequacy to meet ambitious reduction targets. The analysis highlights the impact of individual choices, with the small cabin consuming a significant portion of an individual's carbon budget. Addressing wealth-related carbon footprint disparities through sustainable practices and fair resource distribution is crucial. Looking forward, advancements in technology offer hope for surpassing emission reduction expectations, while material reuse emerges as a practical strategy in the construction sector. In the face of environmental challenges, a collective commitment to practical solutions, technological advancements, and behavioral changes is essential for a more sustainable future.

7.2 Future work

The suggestions for future work are as follows:

Incorporating expenses into the life cycle analysis (LCC) and investigating the factors that contribute to higher costs during various stages of cabin development.

Quantifying and enhancing the environmental emissions and associated expenses linked to transportation.

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Appendix A

60334 Grønn Fritid - Åneggagrenda.															
Materialforbruk bygningsmessige fag															
				price/me ?		?									
	Enhet														
	BNT	**ESK**	**KAN**	**LM**	**M2**	**PAK**	**PK**	**PLA**	**PP**	**RS**	**RUL**	**SEK**	**SET**	**SPA**	**STK**
02 Bærekonstruksjoner															
FURU 115X200 CU IMP LIMTRE MOELVEN				187.00											
FURU 115X233 CU IMP LIMTRE MOELVEN				8.00											
GRAN 115X115 LIMTRE MOELVEN GL 30C				111.00											
GRAN 115X180 LIMTRE MOELVEN GL 30C				17.60											
GRAN 115X225 LIMTRE MOELVEN GL 30C				47.00											
03 - 06 Isolasjon YV, IV, dekker og tak															
NATIVO TREF ISOLASJON 100X565X1220						247.00									
NATIVO TREF ISOLASJON 70X565X1200						1.00									
NATIVO TREFIB ISOLASJON 50X565X1220						80.00									
NATIVO TREFIBISOLASJON 150X565X1200						60.00									
NATIVO TREFIBISOLASJON 200X565X1200						412.00									
03 - 06 Reisverk YV, IV, dekker og tak															
JUSTERT 36X098 K-VIRKE C24				264.00											
JUSTERT 48X068 LEKTER				643.00											
JUSTERT 48X098 K-VIRKE C24				5499.40											
JUSTERT 48X148 K-VIRKE C24				933.20											
JUSTERT 48X198 K-VIRKE C24				2098.00											
03 + 06 YV og tak															
DAMPSPERRE 2,6X15M 150MY 39M2											41.00				
G-F 36X048 LEKT/REKKE KL1				510.00											
JUSTERT 36X048 LEKTER				4526.00											

Figure A.1: Material inventory of Åneggagrenda cabins-1

03 YV															
Beslag Sort. K:109 L.Just Vindu 2 stk				2.00											
Beslag Sort. K:111 L.Just Vindu				58.00											
Beslag Sort. K:162 Overg.beslag				120.00											
Beslag Sort. K:170 L.Just Vindu 3 stk				3.00											
Beslag Sort. K:200 L.Just U/dør				1.00											
Beslag Sort. K:208,8 Overgangsbeslag				160.00											
Beslag Sort. K:98 L.Just Vindu				2.00											
DØRSETT BOD SÆLEN 10X21H UBH															1.00
DØRSTOPPER 27 Ø36X50MM GRÅ GUMMI SB						1.00									
DØRSTOPPER 390 STÅL GRÅ GUMMIBUFFER															0.00
DØRVRIDER NEW YORK UTV B-KROM SB						1.00									
G-F 48X048 LEKT/REKKE KL1				160.71											
GRAN 19X148 D-F 28GR GR+MELLOM				659.00											
GRAN 19X148 D-FALS LÅVEKLED KL1 UBH				98.00											
GRAN 19X148 D-FALS LÅVEKLED MELLOM				7274.00											
JUSTERT 23X048 LEKTER				610.00											
JUSTERT 48X048 LEKTER				2081.00											
Utforinger vinduer og balkongdører - eget vedlegg										1.00					
VINDTETT TREFIBPL 50PK 12X1200X2740								272.00							
Vinduer og balkongdører (inkl ytterdører) - eget vedlegg										1.00					

Figure A.2: Material inventory of Åneggagrenda cabins-2

04 IV															
+KARM IK 8X21 093MM HVIT /E TETTL															7.00
BADEROMSP 110 S HVIT					24.00										
BADEROMSP 2094-F05 S WHITE 60X20					12.00										
BADEROMSP 3091-F24 HG DENVER WHITE					128.00										
DEKKLOKK 14/19 BEIGE A-20						2.00									
DØRBL EASY GW 7X21 KLASSISK HVIT															1.00
DØRBL EASY GW 8X21 KLASSISK HVIT															14.00
DØRBL TRADITION 03 8X21 UBH															2.00
DØRVRIDER PORTO INNV BØRSTET ALU PP									16.00						
FOLIE 2,6X25M 70MY INNERVEGGSFOLIE											13.00				
FUGEKLOSS TIL VEGGPANEL															4.00
FUGEMASSE FIBO TIL VEGGPANEL GRÅ															20.00
FURU 09X034 BRANNMUR				104.00											
FURU 09X045 BRANNMUR UBEH				4.50											
FURU 12X058 DØRSET KARM RUND S0502Y													12.00		
FURU 12X058 KARMLIST RUND				194.00											
FURU 12X058X4400 KARML NCS S0502Y															126.00
Furu 14x120 Slettpanel Natur				15300.00											
FURU 18X045 DØRSETT UTF NCS S0502Y													1.00		
FURU 18X070X2400 UTFOR NCS S0502Y															20.00
Furu 21x120 Gulvbord Natur				1612.00											
FURU 21X120 UTFORING				61.00											
G-F 18X120 UNDERPANEL				70.10											
GIPSPL 900X2500X6,5 REHAB NORGIPS															5.00
HJØRNELIST II INNV TO-DELT 2400MM															30.00

Figure A.3: Material inventory of Åneggagrenda cabins-3

INSPEK.LUKE STD 200X200 HV NORGIPS															1.00
INSPEK.LUKE STD 200X200 NORGIPS															7.00
KARMSETT IK 7X21 093MM HVIT U/TERSK															1.00
KARMSETT IK 8X21 093MM HVIT U/TERSK															6.00
KARMSETT IK 8X21 093MM UBH / E															2.00
KLUT - FIBO-WIPES															8.00
MONTERINGSSKRUER PK A 200 STK															10.00
PLASTLOKK 14/19MM M BRUN A-200						1.00									
PLASTLOKK 14/19MM SVART A-200						1.00									
RENSEMIDDEL FIBO CLEAN															8.00
SOKKELLIST RETTKANT ALU 2400MM															30.00
TERSKEL M7 FLAT 9X92X630 MEL															1.00
TERSKEL M8 MELLOMLIGGENDE 9MM EIK															8.00

Figure A.4: Material inventory of Åneggagrenda cabins-4

05 Dekker															
ARBOR SPONPL GULV 2420 FUKTB								78.00							
EIK 15X045 GULVLIST M/PROFIL LAKK				8.40											
Flis og tilbehør - eget vedlegg										1.00					
FURU 12X058 FOT RUND				454.00											
FURU 21X142 GULV 9% NAT UBEH					217.00										
Gulvbelegg 1 hytte - eget vedlegg										1.00					
JUSTERT 11X036 LEKTER				2040.00											
KRYSSF GRAN 12X2400X1200 TG2 WR FI															120.00
NIVÅPINNER M/SELVKL LIM 50 STK						2.00									
VINDSPERRE BASTION 2800 X 25000 MM															7.00
WEBER FLOOR 4716 PRIMER 5LTR			3.00												
WEBER GULVAVRETTING HURTIG 20KG												256.00			
WEBER STENGELIST 38X50MM L=2M															25.00
WEBERFLOOR 4960 KANTLIST 50M											5.00				

Figure A.5: Material inventory of Åneggagrenda cabins-5

06 Tak															
ENDESTYKKE STÅL 125MM SORT															12.00
FURU 12X044 TAKLIST SH UBEH				623.00											
FURU 21X148 TAK 3,6M 2SPOR BRUN				3874.00											
FURU 21X148 TAK 5,4M 2SPOR BRUN				378.00											
FURU 22X148 REKT EP KL BRUN ROYAL				165.00											
NEDLØPSKLAMME STÅL 75MM SORT															12.00
NEDLØPSRØR STÅL 75MM 3M SORT ISOLA															6.00
PENSEL UTE 75MM BASIC															1.00
RENNEKROK M/FJÆR STÅL 125MM SORT															84.00
RENNESKJØT M/PAKN STÅL 125MM SORT															6.00
TAKRENNE STÅL 125MM 4M SORT ISOLA															12.00
TAPPESTYKKE STÅL 125/75MM SORT															6.00
TREOLJE MØREROYAL BRUN RB 10 0,68 L														1.00	
UNDERTAK BMI KLEMLIST 530MM						20.00									
UNDERTAK TYVEK PRO XTRA 1,50X25M											15.00				
UTKASTER STÅL 75MM SORT ISOLA															6.00
08.1 Trapper og rekkverk															
Hemsstiger og rekkverk-8 hytter										1.00					
Materialer til spilevegg (1 hytte)										1.00					
08.4 Terrasser															
FURU 28X120 CUIMP TERRASSE KL1				1258.00											
FURU 48X098 CUIMP K-VIRKE C24				82.00											
FURU 48X198 CUIMP K-VIRKE C24				712.90											

Figure A.6: Material inventory of Åneggagrenda cabins-6

99 Festemidler, hjelpemidler															
AVFALLSSEKK BASIS LIGHT DISPLAY											1.00				
AVFALLSSEKK IZI KLAR NORFOLIER											1.00				
AVFALLSSEKK KLAR 100L 40MY											21.00				
BESLAGSKRUE 5,0X40 CS A-250						5.00									
DEKKFILT M/PLASTBAKSIDE 1 M X 10 M															10.00
DYKKERT 0-GR 1,2X30 FZB A-6000						2.00									
DYKKERT 0-GR 1,2X38 FZB HVIT						2.00									
DYKKERT 0-GR 1,6X38 FZB A-2400						22.00									
DYKKERT 0-GR 1,6X50 FZB A-2000						6.00									
EKSP BOLT GA M12/45/156 FZV-20						1.00									
FIRKANTSPIKER 2,2X55 FZV -1170						1.00									
FLEKKMALING BOMULL 25ML															1.00
FLUEDUK ALUMINIUM 600MM 10M															3.00
FUGEMASSE H760 GRÅ 600ML															153.00
FUGEMASSE TEC7 HVIT 310 ML															3.00
FUGESKUM FLEX 750 ML															3.00
FUGESKUM P905 ALL SEASON FLEX COMBI															12.00
FURU 28X120 CUIMP TERRASSE KL1				634.50											
GAFFELANKER 390X48X1,5 FZV															102.00
GLAVA DYTTESTRIMMEL I SEKK 25MM						4.00									
GULVSKRUE INV 3,9X58 GUL A-250						1.00									
HULLPLATE 100X300X1,5 FZV A-25															150.00
KARMHYLSE I-P 38MM ZINK A-80						1.00									
KARMHYLSE I-P ZINK 28MM A-100						2.00									
KARMHYLSE I-P ZINK 38MM A-6						1.00									

Figure A.7: Material inventory of Åneggagrenda cabins-7

Appendix B

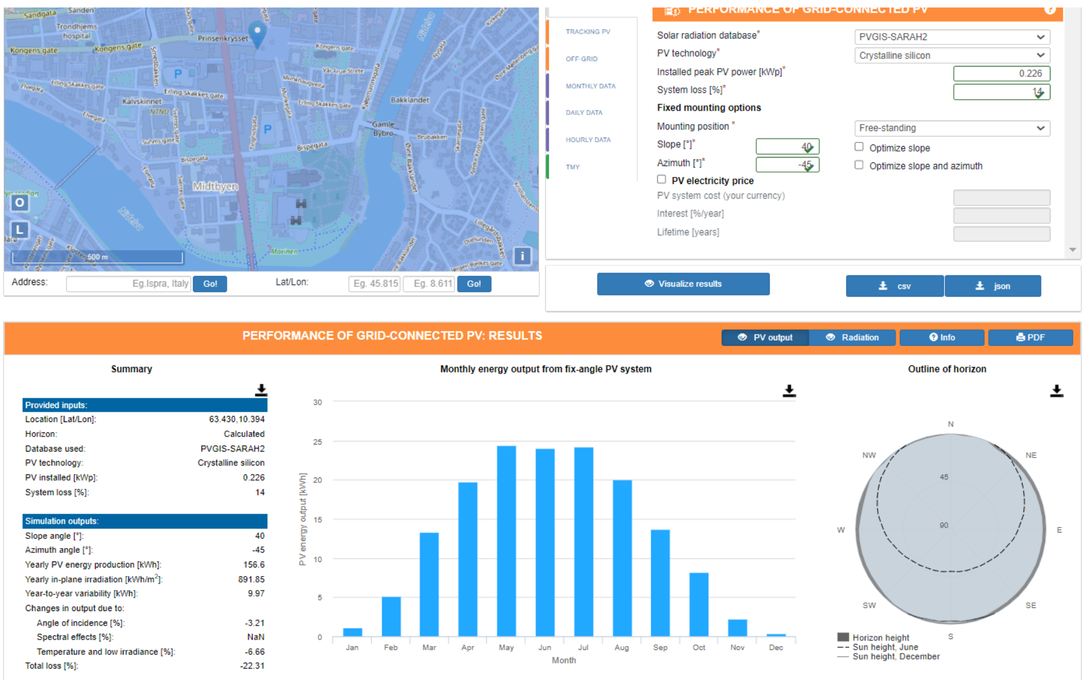

Figure B.1: South-east PV installation [77]

Emisson Source	Production of materials A1-3	Transport of materials to site A4	Construction site activities A5	Use B1	Maintenance B2	Replacements of materials B4	Energy use in operation B6	Travel use in operation B8	De-construction and demolition C1	Transport to waste handling C2	Waste processing C3	Disposal C4	Additional benefits and loads D
Energy in Construction, Operation & End-of-life													
Energy use delivered	–	–	✗	–	–	–	✗	–	✗	–	–	–	–
Energy use exported	–	–	–	–	–	–	–	–	–	–	–	–	✗
Products used													
Production	✓	–	–	–	–	✓	–	–	–	–	–	–	–
Transport	–	✓	–	–	–	✓	–	–	–	–	–	–	–
Biogenic uptake (Used)	–	–	–	✓	–	–	–	–	–	–	–	–	–
Carbonation uptake	–	–	–	✓	–	–	–	–	–	–	–	–	–
Maintenance	–	–	–	–	✗	–	–	–	–	–	–	–	–
Travel use in operation													
Travel use in operation	–	–	–	–	–	–	–	✗	–	–	–	–	–

Figure B.2: LCA stages included in the study [88]

Wastage from products used													
Production	–	–	✓	–	–	✓	–	–	–	–	–	–	–
Transport	–	–	✓	–	–	✓	–	–	–	–	–	–	–
Incineration	–	–	✓	–	–	✓	–	–	–	–	–	–	–
Biogenic uptake (Wastage)	–	–	–	✗	–	–	–	–	–	–	–	–	–
Recyclability	–	–	–	–	–	–	–	–	–	–	–	–	✗
Waste from replacements and end-of-life													
Transport	–	–	–	–	–	✗	–	–	–	✗	–	–	–
Incineration	–	–	–	–	–	✓	–	–	–	–	✓	–	–
Recyclability	–	–	–	–	–	–	–	–	–	–	–	–	✗
Reusability	–	–	–	–	–	–	–	–	–	–	–	–	✓

Figure B.3: LCA stages included in the study [88]

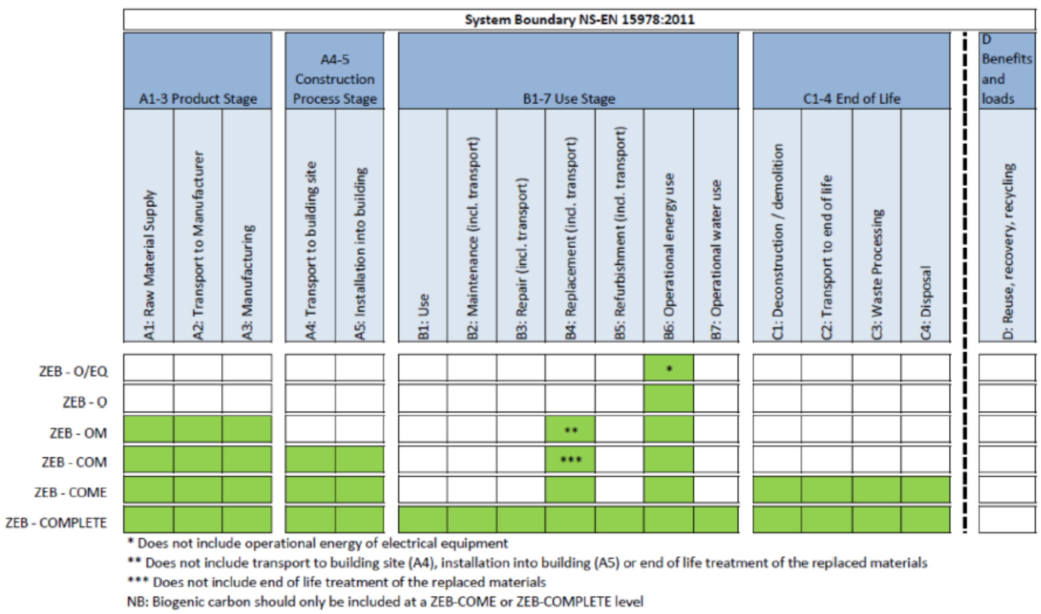

Figure B.4: Life cycle phases included in ZEB-LCA [91]

Appendix C

Calculations

C.1 Operational phase emissions, Co2 factor=17 gCO2eq/kWh

(Heating load kgCo2e/ kWh × 17 gCo2e/ kWh) ÷ 1000 = Operational emissions kgCo2/m2

(24.51 kWh/m2 × 17 gCo2e/ kWh) ÷ 1000 = 0.41 kgCo2/m2 (operational emissions for one year)

Emissions for 60 years, which is the life cycle of the cabin: 60 × 0.41 kgCo2/m2 = 24.6 kgCo2/m2 (operational emissions for 60 years)

C.2 Operational phase emissions Co2 factor=136 gCO2eq/kWh

(24.51 kWh/m2 × 136 gCo2e/ kWh) ÷ 1000 = 3.33 kgCo2/m2 = 199.80 kgCo2/m2 (operational emissions for 60 year)

C.3 Embodied emissions of electric heating system

Electric heater with 20 years of lifetime = 51 kgCO2eq/kW [40]

For the living room, 13.58 m2, with insulated cavity walls which has 3 walls facing outside the size of the heater is: 1.92 kW [73]

For the bedroom, 4 m2, with insulated cavity walls which has 3 walls facing outside the size of the heater is: 1.4 kW [73]

For the bathroom, 3.30 m2, with insulated cavity walls which has 3 walls facing outside the size of the heater is: 1.4 kW [73]

embodied emissions of heaters with a lifespan of 20 years = 240.72 kgCO2eq = 19.50 kgCO2eq/m2

C.4 Ånegga cabin emissions in 2022

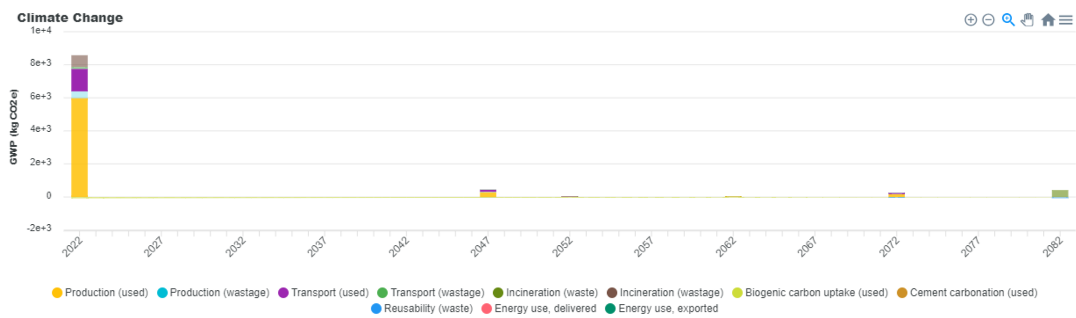

Figure C.1: Yearly embodied emissions of Ånegga cabin extracted from Reduzer results

C.5 Embodied emissions of the heating system

Embodied emissions of ASHP

GHG impact total of ASHP with 20 years of lifetime = 363.8 kgCO2eq/kW [40]

The heat pump for the cabin with 37 m2 is considered 3 kW.

3 kW × 363.8 kgCO2eq/kW = 1091.4 kgCO2eq (embodied emissions of ASHP with a lifespan of 20 years)

1091.4 kgCO2eq ÷ 20 = 54.57 kgCO2eq/year = 1.47 kgCO2eq/year/m2

Embodied emissions of GSHP

GHG impact total of GSHP with 30 years of lifetime = 896.5 kgCO2eq/kW

3 kW × 896.5 kgCO2eq/kW = 2689.5 kgCO2eq (embodied emissions of GSHP with a lifespan of 30 years)

2689.5 kgCO2eq ÷ 30 = 89.65 kgCO2eq/year = 2.42 kgCO2eq/year/m2