ABSTRACT

This sub-thesis, under the greater thesis 'Nordlandsbua: Cabin in Nordlandsruta', aims to tackle heating and firewood usage in the Nordlandsbua cabin.

Nordlandsbua is a 9,7m^2 cabin that will be placed on the site of Tjoarvihytta, about halfway along the Nordlandsruta hiking trail. Firewood transportation to remote sites along the Nordlandsruta begets emissions, especially when firewood supplies run out frequently. In addition, the stove that was chosen as the heating supply in the cabin has a heat output that is far too large for the size of the cabin. Therefore, there is a likelihood that firewood will be overused. These factors, along with the overall aim to design Nordlandsbua as a sustainable cabin, support the need for a calculation of necessary firewood usage to make efficient use of firewood supplies.

This report delves into various calculations and analyses, such as a climate analysis, calculation of the thermal transmittance of the building, establishment of an operative temperature using clo-value and metabolic rate, and a final energy simulation using SIMIEN.

As a result, an estimated firewood demand will be determined in kilograms. This result can be used to establish a rough yearly, monthly or daily firewood need.

ACKNOWLEDGMENTS

First, I would like to thank my supervisor Pasi, for inspiring me to choose this research topic. Your anecdotes about the grotesque misuse of wood-burning stoves in cabins set fire to my curiosity (pun intended).

I would also like to thank Laurent George from NTNU's Institute of Energy and Process Technology for aiding me in developing the strategy that got me to my final results.

A big thank you to Michael Grüner for answering my never-ending questions regarding SIMIEN and for stepping in when I needed help most.

Lastly, to Anneli, Julie and Anastasia, thank you for going on this grand cabin journey with me, for the support throughout all the stressful moments, and for the memories that I will continue to cherish.

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LIST OF ABBREVIATIONS & DEFINITIONS

°C	DEGREES CELSIUS
CO	CARBON MONOXIDE
CO_2	CARBON DIOXIDE
CLO	UNIT OF MEASURING CLOTHING INSULATION LEVEL
DNT	DEN NORSKE TURISTFORNING
EPD	ENVIRONMENTAL PRODUCT DECLARATION
EPW	ENERGYPLUS WEATHER FILE
KG	KILOGRAM
KW	KILOWATT
KWH	KILOWATT-HOUR
LCA	LIFE CYCLE ANALYSIS
MET	UNIT TO MEASURE METABOLIC RATE
OSB	ORIENTED STRAND BOARD
R-VALUE	HEAT-FLOW RESISTANCE
SOT	SULITJELMA OG OMEGN TURISTFORENING
TEK17	BYGGTEKNISK FORSKRIFT
U-VALUE	THERMAL TRANSMITTANCE

INTRODUCTION

The thesis, Nordlandsbua: Cabin in Nordlandsruta, centers around the design of a sustainable cabin on the Nordlandsruta trail. As part of that project, this sub-thesis aims to tackle challenges regarding heating demand and resource usage for heating in the cabin.

In review, the Nordlandsbua prototype was commissioned by the Norwegian Trekking Association (DNT) and Saltan Friluftsråd with the goal of expanding the hiking capacity of the Nordlandsruta hiking trail. The sustainable cabin design could be replicated and placed in various locations along the trail to shorten hiking distances between cabins and also to even out visitor capacity at each overnighting location. The first version of this prototype, which we built, will be installed on the Tjoarvihytta site, about midway through the trail.

Nordlandsbua's design is able to house four people internally, but with the capability of additional sleeping space outside in the summer months. The interior floor area is just shy of $10m^2$ and will be heated with a wood-burning stove.

As will be elaborated on later in this report, the stove's heat output is far greater than the need of the cabin. Therefore, there is a likelihood that cabin users will fill the stove to its maximum and overheat the space, thus burning more wood than is necessary. In addition to this, wood supplies are often delivered by truck, snowmobile or helicopter, all emissions-producing modes of transport. The frequency in which wood supplies must be replenished also adds to these transport emissions.

As part of their Sustainability Strategy for 2021 to 2030, DNT aims to reduce the overall energy consumption and resource usage of its cabins, and Nordlandsbua is no exception.

As a result, the purpose of this thesis is to seek out a strategy to reduce the amount of wood consumption needed for heating in the Nordlandsbua. This thesis is written in tandem with the main design thesis, 'Nordlandsbua: Cabin in Norlandsruta', as well as the other sub-theses, 'Climate Research and Outer Shell Design', 'Materials Selection and Life Cycle Analysis', and 'Circular Economy'.

SCOPE

The objective of this thesis is to calculate an approximate amount of firewood (in kg) that is needed to keep the stove heated over an allotted period of time. This thesis considers that wood-burning stoves do not offer a consistent stream of heat and are often subject to human error. Therefore, only an estimate will be determined, and a general guideline for firewood need will be provided to cabin-goers.

In addition to this, other contributing factors will be investigated, such as the thermal properties and technical requirements of the cabin, other heating solutions, ideal operational temperature, peak-visitor times, as well as an exploration into how changes in these variables affect the final heating demand.

As will be described in the 'Heating Demand' chapter, the results of this thesis are largely affected by the limitations of the energy-simulation program. As most simulation programs are not built to test building systems with no other amenities other than space heating, the results will have to be adjusted to account for these restrictions.

METHODOLOGY

In order to reach the final wood calculation, a variety of steps were followed in order to gather sufficient information.

1. A discussion about heat sources took place in order to determine the appropriate choice for the cabin's design and heat needs.

2. In collaboration with Anastasia Tsivileva, who was responsible for the project's material analysis and LCA report, and with

consideration of the project requirements provided by Saltan Friluftsråd, suitable insulation material and construction for the cabin were decided on.

3. U-values for each of the cabin's surfaces were calculated.

4. Based on the clo-value and the metabolic activity of the cabin's visitors, an approximate optimal operational temperature is set.

5. Based on tourism statistics and information from the manager of Tjoarvihytta, the peak occupancy periods are determined.

6. Using SIMIEN, an energy demand simulation is created to determine how many kWh are needed to heat the space at the peak visitation times throughout the year.

7. Based on the SIMIEN results and data on the energy capacity of typical Norwegian firewood, an approximate weight of wood needed per day, month and year, is calculated.

8. Given that the Nordlandsbua is a prototype and further adaptations of the project may be built, other iterations of this calculation are performed with variations in the data to determine whether improvements can be made.

Each of these phases is divided into its own chapter in this report. Although their organization in this report is chronological, many of these steps were revisited and revised throughout the design and calculation process.

Drawn by Anastasia Tsivileva

TOTAL HEATED AREA 9,67M²

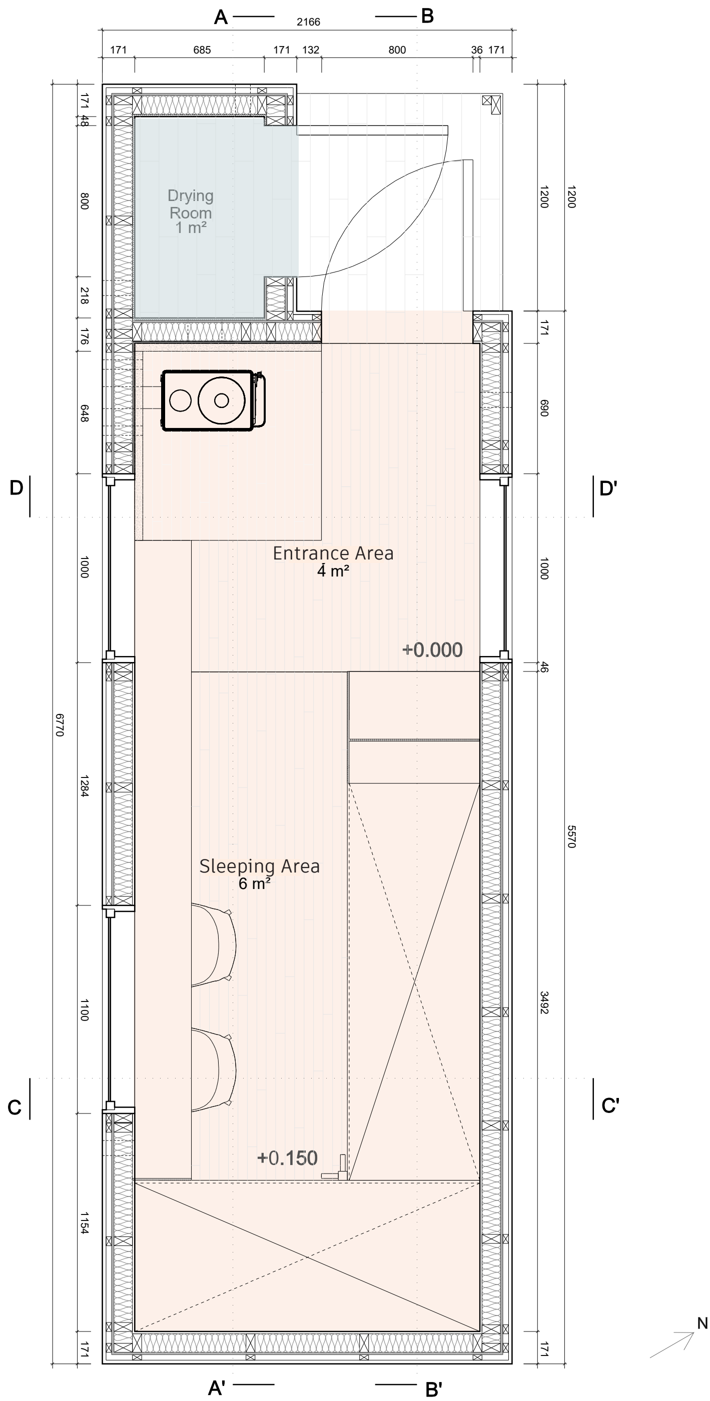

FIGURE 1. PLAN OF THE BUILT CABIN. SCALE 1:40

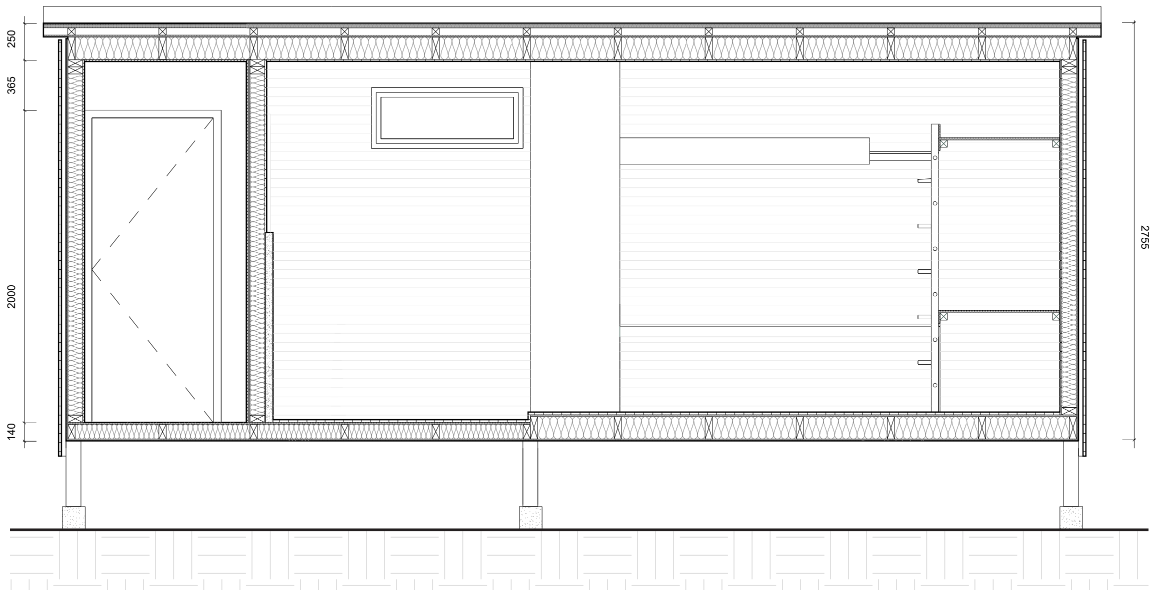

FIGURE 2. SECTION A-A OF THE BUILT CABIN. SCALE 1:50

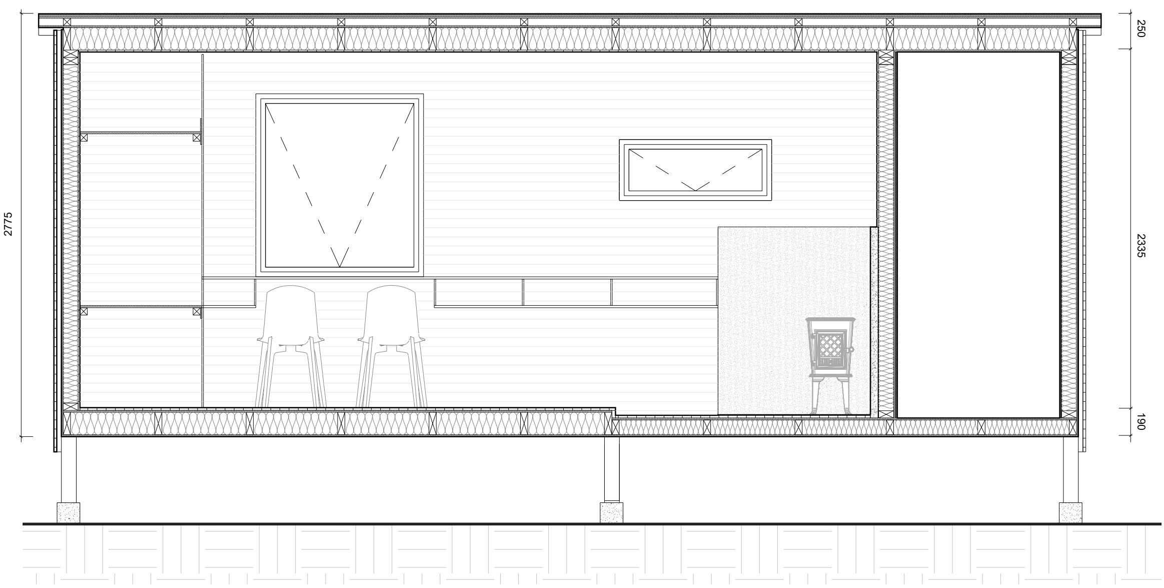

FIGURE 3. SECTION B-B OF THE BUILT CABIN. SCALE 1:50

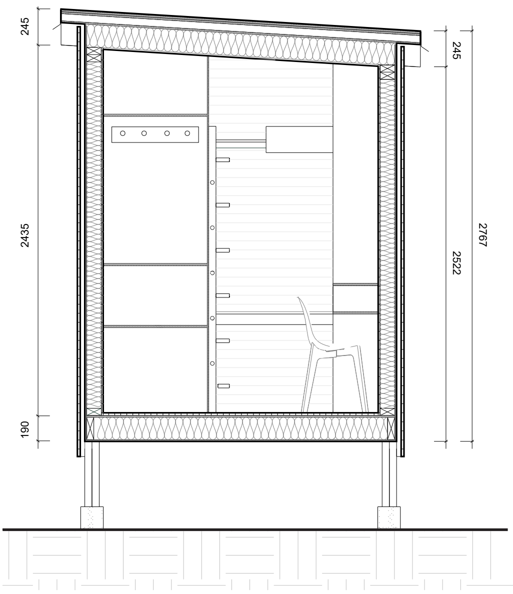

FIGURE 4. SECTION C-C OF THE BUILT CABIN. SCALE 1:50

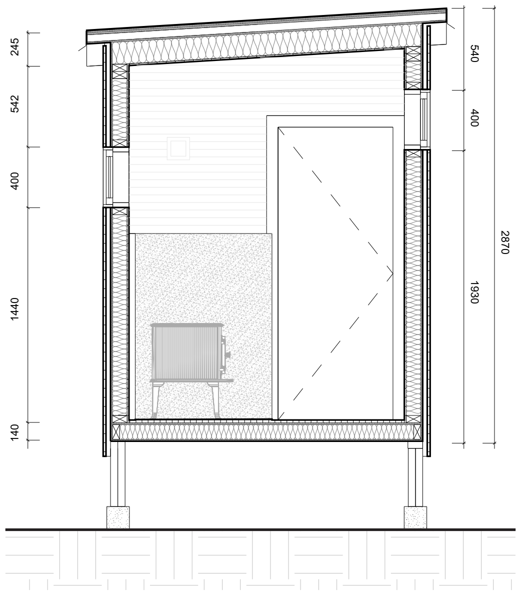

FIGURE 5. SECTION D-D OF THE BUILT CABIN. SCALE 1:50

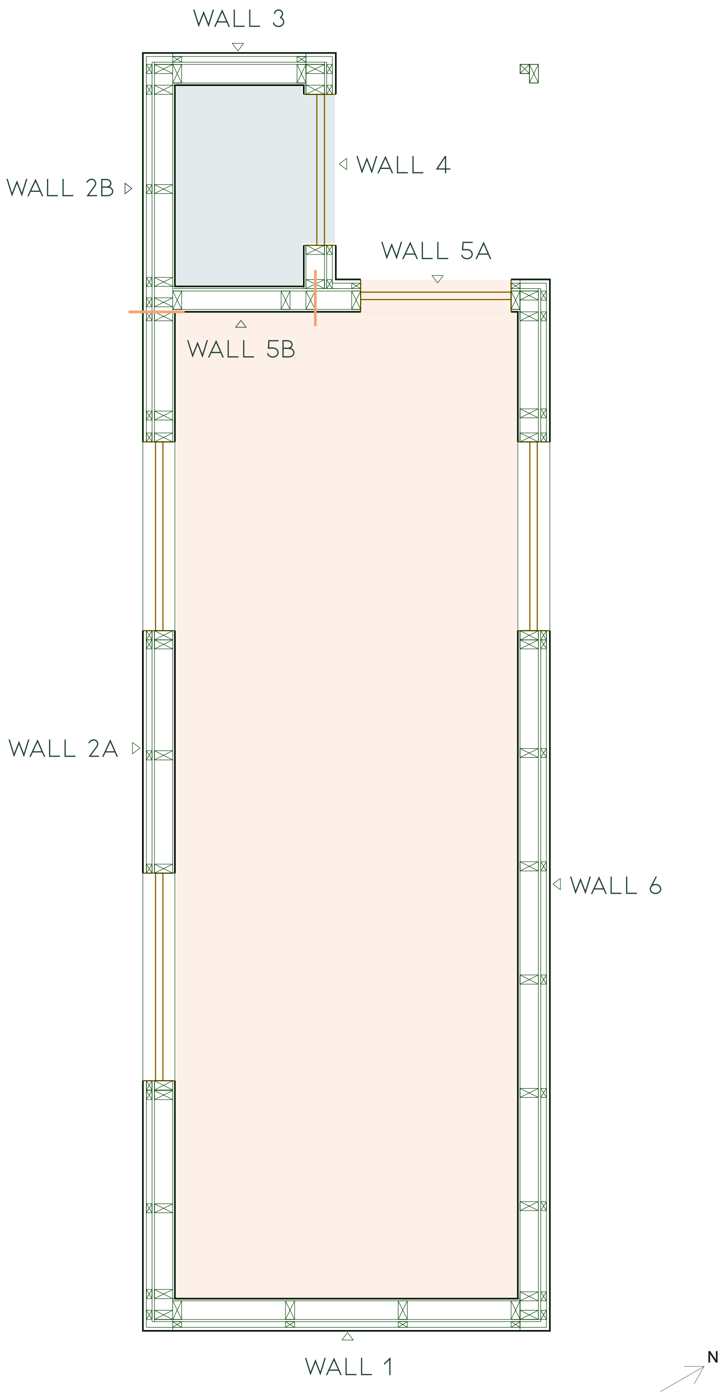

FIGURE 6. NUMBERING OF WALLS. SCALE 1:40

HEAT-SOURCE CHOICE

In choosing a heat source for the cabin, it was accepted early on that we would most likely choose a wood-burning stove. This cabin's remote site location and small size, as well as Norway's long-standing tradition of using wood stoves, proved it to be a favourable choice. It was briefly discussed whether a small heat pump could be used; however, due to their complexity, they are much more difficult to troubleshoot for the average hiker if they malfunction. Getting a mechanic, tools and supplies to a remote location also has its own host of challenges.

The cabin's mere 9,7m^2 would not need a stove with more than 5kWh in output, so the original choice was one of the stoves from the Canadian company, Cubic Mini. Their smallest model, the CB-1008, is about 28x30x26cm in dimension, extremely light-weight (11kg) and has an output of 1,75-4,10kWh. However, the primary obstacle was their lack of availability outside the United States and Canada. Had we chosen this stove, we would have to ship it from Canada to Norway. Given that a Life Cycle Analysis would be done, we would need to include the emissions from the shipping process.

The second stove choice was from the Norwegian company Jøtul. Although their smallest model, the Jøtul 602, is seven times heavier (about 78kg), their production location is just south of Oslo in Fredrikstad, so the transportation emissions would be far fewer.

Deciding between these two options begged whether the effect of their weight on emissions and possible difference in firewood intake would outweigh the transportation emissions. Nevertheless, the choice was made easy due to the Cubic Mini's shipping time not being within the time frame of this project and the appearance of a second-hand Jøtul stove we were able to use. The Jøtul 602 N, which we obtained, is an older model, and is no longer in production. If this project is duplicated in the future, the Jøtul 602 ECO, a more efficient model, could be used.

Although Norway's domestic shipping and road transport have ambitious goals for emissions reductions or eliminations in the future (Simonet, 2019), it would be an interesting exploration to compare the present-day transportation and operational emissions of the two stoves. However, this topic was not within the scope of my research.

CUB CUBIC MINI WOOD STOVE

POWER RANGE
1,75 - 4,1 kWh
EFFICIENCY
unspecified
WEIGHT 11kg
CO EMISSIONS
unknown (these stoves are not yet certified)

FIGURE 7: CB-1008 CUB

JØTUL 602 ECO

NOMINAL POWER
4,9 kWh
EFFICIENCY 81%
WEIGHT 89kg
CO EMISSIONS
0.09% (w/ 13% O_2)

FIGURE 8: Jøtul 602 ECO

JØTUL 602 N

POWER RANGE
2,3-8,5 kW
EFFICIENCY
71% @ 6,1 kW
WEIGHT 78kg
CO EMISSIONS
0.28% (w/ 13% O_2)

FIGURE 9: Second-Hand Jøtul 602 N (Private Photo)

INSULATION & U-VALUE CALCULATION

CHOICE OF INSULATION MATERIAL

In choosing an insulation material, the cabin's size, location and occupants had to be taken into consideration.

As briefly mentioned in the main report, the clients, DNT and Saltan Friluftsråd, had made a specific request regarding the insulation material. They had asked that Glava (fibre-glass) not be used in the cabin. Since the cabin will be placed in a remote location in nature, Glava insulation will be attractive to small rodents and insects as nesting material. According to a University of Nebraska study, Rockwool, Celotex, and Vermiculite would suffer the same fate (Hygnstrom, S. E., 1992). For these reasons, woodfibre insulation was chosen. Although no insulation material is 100% rodent-proof, due to its density and lack of nutritional value, it is not of interest to small animals (Vides Tehnika, 2021). Although Glava is more favourable in terms of production emissions, there is a higher likelihood that, given the site context, wood fibre will be more durable and less likely to need to be replaced.

INSULATION THICKNESS

When seeking out the required U-values for the exterior surfaces of the Nordlandsbua, TEK17 was referred to. While in correspondence with the Direktoratet for byggkvalitet (the building authority that published TEK17), it was determined that the cabin does fall under the category of a 'leisure home'. However, according to Section 14-5: Exceptions and requirements for special projects, "(2) Leisure homes with a heated gross internal area of up to 70m2 are exempt from the requirements in chapter 14." (Direktoratet for byggkvalitet, 2017), which outlines the net energy requirements and U-values for buildings of various sizes. In short, Nordlandsbua, due to its size, does not have any mandatory U-value requirements. Therefore, the insulation thickness was up for debate.

Due to available structural lumber thicknesses, the choice was between 100mm or 150mm of insulation. A thicker layer of insulation (such as 200mm) would also be possible; however, given that the cabin does not need to meet usual u-value regulations, more than 150mm of insulation would not be necessary. A discussion ensued about which choice would result in fewer embodied emissions. 100mm of insulation would mean less material used. On the other hand, it could result in more heat retention and could reduce the amount of firewood needed to keep the cabin heated.

Knowing that visitors would most likely only stay one or two nights before moving further along the trail influenced the decision to prioritize material usage. The final decision resulted in 100mm of insulation for the walls. However, 150mm was kept for the roof in accordance to optimize the stack effect. Due to the 'step' design of the floor, 100mm of insulation was used in the entrance area and 150mm of insulation in the sleeping area.

The nature of this cabin as a prototype would allow for this decision to be tested out. If visitors find the cabin's temperature uncomfortable, future iterations of the cabin could plan for an increase in insulation thickness.

U-VALUE CALCULATION METHOD

U-value calculations were carried out prior to the build, found in Appendix A. However, due to the numerous construction changes that occurred during the build, more accurate calculations had to be done after the building was completed. The U-values for each surface were calculated according to the NS-EN ISO 6946 U-value calculation method for structures with non-homogeneous layers.

Earlier U-value calculations had been done using the Ubakus online tool; however, Ubacus only accounts for vertical bracing in walls and not any additional cross-bracing. Therefore the final calculations were done in Excel (Appendix C). The following is an example of the calculation method on Wall 1:

In a usual cc-60 distance timber stud structure (which is usual for Norway), the ratio between wood and insulation in the insulation layer when using 48mm studs for the walls, floor and roof are 12%, 8% and 8%, respectively. However, during the construction process, additional studs and cross-bracing were added to the wall structure. To proceed with the U-value calculations, the percentage of wood and insulation in each wall needed to be re-evaluated. The new percentages can be found in Appendix B.

In this calculation example, we will look at Wall 1, which had a stud percentage of 21,43%. All the wall layers in Wall 1 can be seen in Table 1. The air cavity behind the exterior cladding is not fully enclosed and is hence ventilated. Therefore, the thermal resistance of the layers beyond the wind barrier (Hunton Vindett Plus) are excluded from the U-value calculation, and an internal surface resistance is used for the exterior of the structure.

Next, the thicknesses and thermal conductivity values were found for each layer of the wall and used to calculate R-values (seen in Table 1). Since there are layers in the wall with more than one material (i.e. wood studs and insulation), the R-values must be divided into the different sections of the wall. Section A is where the insulation is located, and Section B is where the stud is located.

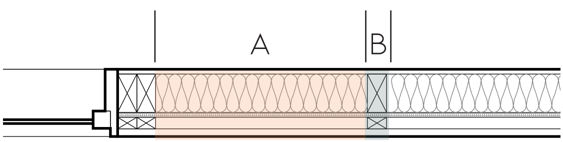

FIGURE 10: Division of wall for U-value calculation

Then, for the stud-insulation layer, an alloy R-value calculation is done.

$$R_x = \frac{1}{\frac{\%\,Area_A}{R_A} + \frac{\%\,Area_B}{R_B}} = \frac{1}{\frac{0{,}786}{2{,}579} + \frac{0{,}214}{0{,}817}} = \frac{1}{0{,}304 + 0{,}261} = \frac{1}{0{,}565} = 1{,}764$$

Then, the upper limit of thermal resistance is calculated using the R-value sums of Sections A and B.

$$R_T = \frac{\%\,Area_A + \%\,Area_B}{\frac{\%\,Area_A}{\sum R_A} + \frac{\%\,Area_B}{\sum R_B}} = \frac{0{,}786 + 0{,}2143}{\frac{0{,}786}{4{,}385} + \frac{0{,}2143}{2{,}622}} = \frac{1}{0{,}179 + 0{,}082} = \frac{1}{0{,}2607} = 3{,}833$$

Then, the average of the upper and lower limit is found.

$$R_{average} = \frac{R_{upper\ limit} + R_{lower\ limit}}{2} = \frac{3{,}833 + 3{,}569}{2} = 3{,}701\ (m^2 \cdot K)/W$$

This R-value is then used to calculate the wall's U-value.

$$U_{Wall\ 1} = \frac{1}{R_{average}} = \frac{1}{3{,}701} = 0{,}270\ W/m^2K$$

This calculation was done for each wall as well as the roof and floors, and can be found in Appendix C. These U-values will be used later to generate a heat demand in SIMIEN.

WALL 1 (TRUE CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M²·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,098	0,038	2,579		1,764
	TIMBER STUD (48X98MM)	0,098	0,12		0,817	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	INTERIOR SPRUCE CLADDING	0,015	0,013	1,154	1,154	1,154
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	4,385	2,622	3,569
			UPPER LIMIT	3,833		
			AVERAGE R-VALUE	3,701		
			U-VALUE (W/M²K)	0,270		

TABLE 1: U-value calculation for Wall 1.

HEATING SEASON AT TJOARVIHYTTA

Although the Nordlandsbua design may be replicated and built on various sites along the Nordlandsruta hiking trail, its first home will be the site of Tjoarvihytta.

CLIMATE OF TJOARVIHYTTA

As mentioned in the main report and further detailed in Julie Nyland Nilsen's thesis 'Climate Research and Outer Shell Design', Tjoarvihytta is located in the centre of the Nordlandsruta trail, and sits at approximately 600m above sea level. Its inland and mountainous location grants the site protection from western winds, allowing for a more 'mild' (for Norwegian standards) micro-climate. As shown in Figure 13, the average temperatures at Tjoarvihytta range between +15°C in summer and -15°C in winter, but can also dip down to -25°C.

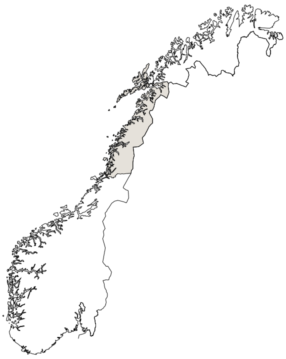

FIGURE 11.
Location of Norlandsruta in Norway
(Map by Julie Nyland Nilsen)

FIGURE 12.
Cabin locations on the Nordlandsruta, with Tjoarvihytta in orange.
(Map by Julie Nyland Nilsen)

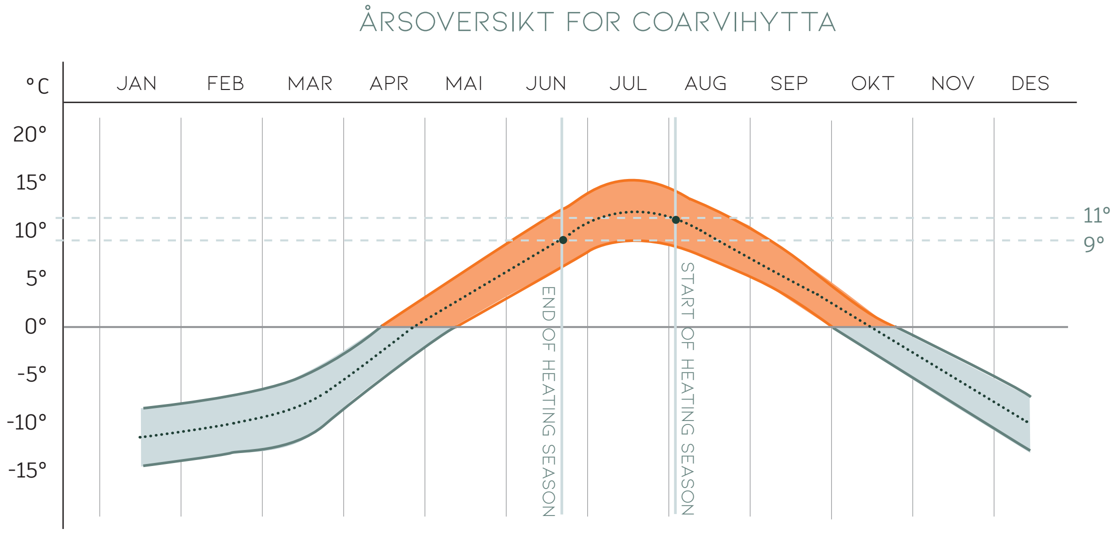

FIGURE 13.
Average minimum and maximum temperatures for Coarvihytta (Tjoarvihytta) over the last 10 years. (Storm.no)

HEATING SEASON

According to a 2002 report from the Norwegian Meteorological Institute, "heating season is traditionally defined as the period from the day the mean daily temperature falls below 11°C during the autumn and until the day it rises above 9°C during the spring." In most other parts of Norway, the heating season falls between the end of September and the end of May. However, for the location of Tjoarvihytta, as seen in Figure 12, the heating season begins around early August and ends in mid-to end- June.

As will be elaborated on later, it is relevant to note that the months in which Tjoarvihytta's average temperatures are above 0°C are April to October.

FUTURE CHANGES TO THE HEATING SEASON

Although the current heating season at Tjoarvihytta will be used to model the energy demand, it is important to note that most of Norway will experience a rise in temperatures due to increasing global temperatures. Based on the study mentioned earlier, it is predicted that the mountainous regions of Norway (Tjoarvihytta included) could experience a decrease of more than 40 heating days between now and 2050 (Skaugen & Tveito, 2002.). Although this may seem positive in terms of reducing the heating demand in buildings; it will, however, negatively affect ecosystems and natural habitats across Norway on a major scale.

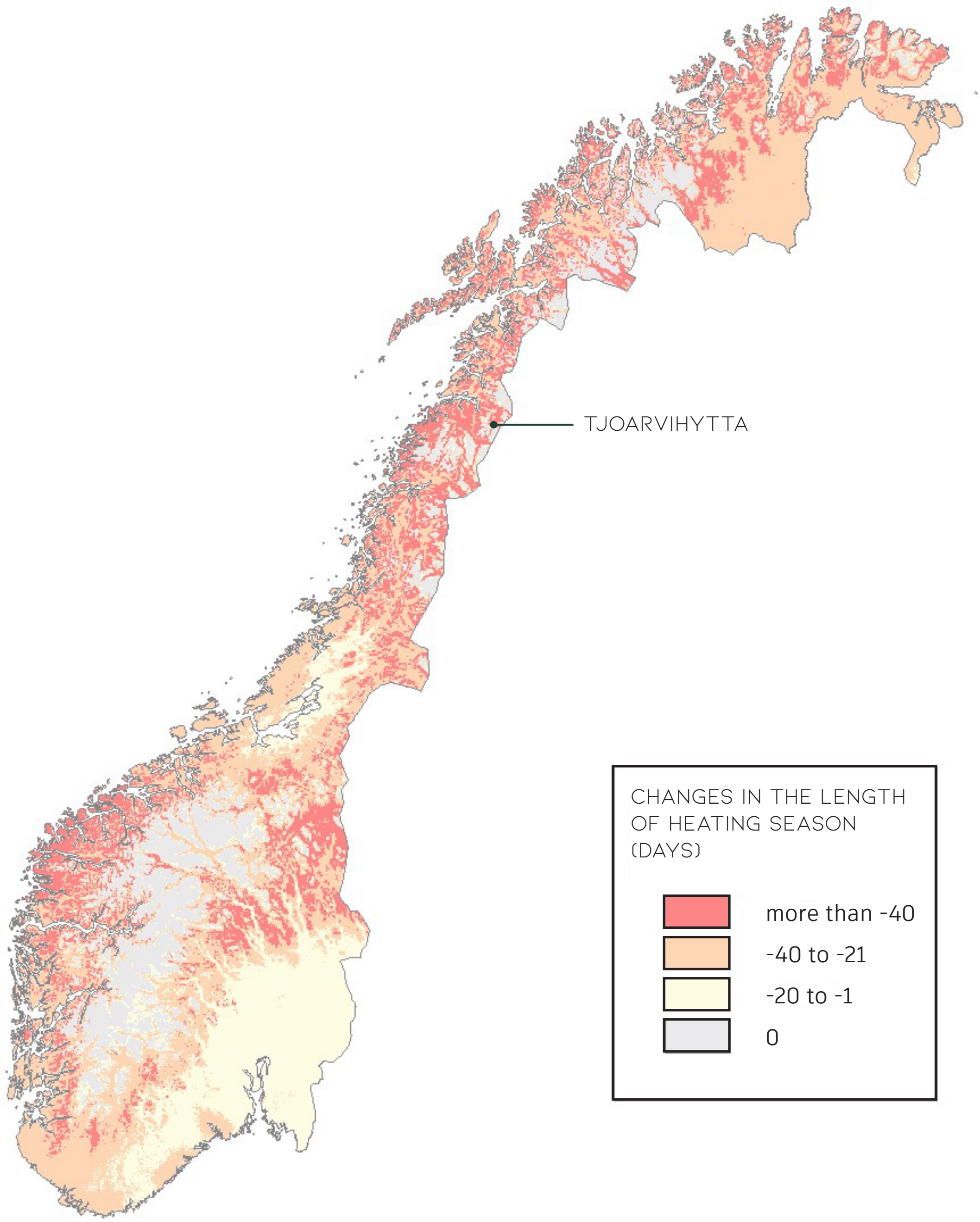

FIGURE 14.
The changes of the length of the heating season between the scenario period (2021-2050) and the normal period (1961-1990) in actual days.
(Skaugen & Tveito, 2002.)

OPERATIONAL TEMPERATURE

In order to determine an operational temperature or set-point temperature for the SIMIEN calculation, NS-EN ISO 7730 on the "Ergonomics of the thermal environment" was used. It should be said that since wood-burning stoves do not give a consistent heat output, the operational temperature is set as a general benchmark for the energy simulation.

This method of determining operational temperature uses the clo-value and metabolic rate. Since activity and clothing level vary in the cabin, two base scenarios are referenced, and an average operational temperature is derived from them.

SCENARIO 1: visitors are wearing woolen sweaters and long underwear (based on recommendations from DNT), and are participating in.

SCENARIO 2: visitors are wearing their sleeping bags and are sleeping lying down.

Both of these scenarios take place during Norway's heating season, as different clothing choices would be made during the warmer months when heating the cabin would not be necessary.

CLO VALUE

A clo-value is the 'resistance to sensible heat transfer provided by a clothing ensemble.' (Mathisen, 2021.). Each item of clothing can be assigned a clo-value based on its insulating properties, and the clo-values of an entire outfit can be added together—the greater the clo-value, the better insulated.

For the first scenario, winter hiking clothing recommendations from DNT were used as a reference to create a general outfit that could be worn while in the cabin. In this scenario, visitors have already entered the cabin, removed any external/ waterproofing layers, and are left with the thermal under-layers. In Table 2, we see the list of recommended clothing items, their clo-values, and the sum of the outfit. For Scenario 1, we have a total clo-value of 1,2.

CLOTHING ITEM	CLO-VALUE
UNDERWEAR	0,03
WOOL LONG UNDERWEAR	0,1
LEGGINGS/LIGHT PANTS	0,25
BRA	0,01
WOOL SHIRT W/LONG SLEEVES	0,3
THICK WOOL SWEATER	0,37
WOOL SOCKS	0,1
SLIPPERS	0,03
Σ	1,2

TABLE 2: Clo-value for outfit in scenario 1.

In Scenario 2, the visitors are dormant and in their sleeping bags. Th clo-value in the scenario is more challenging to pinpoint, as the insulation levels of sleeping bags vary greatly. However, based on the sample sleeping bags in Kuklane and Dejke's 2010 study, the insulation level of each sleeping bag was around 0,4 m^2K/W (or 2,5 clo) when sleeping in a position with one's arms outside of the sleeping bag. This value, nevertheless, does not include any sleeping mattress, which would increase the insulation level. So, we can assume that the total clo-level would be greater than 2,5.

METABOLIC RATE

The human body's metabolic rate is the rate at which energy is produced from consumed food and drink, based on activity level. Metabolic rate can be measured in mets. 1 met is equivalent to 58.2 W/m^2 which is the energy produced per unit surface area of an average person in a seated position when the surface area of an average person is 1.8 m^2. (Mathisen, 2021.)

In Scenario 1, visitors are doing light work, i.e. cooking, walking around or monitoring the stove fire. These types of activities exert an approximate metabolic rate of 1,2 mets. In Scenario 2, visitors are sleeping, and therefore their metabolic rate is at a low 0,8 mets.

OPTIMAL OPERATIVE TEMPERATURE

Both scenarios' clo-value and metabolic rate are plotted on the graph "Optimal operative temperature as a function of clothing and activity level'' from NS-EN-ISO7730.

Since the original graph does not include a clo value higher than 2, the graph was extended to account for the 2,5 clo-value of the sleeping bag.

For Scenario 1, the optimal operative temperature would be approximately 17° C. Given that Scenario 2 would not be available on the original graph, it's optimal operative temperature is more of an estimate. Nonetheless, it also would be somewhere around 17° or 16° C.

Based on the optimal operative temperatures of both scenarios, we can devise that 17° C would be an ideal indoor temperature to set as our benchmark temperature in the SIMIEN energy simulation.

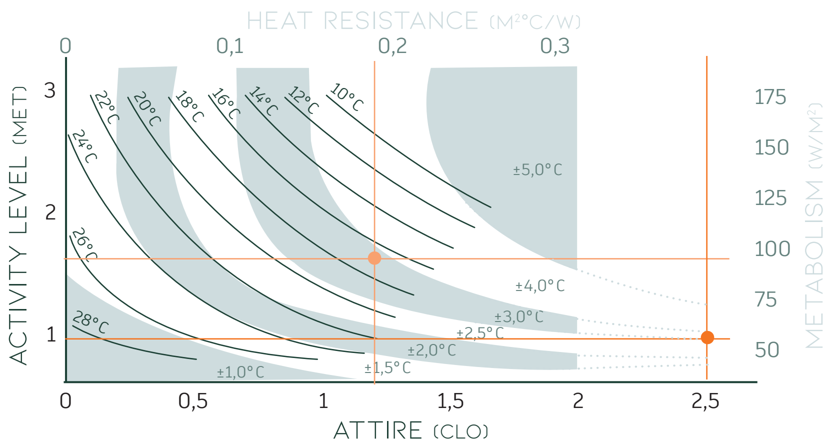

FIGURE 15. Optimal operative temperature as a function of clothing and activity level (NS-EN-ISO7730.)

CABIN OCCUPANCY

Although the Tjoarvihytta cabin site has recently started to use DNT's online booking system (UT.no), we could not obtain visitor data aggregated by month. Therefore, approximations of Tjoarvihytta's, and by extension Nordlandsbua's, monthly operational days were made. This information was necessary to carry out the SIMIEN energy calculation.

STATS ON CABIN ACCOMMODATION

Data was used from Statistisk sentralbyrå (Statistics Norway), who publish their monthly census on 'Intermediaries of cabins'. This data tells us how many guest-nights ("one person spending one night in a cabin/holiday house/apartment/room equals one guest night.") are spent in a cabin or 'holiday home' in each region in Norway, each month. The earliest data is from 2020, since the scope of it's previous categorization had been expanded on to include other cabin intermediaries, not just private ones. The figures on 'Intermediaries of cabins' are the most relevant in deciphering visitor data for a DNT-managed cabin, such as Tjoarvihytta.

Given that cabin accommodation data from years prior to 2020 is not available, a cross-check was done with statistics on overall guest-nights in Northern Norway, in all accommodation types. It was found that through the years 2015-2021, the guest-night numbers stayed relatively constant, even despite the COVID-19 pandemic, which largely effected global tourism in 2019 until the present (2022).

Table 3 shows the total guest-nights in Northern Norway, organized by month, for both 2020 and 2021. Using the numbers for both years, an average percentage of yearly guest nights was calculated for each month. According to the 2020 and 2021 numbers, the most popular months to for cabin-trips are May, June, July and August.

GUEST-NIGHTS AT TJOARVIHYTTA

In order to receive some information about Tjoarvihytta's visitor numbers, Einar Schilliås, Chairman of the SOT Board, was contacted (Appendix E). Unfortunately, there is no concrete information on the number of visitors Tjoarvihytta receives each month. However, the range of annual guests is somewhere between 250 to 550 (E. Schilliås, personal communication, 2021). This is quite a wide range. Seeing as the traffic of Norlandsruta is set to increase, the upper limit of this rage will be used to estimate Tjoarvihytta's monthly occupancy and operating days.

In Table 4, the average percentage of yearly guest-nights in Northern Norway determined in Table 3 was used to create an estimated number of guest-nights per month at Tjoarvihytta.

MONTH	2020 GUEST NIGHTS	2021 GUEST NIGHTS	SUM OF GUEST NIGHTS	AVERAGE % OF YEARLY GUESTS-NIGHTS IN NORTHERN NORWAY
JANUARY	737	60	797	3,3%
FEBRUARY	1107	331	1438	6,0%
MARCH	1115	449	1564	6,5%
APRIL	378	454	832	3,4%
MAY	2735	321	3056	12,7%
JUNE	1472	1518	2990	12,4%
JULY	2371	2179	4550	18,9%
AUGUST	1624	1693	3317	13,8%
SEPTEMBER	2081	1143	3224	13,4%
OCTOBER	700	816	1516	6,3%
NOVEMBER	242	175	417	1,7%
DECEMBER	205	215	420	1,7%
TOTAL	14767	9354	24121	

TABLE 3. Total guest-nights in Northern Norway, organized by month, 2020 and 2021.Also, average percentage of yearly guest nights for each month. (Statistisk sentralbyrå, 2021).

ESTIMATED OPERATIONAL DAYS

Although exact numbers for monthly visitors are not available for Tjoarvihytta, in order to estimate, we can assume that the Nordlandsbua will mostly be used when Tjoarvihytta is booked at full capacity (they offer nine beds). Therefore, the estimated monthly guest-nights for Tjoarvihytta were divided by 9 to obtain the estimated operational days per month.

One exception to the statistic that was made is during the Easter holiday. Not only is the Easter holiday week a very popular time in Norway for cabin-visitation, but Tjoarvihytta hosts an annual 'Påskekafeen' (Easter Cafe) event each year, which welcomes around 500 visitors (E. Schilliås, personal communication, 2021). Although most of these visitors do not stay at Tjoarvihytta overnight, we can safely assume that it is fully booked during this week. Therefore, an additional seven operational days were added to the month of April.

The operational days were sought out for the whole year; however, as will be explained in the next chapter, the estimated operational days from October until March will not be included in the SIMIEN energy calculation.

The resulting estimated operational days for Tjoarvihytta and Nordlandsbua are entirely estimated and do not necessarily represent actual visitor data. However, based on the minimal data available, this estimate was created and will be used in SIMIEN calculation. In the future, if more accurate data is accessible, the following chapters of this thesis could be revised to formulate a more accurate calculation.

MONTH	ESTIMATED GUEST-NIGHTS AT TJOARVIHYYTA	ESTIMATED OPERATIONAL DAYS PER MONTH WHEN AT FULL CAPACITY
JANUARY	20	2
FEBRUARY	27	3
MARCH	29	3
APRIL	24	10
MAY	35	4
JUNE	78	9
JULY	132	15
AUGUST	88	10
SEPTEMBER	42	5
OCTOBER	32	4
NOVEMBER	26	3
DECEMBER	17	2
TOTAL	550	68

TABLE 4. Estimated monthly guest-nights at Tjoarvihytta based on average guest-nights in Northern Norway.

MONTH	ESTIMATED GUEST-NIGHTS AT TJOARVIHYYTA	ESTIMATED OPERATIONAL DAYS PER MONTH WHEN AT FULL CAPACITY
JANUARY	20	2
FEBRUARY	27	3
MARCH	29	3
APRIL	24	10
MAY	35	4
JUNE	78	9
JULY	132	15
AUGUST	88	10
SEPTEMBER	42	5
OCTOBER	32	4
NOVEMBER	26	3
DECEMBER	17	2
TOTAL	550	68

TABLE 5. Estimated operational days per month

HEATING DEMAND

In order to create an estimated yearly energy demand for Nordlandsbua, SIMIEN was used. SIMIEN is a Norwegian energy simulation program which references local climates and building regulations.

CHALLENGES OF USING SIMIEN

One of the difficulties of using SIMIEN, or most complex energy simulating programs for this type of project, is that they are usually designed for larger buildings in continual use. Nordlandsbua is less than 10m^2, with no running water (and therefore no water-heating), no electricity, mechanical ventilation or cooling system. It isn't easy to set up the program without these elements, so they must usually be included anyway and simply ignored in the results. Natural ventilation is especially tricky to simulate; in reality, the majority of ventilation will come from the manual opening and closing of windows at inconsistent times. In addition to this, a major flaw of SIMIEN is its method of setting up climate data. Rather than offering the option to upload an EPW file, one must choose from a selection of pre-loaded cities, most of which are located in the south of Norway.

Lastly, which affected this research the most, is that SIMIEN does not allow for the interior building temperature to drop below 0°C. SIMIEN displays the highest energy demand for months like January, where both the outdoor temperature and occupancy are the lowest. This is because the program expects the heat to stay on at all times to avoid sub-zero interior temperatures. This feature would make sense when testing larger buildings or even houses with plumbing. However, this is not realistic for the location and design of the Nordlandsbua. Unfortunately, this feature can not be bypassed.

Therefore, the scope of this research had to be adjusted to focus solely on peak tourist months, April until September, when the average outdoor temperatures remain above 0°C. Although October at Tjoarvihytta also has average temperatures above 0°C, the climatic location used in SIMIEN, Mo i Rana, does. Therefore, data for October will also not be accurate, and is omitted.

DATA INPUT INTO SIMIEN

CLIMATE: As just mentioned, the climate data used in SIMIEN are pre-determined, and unfortunately, the location of Tjoarvihytta is not one of those available. Therefore, a location with a similar climate must be chosen instead. For this, Mo i Rana was elected. Although it is more south and coastal than Tjoarvihytta, it has a similar temperature range. The other northern options (such as Bardufoss) have too low temperatures and could create an unrealistic energy demand.

ENERGY SUPPLY: For the energy supply, room heating was set to Biofuel with a system efficiency of 71% (as specified by Jøtul for the 602 N model). Although irrelevant, all other settings were set to electricity.

OPERATING DAYS: The operating days from April until September were set as determined in the previous chapter, as the average temperatures for these months stay above 0°C. All other months were set to zero. Although they will yield results, these results will be ignored. Occupational days were mostly set on the weekend.

INTERNAL LOADS: The sole internal loads that were set were people. In the first run of this simulation, only two people were included (about 20,6 W/m2). Since hikers and skiers on the Nordlandsruta trail would most likely be traveling from cabin to cabin, it was assumed that visitors would arrive at Nordlandsbua around 16:00 and would leave around 8:00 in the morning.

VENTILATION: Although difficult to simulate realistically, the ventilation was set to Natural Ventilation.

HEATING: For heating, the set-point temperature was adjusted to 17°C, as determined in 'Optimal Operational Temperature'. If visitors arrive around 16:00, they will most likely start heating the stove as soon as they arrive. Although fueling the stove would subside from around 23:00 or 00:00, given that the stove also has a cooking-top that would be used for making breakfast, the heating would re-start at 6:00 until the guests leave at 8:00. SIMIEN does not register multiple on-and-off times, so the heating time was set to 16:00 until 8:00.

ANNUAL ENERGY DEMAND

When all of these factors are loaded into Simien, the following results are yielded:

In both graphs, the months October to March have been greyed-out. Since their monthly average temperatures are below 0°C, their data is not accurate due to the aforementioned issue with SIMIEN.

Caused by the long daylight hours from April until September, much of the heating balance is from solar heat gains. The small area of the cabin also allows for body heat from visitors to cover a significant amount of heating.

Next, this data was translated into an energy demand per day of each month.

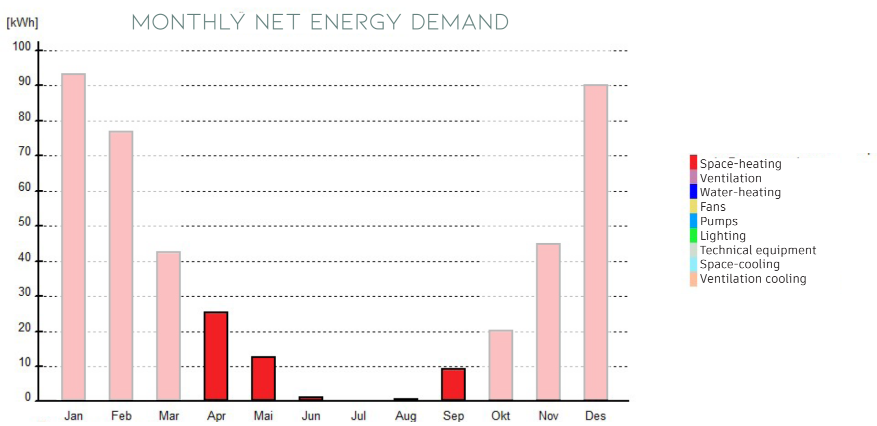

FIGURE 16. Monthly net energy demand

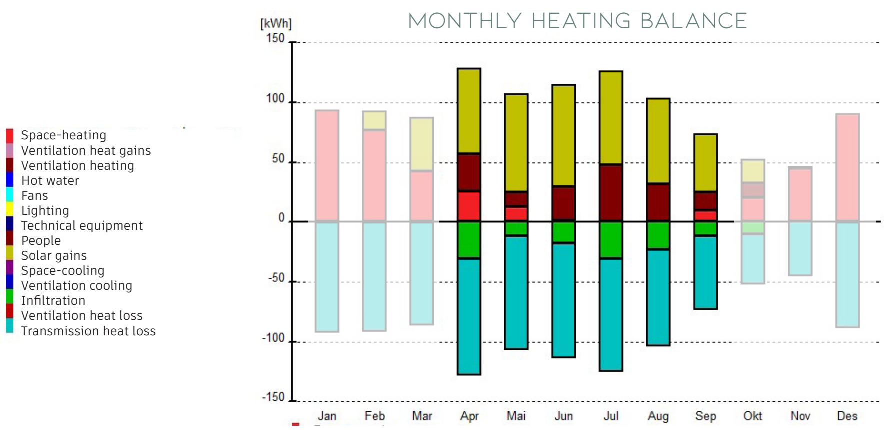

FIGURE 17. Monthly heating balance

MONTHLY ENERGY DEMAND

Based on the number of occupational days set in the chapter ‘Cabin Occupancy’, we can decipher how much of the monthly energy demand will be used per day.

	VARIATION 1		
MONTH	ENERGY DEMAND (KWH)	OCCUPANCY DAYS	ENERGY DEMAND PER DAY (KWH)
APRIL	25,75	10	2,58
MAY	12,5	4	3,25
JUNE	1	9	0,12
JULY	0	15	0,00
AUGUST	0,25	10	0,03
SEPTEMBER	9,5	5	2,05
TOTAL	49	52	

TABLE 6. Energy demand per day, per month

Given that temperatures change daily, these daily energy demands are based on operational days selected in SIMIEN, which mainly were weekend days. More accurate visitor data would allow for specific days to be chosen and, in turn, more accurate results. However, the results in Table 6 give a rough estimate of how much energy is needed for space heating for one day of each month.

HEATING DEMAND WITH VARIATIONS

In the previous chapter, the space-heating energy demand was determined for the current construction of Nordlandsbua, with the assumption that two people would only occupy it at a time. However, other variables could change the space-heating demand of the current cabin or future versions of it. Therefore, the monthly space-heating demand will be tested in SIMIEN with the following scenarios:

1. Current cabin (results in the previous chapter)

2. Occupancy of 4 people

3. An increase in insulation to 150mm

4. New stove, with higher efficiency

The results of these four variations (found in Appendix F) and the current variation will then be compared.

2. OCCUPANCY OF 4 PEOPLE

In this scenario, the location, construction and stove efficiency remain the same; the only change is the internal loads from people, which is increased to 41,2 W/m^2, which represents the heat of four people.

3. INCREASING INSULATION

Here, the insulation was increased from 100mm to 150mm (U-value calculations available in Appendix D). Early on, it was debated whether this extra 50mm of insulation would make a significant difference in the heating demand. The results of this comparison determine whether choosing 100mm was the correct choice.

4. NEW STOVE

Future versions of Nordlandsbua may not have the option to use a second-hand stove and would most likely buy a new, higher efficiency stove, such as the Jøtul 602 ECO, which has an efficiency of 81%. A heating system with this efficiency was tested out.

FINDINGS

In Figure 14, we can see the results of this comparison. In conclusion, having a greater occupancy is the sole factor that would significantly reduce the energy demand of Nordlandsbua. It is surprising to learn of the considerable effect that body heat has on room heating.

In the other variations, the SIMIEN results concluded that it did not, and prioritizing the reduction of material usage and use of 100m of wood-fibre insulation was the right choice. This comparison also revealed that a new stove with increased efficiency did not change the monthly energy demand. It can be estimated that this is due to the small size of the room. A difference would have been noted if these stoves were compared using a larger heating area.

Since the increase in occupants and in turn, body heat, was the primary reducer of energy demand, an additional variation with 3 occupants will later be tested.

	VARIATION 2 (OCCUPANCY W/ 4-PEOPLE)		
MONTH	ENERGY DEMAND (KWH)	OCCUPANCY DAYS	ENERGY DEMAND PER DAY (KWH)
APRIL	9,5	10	0,95
MAY	4	4	1,04
JUNE	0	9	0,00
JULY	0	15	0,00
AUGUST	0	10	0,00
SEPTEMBER	2,5	5	0,54
TOTAL	16	52	

TABLE 7: Energy demand for Variation 2, with 4 occupants

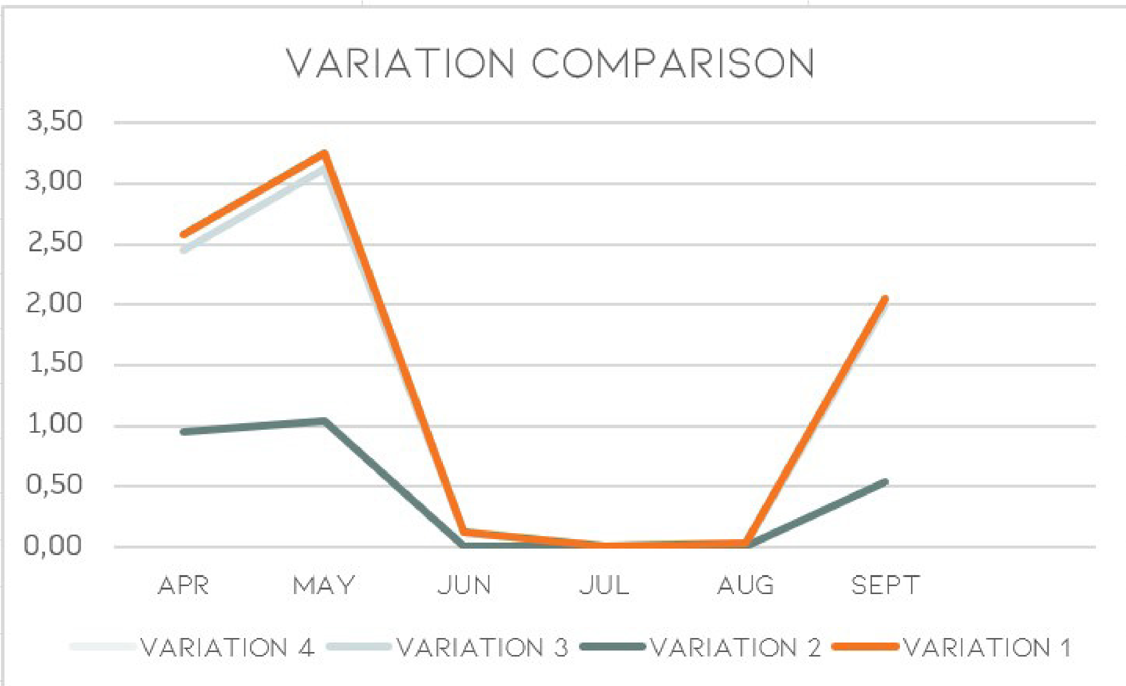

FIGURE 18: Comparison of monthly energy demand of each scenario

WOOD CONSUMPTION

As a result of the findings in the previous chapter, the calculation of monthly firewood needs will only be performed for Variations 1 and 2. The aim of this calculation is to determine an approximation of how much firewood would be needed to heat Nordlandsbua, based on either variation, in each peak-tourist month (April - September).

ENERGY CONTENT OF FIREWOOD

Each species of tree used for firewood holds a different energy capacity. In Norway, the most popular and available type of firewood comes from Birch (Ildstedet, 2018). A 40L bag of Birch (around 13kg) holds around 64,54 kWh of energy at a humidity level of 20% (Byggmax). Based on this information, we can decipher the following:

BIRCH FIREWOOD FROM BYGG MAX		
BAG	40	L
WEIGHT	13	kg
MOISTURE CONTENT	20	%
ENERGY IN ONE BAG	64,54	kWh
ENERGY PER KG	4,96	kWh/kg

TABLE 8: Birch firewood information

ANNUAL FIREWOOD NEED

Using the estimated monthly energy demand and the energy per kilogram as determined in Table 8, we can find the estimated annual firewood for each Variation.

Based on the occupational days determined in the 'Cabin Occupancy' chapter, if the cabin would only receive two guests at a time, then the projected annual firewood need, between April and September, would be 210,83 kg, or fourteen 40L bags. On the other hand, if the cabin would consistently have four visitors at the time, the projected firewood needed during the peak months would be 68,84kg or five 40L bags. This stark difference results in the cabin not needing any heating during June, July and August, with four guests, while only in July with two guests.

To add another comparison, the same calculation was done with three guests (Appendix F), which resulted in an annual firewood need of 129kg per year, or nine 40L bags.

FIREWOOD NEED PER DAY

Since the per-month visitor numbers are up for debate, one last calculation was done of the energy need per day for Variations 1 and 2. The same data of monthly firewood need was divided by the operational days.

This may be the most relevant calculation, as the amount of firewood needed per day of each month could be used with different monthly operational days, should more accurate data become available.

VARIATION 1			
MONTH	E. DEMAND PER MONTH (KWH)	FIREWOOD NEED PER MONTH (KG)	
APRIL	25,75	110,79	
MAY	12,50	53,78	
JUNE	1,00	4,30	
JULY	0,00	0,00	
AUGUST	0,25	1,08	
SEPTEMBER	9,50	40,88	# OF 40L BAGS
TOTAL		210,83	14

TABLE 9: Estimated annual firewood need for Variation 1

VARIATION 2			
MONTH	E. DEMAND PER MONTH (KWH)	FIREWOOD NEED PER MONTH (KG)	
APRIL	9,50	40,88	
MAY	4,00	17,21	
JUNE	0,00	0,00	
JULY	0,00	0,00	
AUGUST	0,00	0,00	
SEPTEMBER	2,50	10,76	# OF 40L BAGS
TOTAL		68,84	5

TABLE 10: Estimated annual firewood need for Variation 2

VARIATION 1		
MONTH	E. DEMAND PER DAY (KWH)	FIREWOOD NEED PER DAY (KG)
APRIL	2,58	11,08
MAY	3,25	13,99
JUNE	0,12	0,50
JULY	0,00	0,00
AUGUST	0,03	0,11
SEPTEMBER	2,05	8,82

TABLE 11: Estimated daily firewood need, per month; Variation 1, with 2 guests

VARIATION 2		
MONTH	E. DEMAND PER DAY (KWH)	FIREWOOD NEED PER DAY (KG)
APRIL	0,95	4,09
MAY	1,04	4,48
JUNE	0,00	0,00
JULY	0,00	0,00
AUGUST	0,00	0,00
SEPTEMBER	0,54	2,32

TABLE 12: Estimated daily firewood need, per month; Variation 2, with 4 guests

EXTRA VARIATION; 3-GUESTS		
MONTH	E. DEMAND PER DAY (KWH)	FIREWOOD NEED PER DAY (KG)
APRIL	1,60	6,88
MAY	2,08	8,95
JUNE	0,00	0,00
JULY	0,00	0,00
AUGUST	0,00	0,00
SEPTEMBER	1,29	5,57

TABLE 13: Estimated daily firewood need, per month; Variation 5, with 3 guests

The calculations in Tables 11, 12 or 13 could be used to calculate the amount of firewood needed for one night, based on the month and the number of guests staying.

CONCLUSION

A roaring fire in a cabin brings about feelings of warmth and cosiness. Since wood-burning stoves use a natural bio-fuel, few consider the consequences of using so much wood, not in the same way as fossil fuels. The transportation of firewood to remote locations also does not receive much thought, as it is always just conveniently there on the site when travelers arrive at a cabin. However, the burning and transportation of wood, as well as the general emissions of cabins have become a concern for DNT. Thus, this thesis aimed to find an estimate of how much firewood is needed at Nordlandsbua in an attempt to reduce the amount of needlessly consumed firewood and the frequency of firewood delivery to the site.

The process in which this calculation was done applied various methods to find the data needed for the final energy calculation in SIMIEN, from stove research to climate analysis, U-value calculations, and adjustment of statistics. Although this thesis yielded results, it should be mentioned that these results are merely an approximation. Numerous factors hindered a more precise result.

LACK OF VISITOR DATA

Since the managers of Tjoarvihytta could not collect precise visitor data, it was difficult to determine when the majority of energy usage would occur. Temperatures and in turn, heating needs vary so much from month to month (or even week to week); it would have been beneficial to have even a ball-park range of how many guests visit Tjoarvihytta per month rather than per year. This lack of visitor data certainly created the most uncertainty in the yearly firewood need results.

LIMITATIONS OF SIMIEN

As described in the 'Heating Demand' chapter, SIMIEN also contrived many obstacles in the way of receiving an accurate simulation. Firstly, the program does not allow the upload of location-specific climate data. In terms of occupancy, the program does not account for variations, as it always assumes the number of visitors is the same. This is the reason that the results were split into categories of guest quantity. Similarly, SIMIEN also cannot account for switching the heat source on and off more than once a day. For example, in a cabin, visitors usually stop adding more firewood at some point in the evening because they have gone to sleep and start re-heating in the morning if they wish to use the stove for cooking. Therefore, consistent heat usage through the night was included in the energy demand.

Lastly, this 'quirk' that SIMIEN has about sub-zero indoor temperatures was a drawback in this research. The area around Tjoarvihytta includes many excellent cross-country skiing trails, and there are most likely winter guests. Due to this setting in SIMIEN, the guests of half the year had to be omitted from the results.

OLD TECHNOLOGY VS NEW TECHNOLOGY

Burning wood as a heat source has been common practice throughout many centuries and civilizations. Despite the increase in the sophistication of energy simulation programs, the ability to accurately simulate a wood-burning stove operated by humans has not evolved as drastically. However, the simulation has tried to depict the energy output of the cabin to the best of its abilities. It must nevertheless be acknowledged that the simulation will not fully replicate reality.

HUMAN ERROR

On the same topic of human nuance, it is also essential to keep in mind that simulation programs cannot simulate the intricacies of human activity. There is no way to measure when, how many times, and how often the windows or doors are opened. The frequency of new logs placed in the stove, how late a hiking group goes to sleep or wakes up, or a multitude of other behaviours will not be accounted for

Although the heat from bodies can be measured, the quantity of humidity they produce was also left out of this research.

Due to Nordlandsbua’s size, many of these factors will affect the cabin’s function and heating needs but can not be considered quantitatively.

LEARNING OUTCOMES

Finding the yearly, monthly, and daily firewood need brought about much insight into the nuances of heating such a small space. The factors that I expected would make a significant difference in energy demand turned out to be inconsequential and visa-versa.

This research also brought awareness to the limitations of using simulation programs and a new appreciation for calculating things the old-fashioned way, by hand.

Much patience and perseverance were needed to continue with the research, despite the lack of necessary data. Nevertheless, finding a reasonable result, which will translate to real-life solutions, was gratifying.

FINAL RESULTS

The final results of this thesis will be used as a starting point in determining Nordlandsruta’s actual firewood needs. Furthermore, due to the cabin’s presence as a prototype, the validity of this research’s results will be tested in real-life. Aside from this, the concluding quantity of firewood was also implemented on a design level to the firewood storage facility designed in Julie Nyland Nilsen’s sub-thesis ‘Climate Research and Outer Shell Design’.

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FIGURE 7:
CB-1008 Cub Cubic Mini Wood Stove. Cubic Mini Wood Stoves. (n.d.). Retrieved from https://cubicminiwoodstoves.com/collections/cub-cb-108/products/cb-1008-br-cubic-mini-wood-stove

FIGURE 8:
Jøtul F 602 ECO. Jøtul. https://www.jotul.no/produkter/vedovner/jotul-f-602-eco

FIGURE 13:

Årsoversikt for Coarvihytta. Storm.no. https://www.storm.no/134168774.

FIGURE 14:

Skaugen, T. E., & Tveito, O. E. (2002). *The changes of the length of the heating season between the scenario period (2021-2050) and the normal period (1961-1990) in actual days.* Norwegian Meteorological Institute.

FIGURE 15:

Optimal operative temperature as a function of clothing and activity level. NS-EN ISO 7730:2005. Issue 3 (2006-03-01).

APPENDICES

APPENDIX A: U-VALUE CALCULATION PRIOR TO CONSTRUCTION

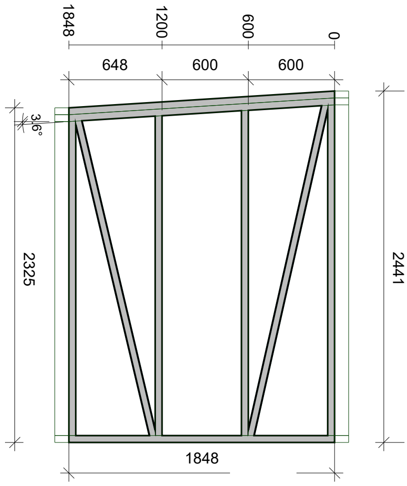
WALL (PRE-CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A (88%)	SECTION B (12%)	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,098	0,038	2,579		2,049
	TIMBER STUD (48X98MM)	0,098	0,12		0,817	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	INTERIOR SPRUCE CLADDING	0,015	0,013	1,154	1,154	1,154
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,13
			SUM	4,385	2,622	3,854
			UPPER LIMIT	3,763		
			AVERAGE R-VALUE	3,809		
			U-VALUE (W/M^2K)	0,263		

ROOF (PRE -CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A (92%)	SECTION B (8%)	
	EXTERNAL SURFACE RESISTANCE			0,04	0,04	0,04
1	UNIFLEX BITUMEN-FELT ROOF	0,003	0,17	0,018	0,018	0,018
2	HUNTON UNTERTAK	0,018	0,05	0,360	0,360	0,360
3	STATIC AIR (22,3%)	0,048	0,3	0,160		0,419
	HUNTON INTELLO PLUS (0,9%)	0,002	0,17	0,012		
	ROOF JOISTS (48X198) (8%)	0,198	0,12		1,650	
	HUNTON WOODFIBER INSULATION (68,9%)	0,148	0,038	3,895		
4	HUNTON INTELLO PLUS	0,002	0,17		0,012	0,058
5	ASPEN CLADDING	0,015	0,17	0,088		
7	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	4,702	2,209	1,025
			UPPER LIMIT	4,313		
			AVERAGE R-VALUE	2,669		
			U-VALUE (W/M^2K)	0,375		

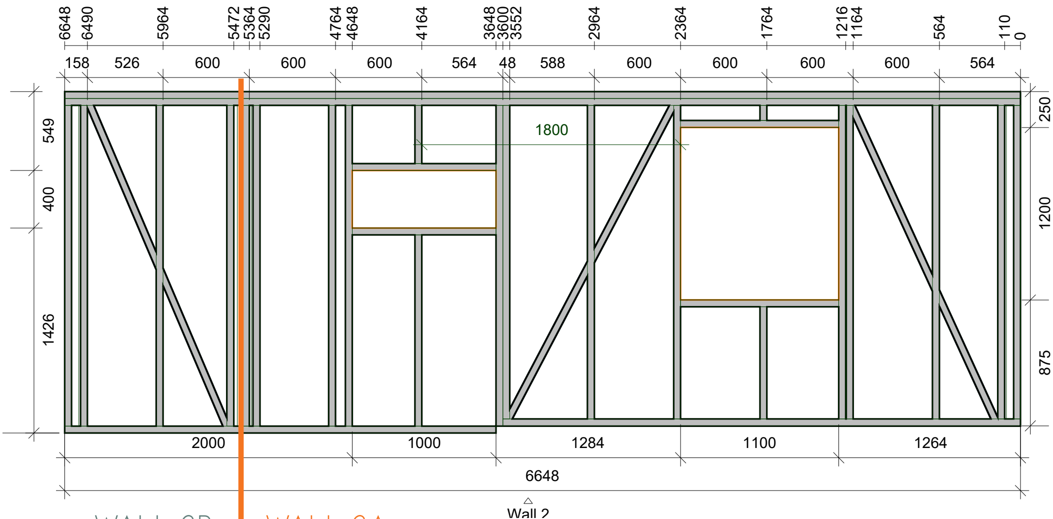
UPPER FLOOR (PRE CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A (92%)	SECTION B (8%)	
	EXTERNAL SURFACE RESISTANCE			0,04	0,04	0,04
1	OSB	0,012	0,13	0,092	0,092	0,092
2	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
3	HUNTON WOODFIBER INSULATION	0,148	0,038	3,895		3,321
	FLOOR BEAMS (48X148)	0,148	0,12		1,233	
4	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
5	HUNTON SILENCIO PARKETTUNDERLAG	0,012	0,05	0,24	0,24	0,24
6	OAK FLOORING	0,014	0,17	0,082	0,082	0,082
	INTERNAL TRANSITION RESISTANCE			0,13	0,13	0,13
			SUM	4,503	1,842	3,930
			UPPER LIMIT	4,036		
			AVERAGE R-VALUE	3,983		
			U-VALUE (W/M^2K)	0,251		

APPENDIX B: CALCULATION OF STUD PERCENTAGE IN WALL INSULATION LAYER

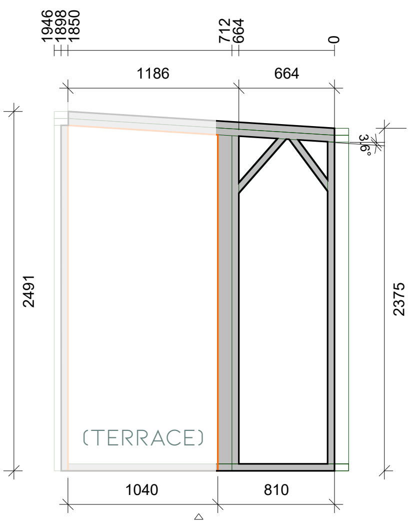
TIMBER STRUCTURE OF EACH WALL



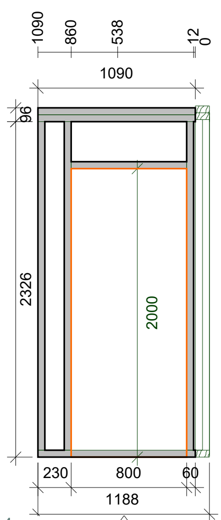
WALL 1



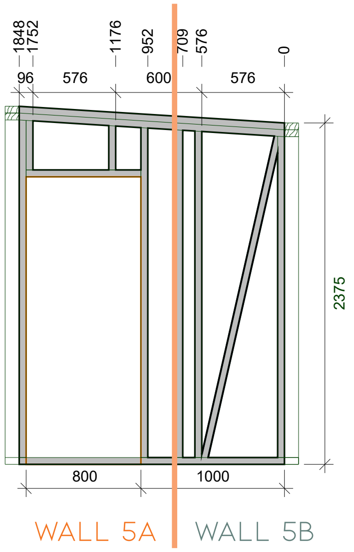
WALL 2B | WALL 2A

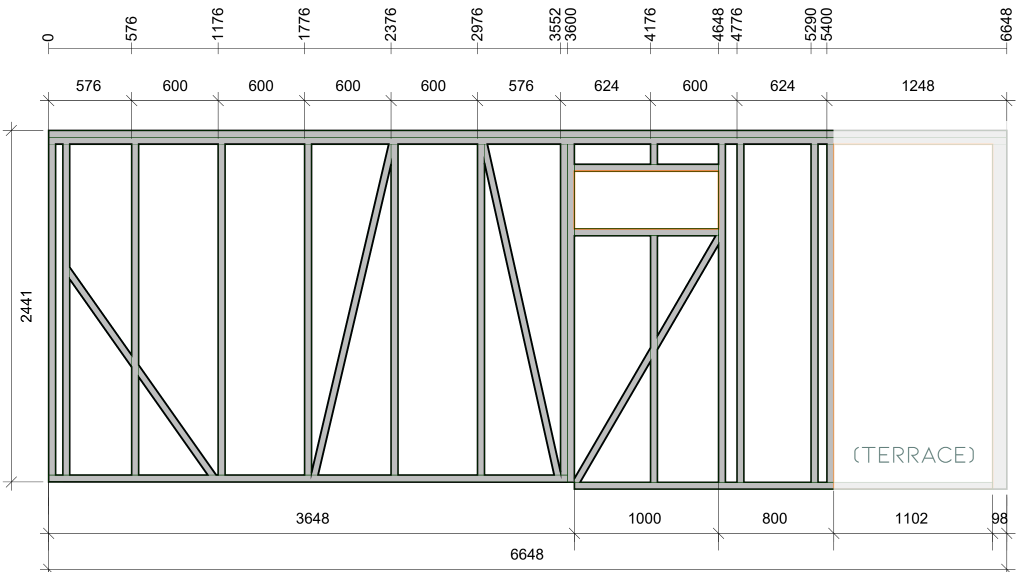


WALL 3



WALL 4





WALL 6

COMPARISON OF TIMBER AREA TO TOTAL WALL AREA

STUD TO INSULATION RATIO								
(FROM AUTOCAD)	WALL 1	WALL 2A	WALL 2B	WALL 3	WALL 4	WALL 5A	WALL 5B	WALL 6
TOTAL WALL AREA	4487726,582	12773197,28	2939093,263	1947786,447	2643268,449	1122905,724	1832986,558	13423675,786
STUD AREA	961785,614	2786761,555	745335,3202	615536,7843	567223,6612	464272,092	564259,9998	2829309,654
PERCENTAGE OF STUD IN WALL	21,43%	21,82%	25,36%	31,60%	21,46%	41,35%	30,78%	21,08%
PERCENTAGE OF INSULATION IN WALL	78,57%	78,18%	74,64%	68,40%	78,54%	58,65%	69,22%	78,92%

APPENDIX C. U-VALUE CALCULATION OF TRUE CONSTRUCTION (100MM INSULATION)

WALL 1 (TRUE CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,098	0,038	2,579		1,764
	TIMBER STUD (48X98MM)	0,098	0,12		0,817	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	INTERIOR SPRUCE CLADDING	0,015	0,013	1,154	1,154	1,154
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	4,385	2,622	3,569
			UPPER LIMIT	3,833		
			AVERAGE R-VALUE	3,701		
			U-VALUE (W/M^2K)	0,270		

WALL 2A (TRUE CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,098	0,038	2,579		1,754
	TIMBER STUD (48X98MM)	0,098	0,12		0,817	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	INTERIOR SPRUCE CLADDING	0,015	0,013	1,154	1,154	1,154
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	4,385	2,622	3,559
			UPPER LIMIT	3,824		
			AVERAGE R-VALUE	3,692		
			U-VALUE (W/M^2K)	0,271		

WALL 2B (TRUE CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,098	0,038	2,579		1,667
	TIMBER STUD (48X98MM)	0,098	0,12		0,817	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	PLYWOOD	0,012	0,013	0,923	0,923	0,923
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	4,154	2,392	3,242
			UPPER LIMIT	3,500		
			AVERAGE R-VALUE	3,371		
			U-VALUE (W/M^2K)	0,297		

WALL 3 (TRUE CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,098	0,038	2,579		1,534
	TIMBER STUD (48X98MM)	0,098	0,12		0,817	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	PLYWOOD	0,012	0,013	0,923	0,923	0,923
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	4,154	2,392	3,109
			UPPER LIMIT	3,369		
			AVERAGE R-VALUE	3,239		
			U-VALUE (W/M^2K)	0,309		

WALL 4 (TRUE CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,098	0,038	2,579		1,763
	TIMBER STUD (48X98MM)	0,098	0,12		0,817	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	PLYWOOD	0,012	0,013	0,923	0,923	0,923
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	4,154	2,392	3,338
			UPPER LIMIT	3,502		
			AVERAGE R-VALUE	3,420		
			U-VALUE (W/M^2K)	0,292		

WALL 5A (TRUE CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M²·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,098	0,038	2,579		1,363
	TIMBER STUD (48X98MM)	0,098	0,12		0,817	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	INTERIOR SPRUCE CLADDING	0,015	0,013	1,154	1,154	1,154
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	4,385	2,622	3,169
			UPPER LIMIT	3,431		
			AVERAGE R-VALUE	3,300		
			U-VALUE (W/M²K)	0,303		

WALL 5B (TRUE CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M²·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	* TRANSITION RESISTANCE			0,389	0,389	0,389
1	PLYWOOD	0,012	0,013	0,923	0,923	0,923
2	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
3	WOODFIBER INSULATION	0,098	0,038	2,579		1,550
	TIMBER STUD (48X98MM)	0,098	0,12		0,817	
4	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
5	INTERIOR SPRUCE CLADDING	0,015	0,013	1,154	1,154	1,154
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	5,567	3,805	4,538
			UPPER LIMIT	4,872		
			AVERAGE R-VALUE	4,705		
			U-VALUE (W/M²K)	0,213		

An additional calculation had to be done to find the transitional resistance of the drying room side of Wall 5B (between the heated room and the unheated drying room), since there is no constant

* TRANSITIONAL RESISTANCE TO UNCONDITIONED SPACE (WALL 5B)				
AREA OF THE INTERNAL WALL ADJOINING THE UNCONDITIONED SPACE (M2)	Ai (wall 5B)	1,833		
AREA OF THE UNCONDITIONED SPACE WALLS, ROOF, AND SUSPENDED FLOOR (M2)	Ae (wall 2B)	2,94	(Ae · Ue) wall 2B	0,8722
	Ae (wall 3)	1,94	(Ae · Ue) wall 3	0,599
	Ae (wall 4)	2,64	(Ae · Ue) wall 4	0,772
	Ae (floor)	0,698	(Ae · Ue) floor	0,26
	Ae (roof)	0,833	(Ae · Ue) roof	0,6544
U-VALUES OF THESE SURFACES (W/M2K)	Ue (wall 2B)	0,297	Σ	3,1576
	Ue (wall 3)	0,309		
	Ue (wall 4)	0,292		
	** Ue (floor)	0,373		
	Ue (roof)	0,786		
VOLUME OF UNCONDITIONED SPACE (M3)	V	1,565		
AIR CHANGE RATE	n	3		
$R_u = \frac{A_i}{\sum(A_e \times U_e) + 0.33 \times n \times V}$	Ru =	0,389		

** "ISO 6946 suggests n=3 ACH for unknown and this is definitely conservative unless you have intentional ventilation opening." (Quinn, 2021.)

In Norway, U-values to unheated room must also take into account, a reduction factor (0.93), so the final U-value of Wall 5B would equal 0,23 W/m²K.

WALL 6 (TRUE CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M²·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,098	0,038	2,579		1,773
	TIMBER STUD (48X98MM)	0,098	0,12		0,817	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	INTERIOR SPRUCE CLADDING	0,015	0,013	1,154	1,154	1,154
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	4,385	2,622	3,579
			UPPER LIMIT	3,841		
			AVERAGE R-VALUE	3,710		
			U-VALUE (W/M²K)	0,270		

APPENDIX D. U-VALUE CALCULATION OF CONSTRUCTION WITH 150MM INSULATION

EXTERNAL CONSTRUCTION WITH 150MM, DRYING ROOM CONSTRUCTION REMAINS 100MM

WALL 1 (TRUE CONSTRUCTION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,148	0,038	3,895		2,663
	TIMBER STUD (48X98MM)	0,148	0,12		1,233	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	INTERIOR SPRUCE CLADDING	0,015	0,013	1,154	1,154	1,154
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	5,700	3,039	4,469
			UPPER LIMIT	4,800		
			AVERAGE R-VALUE	4,634		
			U-VALUE (W/M^{2}K)	0,216		

WALL 2A (150MM INSULATION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,148	0,038	3,895		2,648
	TIMBER STUD (48X98MM)	0,148	0,12		1,233	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	INTERIOR SPRUCE CLADDING	0,015	0,013	1,154	1,154	1,154
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	5,700	3,039	4,454
			UPPER LIMIT	4,786		
			AVERAGE R-VALUE	4,620		
			U-VALUE (W/M^{2}K)	0,216		

WALL 5A (150MM INSULATION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,148	0,038	3,895		2,058
	TIMBER STUD (48X98MM)	0,148	0,12		1,233	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	INTERIOR SPRUCE CLADDING	0,015	0,013	1,154	1,154	1,154
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	5,700	3,039	3,864
			UPPER LIMIT	4,185		
			AVERAGE R-VALUE	4,024		
			U-VALUE (W/M^{2}K)	0,248		

WALL 5B (150MM INSULATION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	TRANSITION RESISTANCE**			0,000	0,000	0,000
1	PLYWOOD	0,012	0,013	0,923	0,923	0,923
2	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
3	WOODFIBER INSULATION	0,148	0,038	3,895		2,340
	TIMBER STUD (48X98MM)	0,148	0,12		1,233	
4	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
5	INTERIOR SPRUCE CLADDING	0,015	0,013	1,154	1,154	1,154
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	6,493	3,832	4,939
			UPPER LIMIT	5,350		
			AVERAGE R-VALUE	5,144		
			U-VALUE (W/M^{2}K)	0,194	(W/REDUCTION FACTOR)	0,21

WALL 6 (150MM INSULATION)						
LAYER	MATERIAL	THICKNESS (M)	THERMAL CONDUCTIVITY (W/(M·K))	R-VALUE (M^2·K/W)		
				UPPER LIMIT		LOWER LIMIT
				SECTION A	SECTION B	
	(INTERNAL TRANSITION RESISTANCE)			0,130	0,130	0,130
1	HUNTON VINDETT PLUS	0,019	0,05	0,380	0,38	0,38
2	WOODFIBER INSULATION	0,148	0,038	3,895		2,677
	TIMBER STUD (48X98MM)	0,148	0,12		1,233	
3	HUNTON INTELLO PLUS	0,002	0,17	0,012	0,012	0,012
4	INTERIOR SPRUCE CLADDING	0,015	0,013	1,154	1,154	1,154
	INTERNAL TRANSITION RESISTANCE			0,130	0,130	0,130
			SUM	5,700	3,039	4,483
			UPPER LIMIT	4,812		
			AVERAGE R-VALUE	4,647		
			U-VALUE (W/M^{2}K)	0,215		

APPENDIX E: TJOARVIHYTTA VISITOR NUMBERS

SMS CORRESPONDENCE BETWEEN ANNELI KOLÅS AND EINER SCHILLIÅS (SULITJELMA OG OMEGN TURISTFORENING BOARD CHAIRMAN)

930 43 763

mandag 25. apr. • 12:26

Sender tekstmeldinger med 930 43 763 (SMS/MMS)

Hei, jeg var i kontakt med Lars på tjorvihytta angående tall på hvor mange som besøker hytten årlig og han henviste meg videre til deg. Jeg jobber med masterprosjekt i forbindelse med det. Vet du antall besøkende per år? Gjerne hver måned, hvis du har opplysning om det.
Med vennlig hilsen,
Anneli Kolås

mandag 2. mai • 21:56

Vi har ikke ført månedlig besøkstall for hyttene våre. 2 siste år har vi hatt lave besøkstall under pandemien Etter overgang til booking via Visbook for 2 år sida har systemet vært vanskelig å få ut slike rapporter. Ting bedrer seg, slik at vi framover kan hente mer info fra systemet. Har sett på tidligere års overnattingstall. Tallenr for Tjoarvihytta varierer fra 250 til 550, alt etter hvor mange skoleklasser som bruker hytta. Fjellfarer kjører hver vinter flotte spor fram til hytta, slik at mange tar turen dit i skisesongen . Vi holder også påskekafe hvert år i hytta med rundt 500 besøkende. Mange bruker også hytta som utgangspunkt for jakt og fisketurer øst for hytta og Balvatnet
Mvh Einar Schilliås Styreleder SOT.

16:43

Hei! Jeg glemte å svare deg på denne melding. Det var hyggelig å treffe på deg i Bodø. Når du sier at det varierer fra 250-500 gjester, mener du per måned?
Mvh Anneli

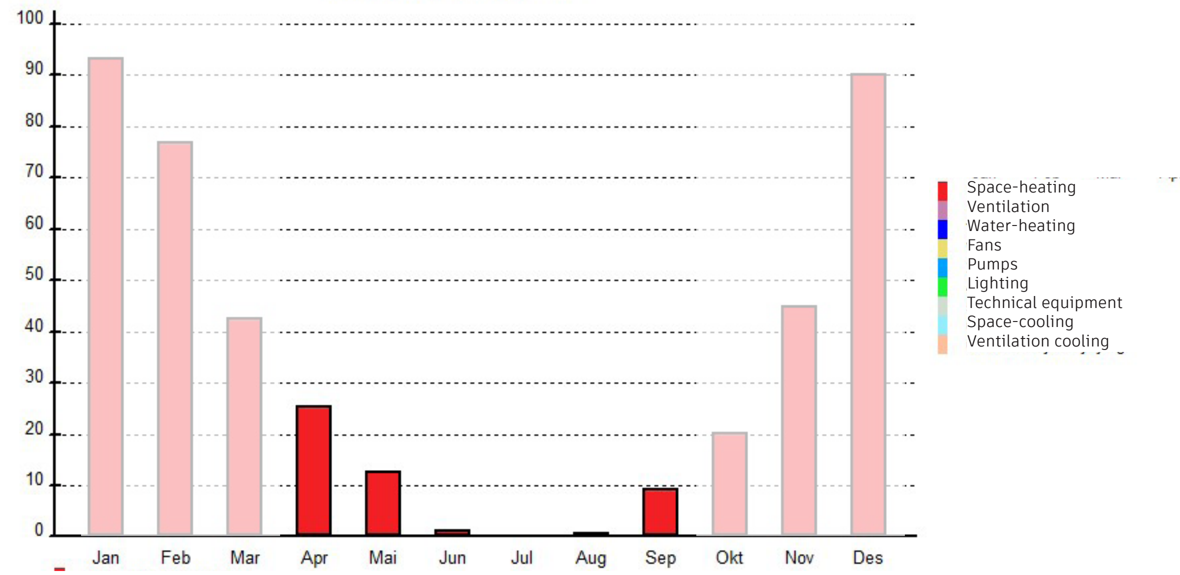
20:14

Pr.år

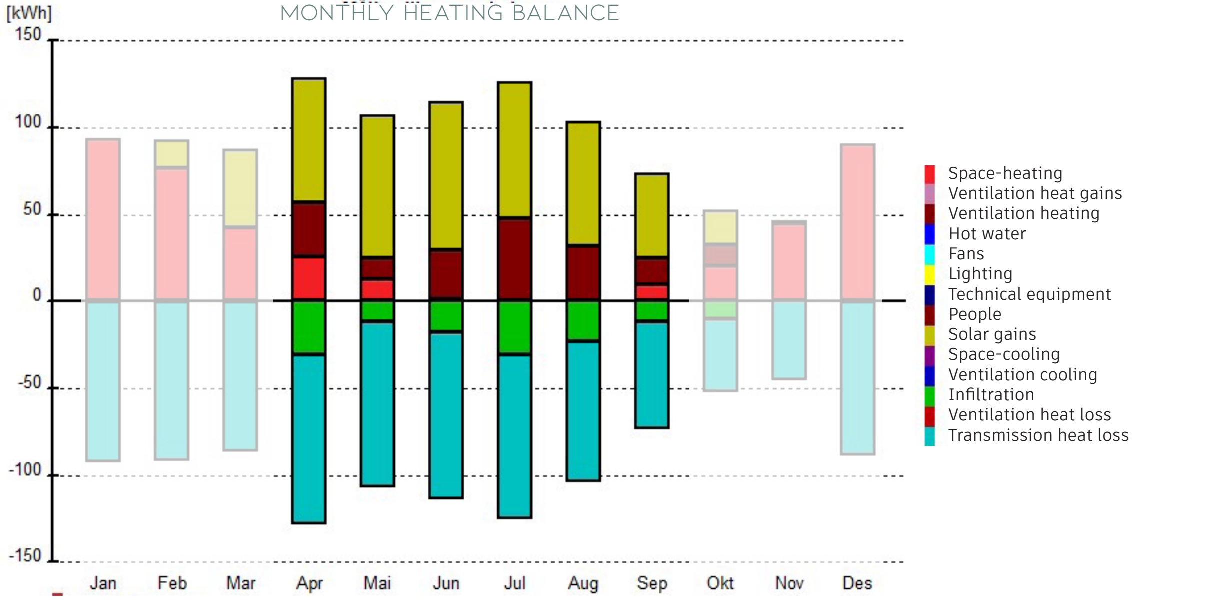
APPENDIX F: SIMIEN RESULTS

VARIATION 1:
TRUE CONSTRUCTION, 2-PERSON OCCUPANCY, TRUE STOVE (71% EFFICIENCY)

MONTHLY NET ENERGY DEMAND



MONTHLY HEATING BALANCE

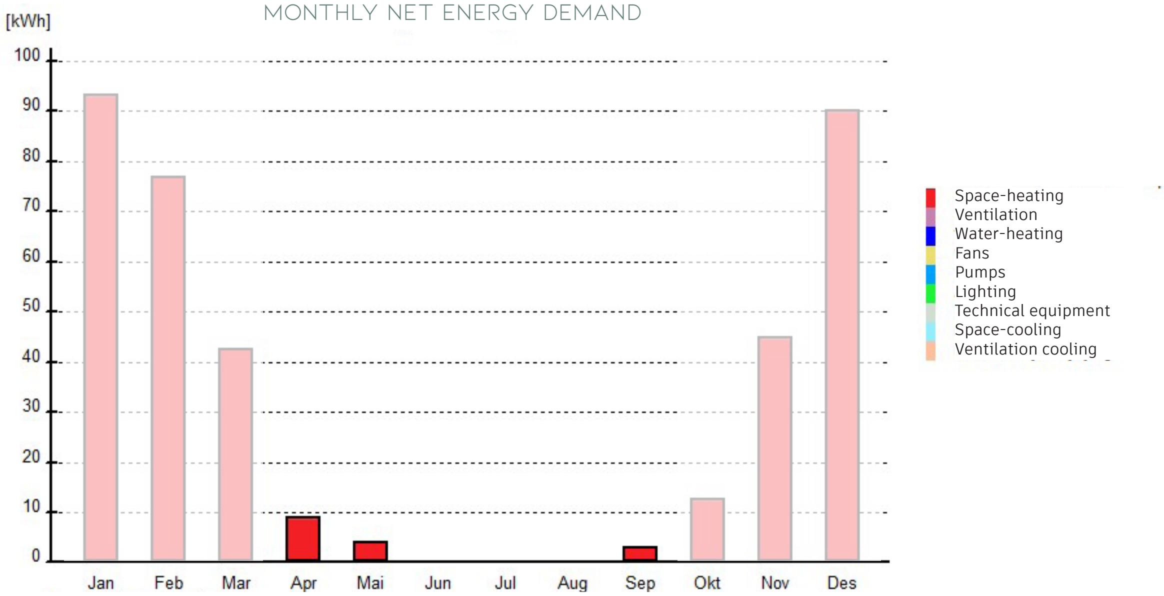


ENERGY DEMAND PER DAY, PER MONTH

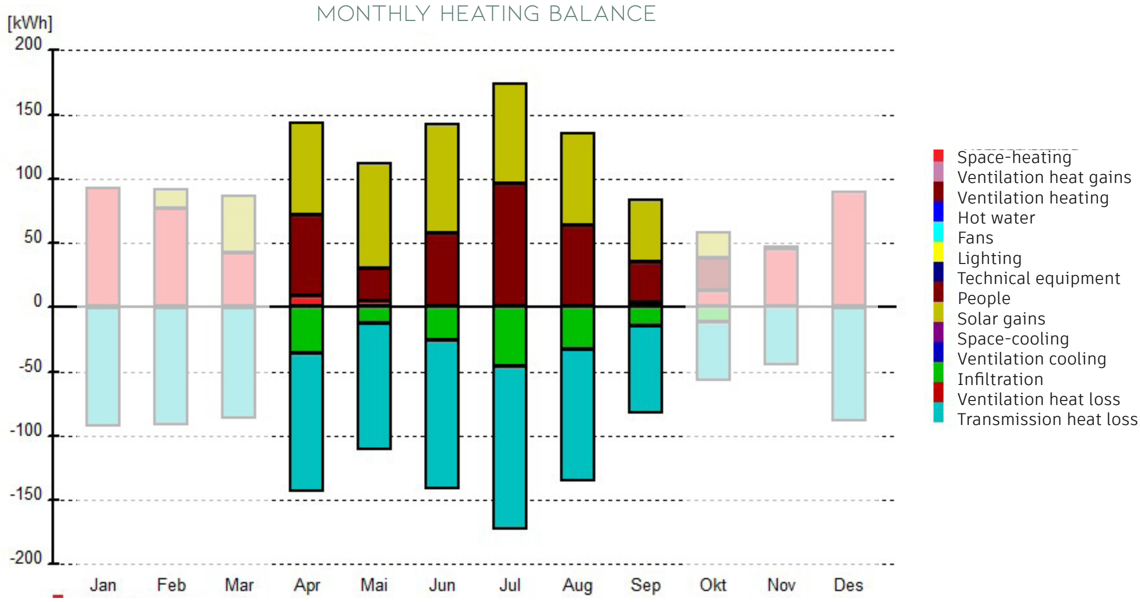
	VARIATION 1		
MONTH	ENERGY DEMAND (KWH)	OCCUPANCY DAYS	ENERGY DEMAND PER DAY (KWH)
APRIL	25,75	10	2,58
MAY	12,5	4	3,25
JUNE	1	9	0,12
JULY	0	15	0,00
AUGUST	0,25	10	0,03
SEPTEMBER	9,5	5	2,05
TOTAL	49	52	

VARIATION 2:
TRUE CONSTRUCTION, 4-PERSON OCCUPANCY, TRUE STOVE (71% EFFICIENCY)

MONTHLY NET ENERGY DEMAND



MONTHLY HEATING BALANCE

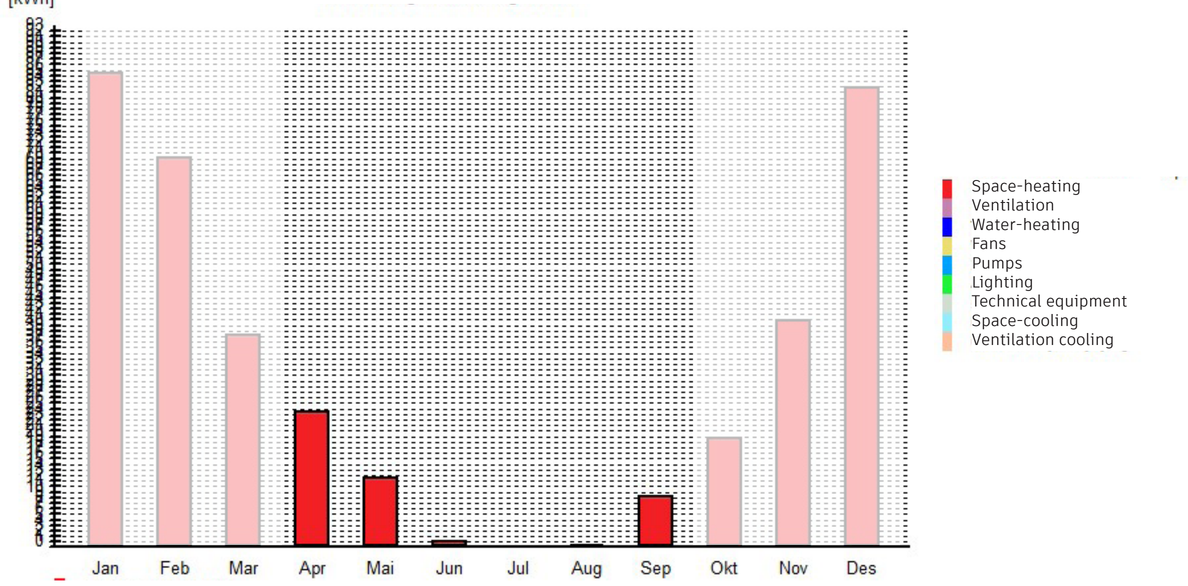


ENERGY DEMAND PER DAY, PER MONTH

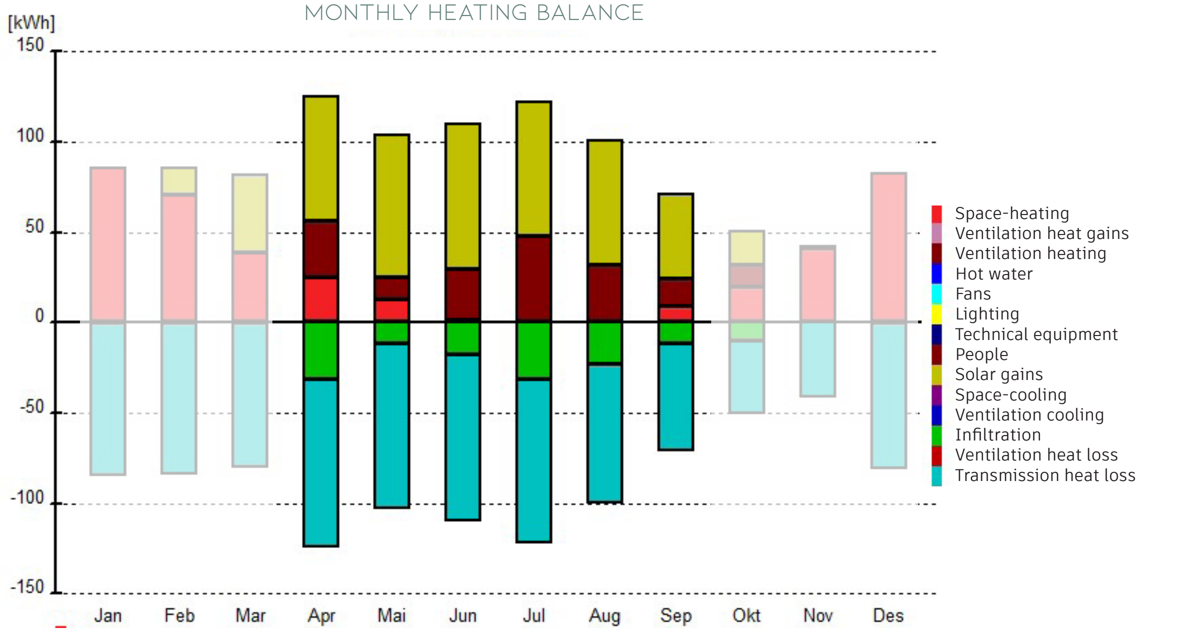
	VARIATION 2 (OCCUPANCY W/ 4-PEOPLE)		
MONTH	ENERGY DEMAND (KWH)	OCCUPANCY DAYS	ENERGY DEMAND PER DAY (KWH)
APRIL	9,5	10	0,95
MAY	4	4	1,04
JUNE	0	9	0,00
JULY	0	15	0,00
AUGUST	0	10	0,00
SEPTEMBER	2,5	5	0,54
TOTAL	16	52	

VARIATION 3:
150MM INSULATION, 2-PERSON OCCUPANCY, TRUE STOVE (71% EFFICIENCY)

MONTHLY NET ENERGY DEMAND



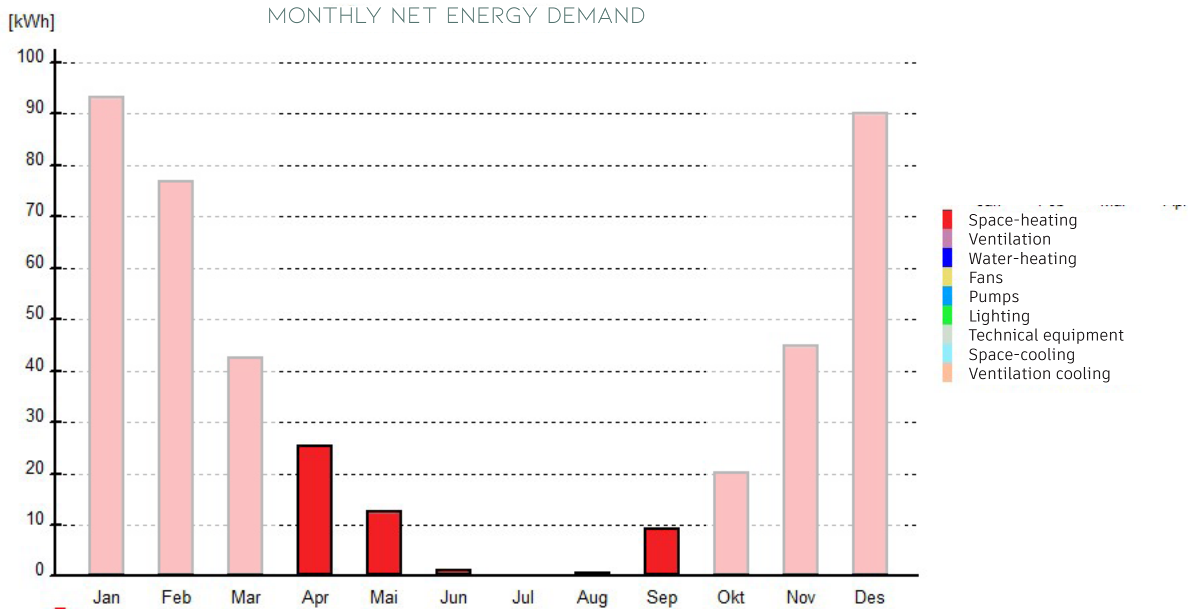
MONTHLY HEATING BALANCE

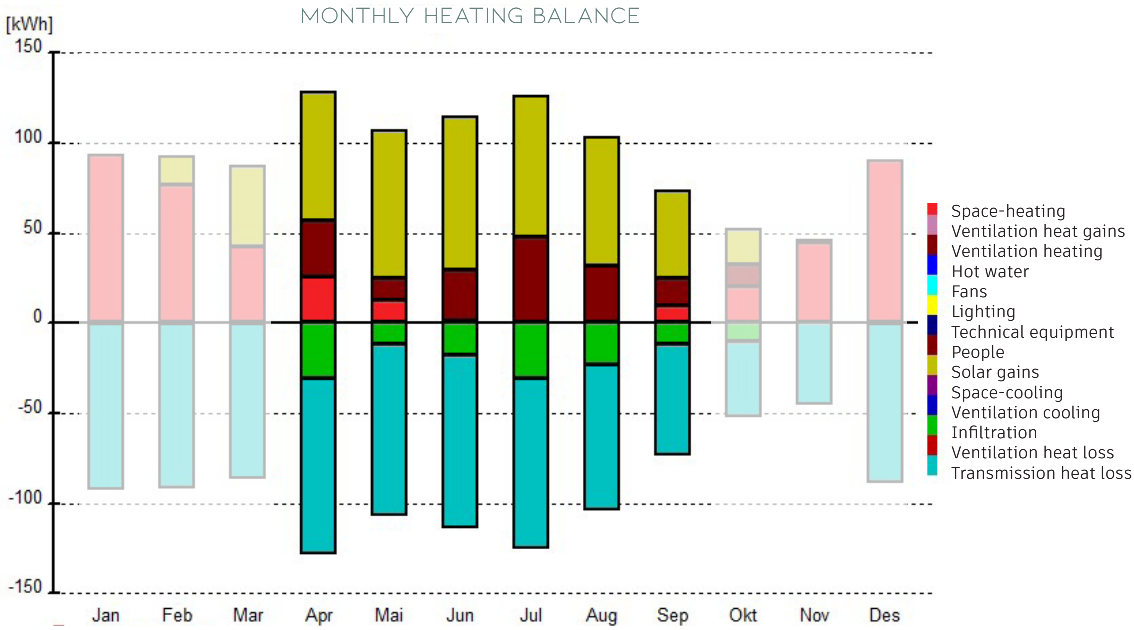


ENERGY DEMAND PER DAY, PER MONTH

	VARIATION 3 (150MM INSULATION)		
MONTH	ENERGY DEMAND (KWH)	OCCUPANCY DAYS	ENERGY DEMAND PER DAY (KWH)
APRIL	24,5	10	2,45
MAY	12	4	3,12
JUNE	1	9	0,12
JULY	0	15	0,00
AUGUST	0,15	10	0,02
SEPTEMBER	9,25	5	2,00
TOTAL	46,9	52	

VARIATION 4:
TRUE CONSTRUCTION, 2-PERSON OCCUPANCY, NEW STOVE (81% EFFICIENCY)

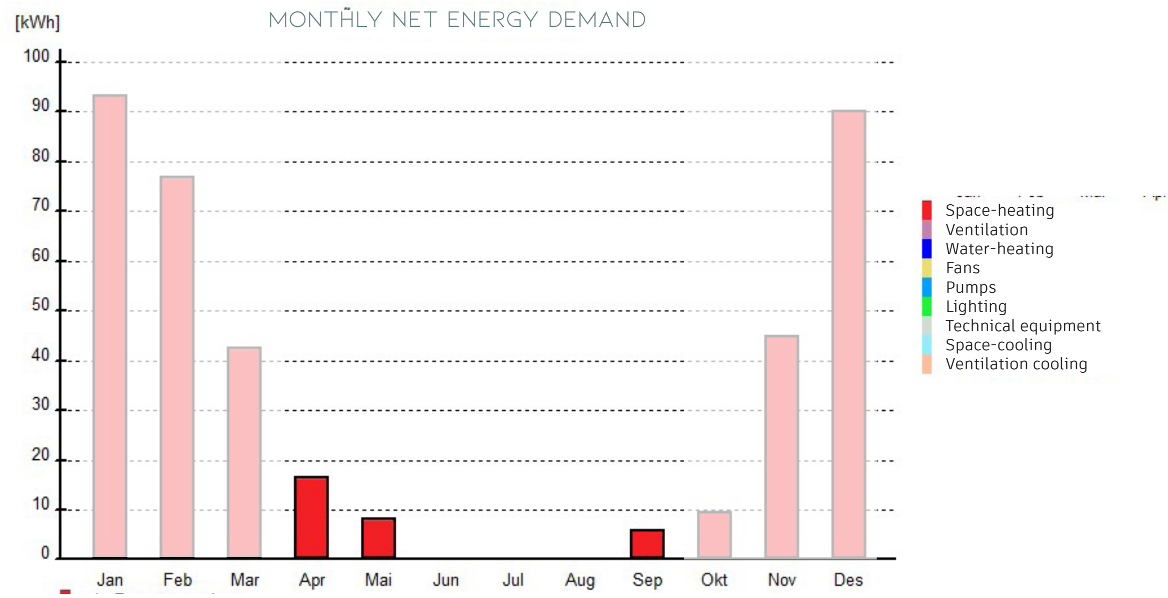




ENERGY DEMAND PER DAY, PER MONTH

	VARIATION 4 (NEW STOVE)		
MONTH	ENERGY DEMAND (KWH)	OCCUPANCY DAYS	ENERGY DEMAND PER DAY (KWH)
APRIL	25,75	10	2,58
MAY	12,5	4	3,25
JUNE	1	9	0,12
JULY	0	15	0,00
AUGUST	0,25	10	0,03
SEPTEMBER	9,5	5	2,05
TOTAL	49	52	

APPENDIX G: FIREWOOD CALCULATION WITH OCCUPANCY OF 3 GUESTS



ENERGY DEMAND PER DAY, PER MONTH

	VARIATION 5 (OCCUPANCY W/ 3 PEOPLE)		
MONTH	ENERGY DEMAND (KWH)	OCCUPANCY DAYS	ENERGY DEMAND PER DAY (KWH)
APRIL	16	10	1,60
MAY	8	4	2,08
JUNE	0	9	0,00
JULY	0	15	0,00
AUGUST	0	10	0,00
SEPTEMBER	6	5	1,29
TOTAL	49	52	

FIREWOOD CALCULATION

VARIATION 5			
MONTH	E. DEMAND PER MONTH (KWH)	FIREWOOD NEED PER MONTH (KG)	
APRIL	16,00	68,84	
MAY	8,00	34,42	
JUNE	0,00	0,00	
JULY	0,00	0,00	
AUGUST	0,00	0,00	
SEPTEMBER	6,00	25,82	# OF 40L BAGS
TOTAL		129,08	9