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Optimising tiny spaces: energy flow analysis for self-sufficient living

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AUTOR: López Urquiola, María del Mar

Tutores: Cloquell Ballester, Víctor Andrés; Grant, Richard John

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Optimising Tiny Spaces: Energy Flow Analysis for Self-Sufficient Living

MARÍA DEL MAR LÓPEZ URQUIOLA

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Optimising Tiny Spaces: Energy Flow Analysis for Self-Sufficient Living

María del Mar López Urquiola

Department of Mechanical Engineering and Maritime Studies

Western Norway University of Applied Sciences

NO-5063 Bergen, Norway

IMM 2024- M 05

Western Norway University of Applied Sciences (Høgskulen pay Vestlandet, HVL)

Faculty of Technology, Environmental and Social Sciences

Department of Mechanical Engineering and Maritime Studies

Indoleamine 28

NO-5063 Bergen, Norge

Author(s), student number:	María del Mar López Urquiola, 798872
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Supervisor at HHVL:	Richard John Grant, HVL
Assigned by:	HVL

Preface

This bachelor's thesis is submitted to the Department of Mechanical Engineering and Maritime Studies at the Western Norway University of Applied Sciences (WNUAS), as a part of an Erasmus program carried on in Bergen, Norway.

As a student in Polytechnic University of Valencia (UPV) in Spain, I joined the Erasmus program in the beginning of the Spring Semester, to complete my final semester of the Energy Engineering Degree to discover new perspectives of the energy development in other countries with that different climate and resources as Norway.

This report is conducted under the guidance of Dr. Richard John Grant from WNUAS and Dr. Víctor Andrés Cloquell Ballester from UPV. In this way, both institutions have been involved in the project, resulting in a synergistic collaboration aimed at fostering research and development in the field of energy engineering. During the process, both WNUAS and UPV provided substantial resources which greatly enhanced the research quality and execution.

Working away from home for the first time, in another country, in another language, and with a very different lifestyle has been a challenge. However, these potential difficulties have been what has enriched this experience so much, allowing me to learn and cope with situations I have never experienced before. Many discoveries, learnings, and many new doors for the projection of my professional life come home with me after this experience.

I would like to express my gratitude to all who have assisted me in this research. To my tutors and my teachers, whose technical advice and help in the experimental setup was crucial for carrying out the research. Also, I would like to thank all my friends and family back home who encouraged me to begin this journey and had supported me during the semester. And finally, all the friends and great professionals that I have met here, in Bergen, that who have made this experience a personal and professional growth and enrichment.

This bachelor's thesis and this experience will go home with me. However, from now on, part of myself will always stay in Norway.

Abstract

In the context where environmental awareness is increasing, this bachelor's thesis tackles the challenge of proposing an energy flow model for tiny living spaces allowing the self-sufficient living in terms of energy demand. The study analyses energy flows in a passive house model to develop an energy system that includes the simulation of different levels of residential occupancy, thus assessing the energy demands necessary for self-sufficiency. Using the SIMIEN energy modeling software, heat losses and gains in an existing construction adhering to passive house standards are analysed. Based on these characteristics, an energy flow model is developed that proposes integrated and sustainable energy solutions. The study aims at significantly optimizing resource use in tiny homes, contributing to a more sustainable and efficient lifestyle. The results demonstrate that significant improvements in energy self-sufficiency can be achieved through careful adjustments in design and the implementation of appropriate technologies.

This work not only enhances our understanding of energy-efficient building design but also illustrates the practical steps towards achieving minimal environmental impact in residential architecture.

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1. Introduction

1.1 Background

Nowadays, environmental awareness is increasing in society and ever more people are supporting sustainability as a lifestyle. Therefore, we are evolving into a society that prioritise enhancing efficiency and self-consumption; adopting a minimalist lifestyle and using renewable energy resources to power their evolving lifestyle requirements.
The prevalent approach to enhancing sustainability has consisted of integrating renewable energy systems such as photovoltaic panels, thermal systems, and smart technology systems in residences.

Nevertheless, there is a need to shift the perspective towards the sustainable path by optimising the process, not the result. By adopting this mindset, the energy efficiency achieved will be higher through the development of specific energy system tailored to the unique conditions of each building. Therefore, the current limitations on improving efficiency due to the existent structure will be avoided as well as the perceived benefits. Incorporating the energy system as a base of the architectural design of the houses will result into a significant improvement of the energy efficiency and a big step in the sustainability path.

Furthermore, minimalist living is gaining importance: minimal space, few items, just the essentials. This lifestyle has become popular the recent years as people seek to counteract the incentives of contemporary living, opting instead for simply life with few physical belongings, small houses and just the necessary. The concept and movement towards tiny house living becoming increasingly popular around the world.

Therefore, developing highly efficient energy systems for tiny houses is essential to promote energy independence, allowing individuals to sustainably manage their energy needs in their daily lives.

1.2 Concept introduction

The passive house is a concept that marks a radical shift in building design; it involves ultra-low energy buildings that require virtually no energy for space heating or cooling. Hailing from Germany as "Passivhaus," this design philosophy has spread like a firestorm, adapting to different climatic and cultural contexts. Passive houses achieve their energy efficiency through superinsulation, airtightness, high-performance windows, heat recovery ventilation, and maximizing solar gain, while minimizing thermal bridges and heat loss.

As concern for the environment and energy costs grows, passive houses have gained favour in extreme climates. The passive house standards ensure that these houses use 90% less heating and cooling energy and have 75% less total energy demand than other conventional houses. This has a lot of benefits, not only for the owners of the houses that will have their energy bills reduced, but also for the environment, since it reduce the energy demand of energy resources that generate carbon emissions.

The past few years have also seen the rise of tiny homes, which combine perfectly with passive house standards. These little living spaces bring the ecological footprint down further, with less space and resources in use, thereby proving that size does matter in terms of energy efficiency. Often, tiny houses have multi-functional furniture and innovative storage solutions to get the most use out of every inch.

The laws regarding passive houses and tiny houses are different from area to area. While the Passivhaus standard appears to be dominant in the European context regarding the design and construction of passive houses, in the United States, the Passive House Institute US has developed standards suitable for the various climates of America. These standards spell out in comprehensive detail the limits of energy use, airtightness, and thermal comfort so that the certified buildings maintain consistent indoor temperatures and air quality throughout the year. Moreover, in each country of Europe, there are several different types of standards.

Further, there are changes in building codes and regulations, which are gradually being adjusted to sustainability goals; they therefore encourage wider adoption of passive house principles. The integration of some aspects from the standards into the building codes is observed in some regions these are seen to realize that the long-term benefits from energy-efficient construction are a reality.

Passive houses and tiny houses reflect a general change in life. When the world is troubled by climate change, energy shortage, and urban density issues, the principles of the passive house concept offer a blueprint for further development. This ultra-efficient, compact living style not only addresses today's most pressing environmental challenges but also changes our understanding of comfort and style in the built environment.

In our case of study, the passive house called "SolarLab" is located in Norway. This will have an influence in the requirements applied for the passive house buildings due to the weather temperatures to reach the comfort temperatures for the occupancy living indoors. Therefore, the U-values are standardized as a recommendation defined by Standards Norge (SN) with NS3700 Passivhus [1]. These values can be compared with the U-values for a normal apartment building in Norway standardized by Norwegian Husbanken TEK17 [2] and with the standards of a Passive House in Spain [3] as an example of another type of climate to get a complete understanding of the references:

Table 1. U-values standards

U-values [W/(m2K)]			
Surface	NS3700 Passive house	TEK17 Standard building	CTE Passive House Spain
Exterior wall	0,10 – 0,12	≤ 0,18	0,56
Roof	0,08 – 0,09	≤ 0,13	0,44
Floor	0,08	≤ 0,10	0,56
Window and doors	≤ 0,8	≤ 0,8	2,3

Source: Own work adapted from NS3700, TEK17 and CTE

As mentioned, the climate zone considered at it will have an impact on the energy flows of the passive house. According to Passipedia [4], the map of the climate zones is the next one:

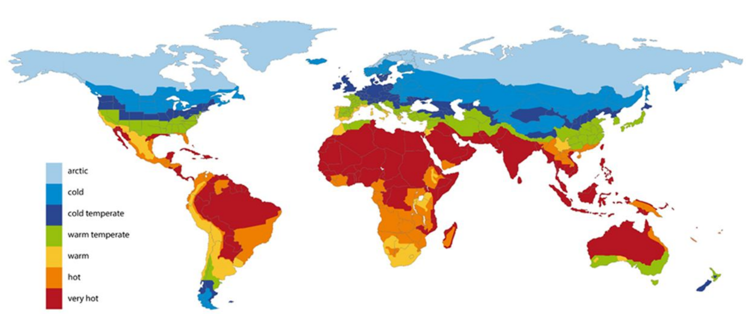


Figure 1. Climate Map (Passipedia)

In this context, Norway is located in the "cold" zone, therefore, it will have different standard of the U-values from the countries the others climate zones.

For a cold region, as mentioned above, the maximum heat transfer coefficient should be less than 0,12kWh/m2: [5]

Table 2. U-values climate zones

Table 1: Certification criteria

Climate zone	Hygiene criterion[8]	Comfort criterion	Efficiency criteria			Moisture criteria[6]	
	$f_{Rsi=0.25\,m^2K/W}$ ≥[3]	U-value of the installed window[1] ≤	U-value of the exterior building component $U_{opaque} * f_{R\,PHI}$[2] ≤	Purely opaque details $f_{Rsi=0.25\,m^2K/W}$ ≥[3]	Absence of thermal bridges Ψ_a ≤[4]	Condensation	Ma limit according to DIN EN ISO 13788 ≤
	[-]	[W/(m²K)]	[W/(m²K)]	[-]	[W/(mK)]	[-]	[g/m²]
1 Arctic	0.80	0.45 (0.35)	0.09	0.90	0.010[5]	Condensation should be completely evaporated at the end of 12 months	200[7]
2 Cold	0.75	0.65 (0.52)	0.12	0.88			
3 Cool, temperate	0.70	0.85 (0.70)	0.15	0.86			
4 Warm,temperate	0.65	1.05 (0.90)	0.25	0.82			
5 Warm	0.55	1.25 (1.10)	0.50	0.74			
6 Hot	None	1.25 (1.10)	0.50	0.74			
7 Very hot	None	1.05 (0.90)	0.25	0.82			

Source: Passipedia

Considering all these aspects, this project will be supported by different reports, articles and websites about passive houses, tiny living, and energy optimisation. [6, 7]

1.3 Aim

This project aims to study the energy flows in a tiny house to develop an energy model which includes the simulation of living occupancy with the view to assessing the energy demands for self- sufficiency.

1.4 Objectives

The aim of this project will be reached following different objectives. The goals proposed in this projects area:

1. Analyse the heat losses and gains of an existent (tiny) passive house standard building "SolarLab" using energy modelling software.
2. Develop a model of the energy flow based on the characteristics of the tiny passive house.
3. By extending the analysis of the current building, evaluate the energy consumption in a theoretical living environment within the tiny house.
4. Propose an integrated model with sustainable energy solutions for optimising year- round self-sufficiency in the tiny house.

1.5 Methodology: SIMIEN software

To complete the objectives of the project, the software of SIMIEN will be used. This software calculates the energy flow in any type of building in Norway using the building regulation and the different standards according to the requirements of the building.

2. Energy flow analysis SolarLab: SIMIEN

This chapter will detail an analysis of the current SolarLab to understand the model defined in the software SIMIEN.

The SolarLab is passive house designed approximately ten years ago by Anne Sofie Bjelland and it was translated and converted into the actual SolarLab five years ago. During this period, many students have taken part in the research of improving this building and converting it into a model of energy self-sufficiency.

2.1. Location and surroundings

The SolarLab is located in the Western Norway University of Applied Sciences, in Bergen, Norway with address and location:

Location: University Høgskulen på Vestlandet (HVL), 5063 Bergen, Vestland, Norway, coordinates UTM 60.36779117801946, 5.350764245947548º

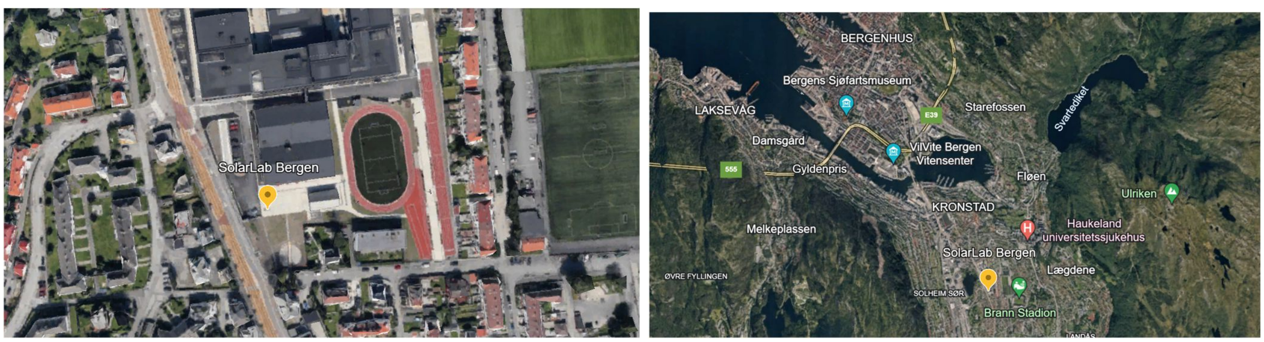


Figure 1. Orthoimage map of the location (from google maps, no scale represented)

The building is surrounded by different objects and other buildings:

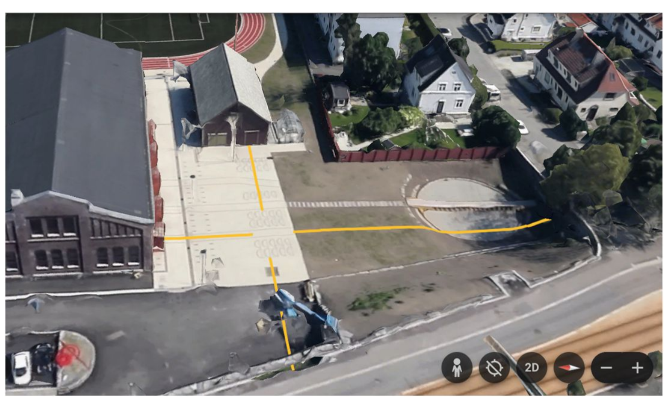


Figure 2. View of the SolarLab (from google maps).

Moreover, Bergen is surrounded by seven mountains. This particular situation has a big influence in the shadows projected in Bergen. In this case, the main mountains that affects the location of the SolarLab are Ulriken (643m above sea level) and Løvstakken (479m above sea level):

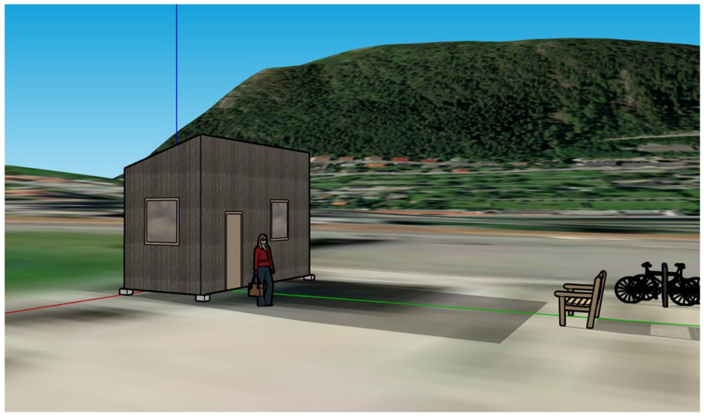


Figure 3. SolarLab with the view of Løvstakken (SketchUP).

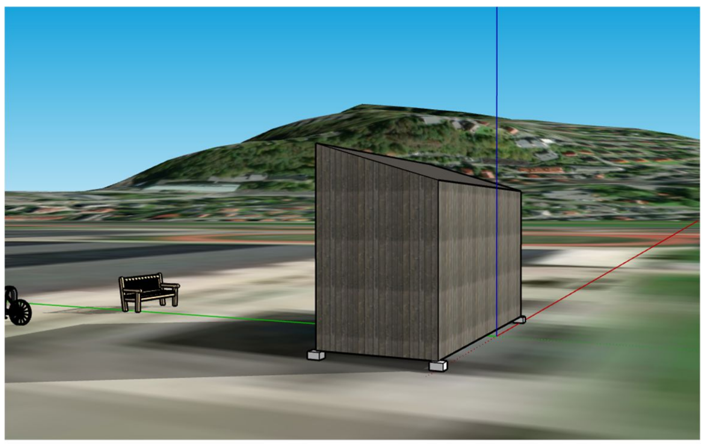


Figure 4. SolarLab with the view of Ulriken (SketchUP).

In Attachment 1 is shown a plane of the different building that may have an influence on the SolarLab.

2.2. Size and geometry

All the measurements of the building have been recorded manually; therefore, they can contain inaccuracies. However, 3 different sweeps of measurements collection have been done to obtain the error of the measurement process and, in case of a big percentage of error, it has been modelled in SIMIEN (Table 1).

Table 1. Size chart Solar Lab.

SIZE CHART SOLAR LAB			
External measurement			
Surface	**Height (m)**	**Wide (m)**	**Area (m^2)**
North Wall	4,000 ± 0,197	6,207 ± 0,149	24,828
South Wall	3,310 ± 0,150	6,207	20,545

East Wall	-	2,655 ± 0,003	9,704
West Wall	-	2,655	9,704
Surface	**Height (m)**	**Base (m)**	**Area (m^2)**
Ground	6,207	2,655	16,480
Roof	6,207	2,743	17,027
Internal Measurement			
Surface	**Height (m)**	**Wide (m)**	**Area (m^2)**
North Wall	2,710 ± 0,09	5,62 ± 0,012	15,230
South Wall	2,210 ± 0,07	5,62	12,420
East Wall	-	1,99 ± 0,003	4,588
West Wall	-	1,99	4,588
Surface	**Height (m)**	**Base (m)**	**Area (m^2)**
Ground	5,620	1,990	11,184
Roof	5,620	2,052	11,531
Others surfaces			
Surface	**Height (m)**	**Wide (m)**	**Area (m2)**
Window's gap	1,195± 0,03	1,200 ± 0,069	1,434
Door's gap	2,100 ± 0,049	0,835 ± 0,021	1,753

Source: Own work

According with table 1, the internal volume of the building is: 30,3 m^3

In the Attachment 2 is shown the different views of the house to have a better understanding of the situation.

2.3. Insulation: "highly isolated envelop"

In this chapter, the passive house's insulation will be described in detail. All the parts of the structure will be considered for the energy flow analysis as it is one of the most important factors of the building:

The materials that compose the hole envelop relate to the energy efficiency of the building as it is one of the main points of heat loss [8]. The structure and composition of the walls of the house act like a thermal barrier that can slow down the heat transfer between the interior and exterior environments. Therefore, a well-insulated envelope will minimize the energy demands reducing the need for heating and cooling in summer and winter. Moreover, good insulation will also act as a moisture barrier preventing condensation and mold growth, a factor that can affect the air quality indoors. [9, 10]

Regarding the heat losses and gains due to thermal bridges in the building envelope, we will choose the normalized thermal bridge value of the requirements of the passive house: ≤0,03 W/m^{2}K [11].

2.3.1. Walls

The passive house is structured with four walls. All of them are well insulated with approximately 455 mm thickness in total and with an insulation thickness of 350mm, manually recorded from the wall section model of the laboratory.

The composition of the walls consists of a wood lattice with fiberglass closed with two wood panels. The insulation has been improved to avoid the filtration of water and it contains an airgap to promote ventilation and a plastic to ensure that the water that could remain inside does not get inside. This plastic separates too the 48mm of fiberglass where the conductions pass through.

In the next photo, we have the detailed analysis of the section of the passive house (figure 5):

Figure 5. Image wall's section, of own authorship.

Outside → Inside	
1st layer: wooden panel cladding	25 mm
2nd airgap	60 mm
3rd layer: textile breathable wind membrane	
4th layer: Impregnated fiber board	10 mm
5th layer: fiberglass/rockwool	300 mm
6th layer: plastic	
7th layer: fiberglass/rockwool	48 mm (2 tommas)
8th layer: wooden panel/plaster board	12 mm

Table 2. Detailed insulation material.

2.3.2. Ground

The floor of the house is also well-insulated with a similar composition as the walls. In this case, it is necessary to consider that the building is not set out on the ground: it stands on several blocks that elevate the building from the ground by 15 cm.

As there is no access to information about the detailed ground composition and because the thickness of the floor is in the range of the walls, it will be considered that the floor accomplishes the passive house requirements for the U-value, which corresponds to 0,08 W/m^2 K or less. This consideration is being made as the thickness of the ground is approximately 370 mm (recorded manually). Moreover, it has a wooden panel layer, an air gap, and an insulation material that could be fiberglass or rock wool, similar to the composition of the wall.

In terms of the indoor floor, we can conclude that is a parquet floor.

Figure 5. Image SolarLab's ground, of own authorship.

2.3.3. Roof

In the case of the roof, there is not much information about the composition, however, there is information about the thickness of the roof is 500mm and it accomplishes the U-value requirements for the passive houses: 0,09 W/m^2K. [12]

The roof inclines of approximately 15º toward the south.

2.3.4. Door

The Solar Lab has two doors: the main external door and an internal door that separates the two rooms of the building.

The main door is the entrance made of wood that incorporates a window in its design (it will be considered in the window's chapter). The door's gap is approximately 835x2100 mm, the door leaf is approximately 800x2000 mm with a thickness of 590 mm (as measured).

The door is not well insulated as the thickness and the materials are not appropriate for avoiding infiltration [13]. Thus, it doesn't accomplish the regulation of the U-value of the passive house. Therefore, it will be considered a "middle insulated door" for SIMIEN.

Figure 6. Image SolarLab's entrance door, of own authorship

The second door divides the building into two small rooms. This one has same structure as the entrance door but without a window. In this case, the gap door is 725 mm. In the simulation, this door will not be considered as it stays always open allowing the free air circulation between the two rooms. Therefore, we will consider the building as a single room.

2.3.5. Window

The Solar Lab has two triple-glazed windows, one of them is located on the east wall of the building and the other on the north wall, next to the entrance door.

Both windows have the same structure: the window's gap is 120x120 mm, the window's size considering the frame is 1155x1155 mm, the glass size is 997x1000 mm and the total thickness of the window is 110 mm (as measured manually).

Figure 7. Image SolarLab's window, of own authorship.

Table 3. Window's areas.

Area	Window	Frame
(m)	0,997	0,337

The windows, according with a care inspection, are triple glassed separated by approximately 3 cm with a pocket of gas and with thermal bridge break. There is no available information about the composition of the inner window, however, the consideration will be taken knowing that the common gases used for doubled and triple-glazed windows are the heavy inert gas argon and krypton, especially for the Nordic countries [14].

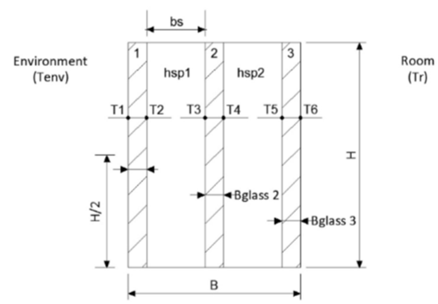
To select between both, it will be considered different criteria. In the first approach, argon gas seemed to be the most plausible option as it is more common in the market since it is not only used in triple-glazed windows but also double-glazed windows [15,16].

As a second approach, an economic criterium could be considered, Argon gas is more than fifty times cheaper than krypton gas [17]. Moreover, despite the fact that for the same window with the exactly same characteristics (such as frame material, chemical proprieties, distance), krypton gas has better thermal proprieties, reaching lower U-values [18] than argon gas, however, argon gas can reach lower U-values leaving more space between the window panels, and this additional material needed will not suppose a big difference with the price. Therefore, relating the economic and the efficient aspects, the triple-glazed window with argon gas is a more plausible option.

Finally, considering the space between the three window panels, which is approximately 55mm and incorporates the thickness of the window, we can conclude that the noble gas inside is argon, as it needs more space than krypton gas, which normally is used within a space of 6-9mm [19].

Moreover, considering the passive house requirements: the U-value for windows the ≤0,8 W/m^2K and for the installed window is ≤0,85 W/m^2K [20], combining the different options, the only one that accomplish the requirement is argon gas with 2 low-emissions with an insulated wooden frame with a warm edge, that results in a total U-value of 0,78 W/m^2K.

Figure 8. Image window's thickness, of own authorship.



hsp(W/m²K) = heat transfer coefficients at triple glass gaps

Bglass(m) = glass widths

T(◦C) = temperatures at glass surface

Figure 9. Diagram triple-glazed windows [39,40,41].

In the case of the external components, these windows don't have any internal blinds, there is a constant sun shading. Moreover, there are not any building projections that could cause shadows in the windows, only the shadows related with the building near the passive house.

Apart from these two windows, it will be considered the window of the entrance door. The window size is 534x530 mm, including the frame is 550x552 mm. This double-glazed window cannot be opened. It will be considered that the window has argon gas and 1 low emission considering the hypothesis done for the triple glazed windows.

Figure 10. Image SolarLab's window's entrance door, of own authorship.

2.4. Ventilation system

The temperature of the SolarLab is controlled by a *Flexit Spirit Uni 2*. This air handling unit provides efficient balanced ventilation in the building with few electricity demands.

The unit is installed on the south wall next to the east wall.

2.4.1. Theoretical functionalities

The ventilation system works with a mechanical configuration with a rotor and a heating element that raises the temperature to adapt it to the temperature set inside the home. Apart from these components, the unit has two different fans, two filters, and two temperature sensors to ensure the correct function of the device.

The system employs outdoor air that will be supplied inside the building after passing through the filter (F11) to ensure the cleaning of the air. A temperature sensor (B4) collects the data of the air outside and it passes through the rotary wheel-type heat exchanger (HR-R) that works a heat magazine: it takes the heat from the extracted air and transfers it to the supply air. Subsequently, the air arrives at the fan (M1) and it reaches the heating element that will be used when the energy recovered from the extract air (from the rotor) is insufficient to maintain the set supply air temperature to raise the temperature. This heating element contains two thermostats (F10, F20) to ensure the safety of the system. Finally, a temperature sensor (B1) registers the temperature of the air after the heating battery, and the air is ready to be supplied indoors the house.

Meanwhile, this process is going on, in parallel, the air inside the building is being extracted and it passes through a filter (F12). It goes through the rotor heating one part of it and, finally, with a fan (M2), the air is exhausted. Apart from this air, the air from the kitchen hood can be extracted from the building too.

In case the difference between the temperature outside and the temperature configured for the inside is very big and the heating element is not enough, an auxiliar battery heater is installed to ensure the right temperature on the inside. Nevertheless, this auxiliary battery is not being used as this situation hardly ever happens.

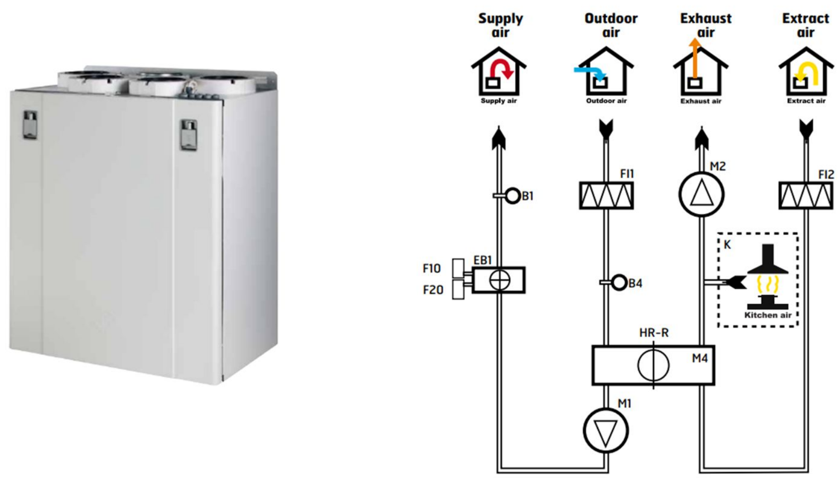


Figure 11. Ventilation system model

2.4.2. Configuration

To understand the specific function of the ventilation in the building it is needed to consider that the building is not hermetically closed. The windows can be opened, and the door normally is opened 5/6 times a day. This results in an unbalanced change of the air and, therefore, the ventilation system will work 24h/day and will restore the temperature indoors to adjust it to the screen monitor demand.

The temperature for the building is configured depending on the weather conditions and the season of the year. During the period with occupancy inside (9:00-17:00h), in the winter months, the indoors temperature is normally configured to 21ºC, however, in the summer months (May-August), it is often configured to 18ºC. For the night, it is normally configured for a minimum of 18ºC in winter and 16ºC in summer.

In this case, the criterion for the passive house is that, at least, 80% (MVHR) of the heat from the exhausted air must be transferred to the supply air, in our case, it is done by the rotor [21]. Moreover, the air changes per hour (ACH) for the passive house requirements should not fall below 0,3 ACH, and it normally stays between 0,3 and 0,5 ACH [22]. As the volume of the building is not very big, the higher the value, the better the quality of the air. Regarding the SFP, for the ventilation model, it will be 1 kW/(m^3/s).

Considering that the system has three types of configurations depending on the level of occupancy inside the building: “min” (no activity in the house – 50%), “normal” (75%), “max” (high level of occupancy – 100%), considering the volume of the building, the area, and 0,5 ACH, and that the volume of the supplied air and the extracted air will be considered the same, the air flow can be obtained in different circumstances:

a) Normal home activity

$$Supply\ air = \frac{24{,}66m^3 \times 0{,}5\frac{changes}{h}}{10{,}103\ m^2} = 1{,}22\ \frac{m^3}{m^2 h}$$

This value is similar to the passive house requirement of the minimun air volume for the ventilation system [21]. Therefore, we will assume that the supposition is plausible for the normal level of occupancy.

b) Nights, weekends, and holidays
In this case, the system is established to the minimum level of occupancy:

$$Supply\ air = 1{,}22 \times 0{,}5 = 0{,}61\ \frac{m^3}{m^2 h}$$

2.5. Electric devices and equipment

The function of the SolarLab is based on a system off-grid and grid-tied backup. The main goal is to stay off-grid as much as possible, thus, solar panels are installed in the house to provide enough energy to allow the building to work as a self-sufficient building in terms of energy demand. However, in some cases where the energy demand is higher than the energy generated, a generator will provide the energy needed. Therefore, this system requires the participation of several components to ensure the perfect function of the passive house and to guarantee the energy self-sufficiency of the building:

2.5.1. Energy Management System

I. Photovoltaic module

Detailed information related to the solar panels can be found in 2.7. Solar Panels

II. Sunny boys

Three inverters fabricated by SMA Solar Technology. Model: SB 1.5-1 VL-40.
These SBs, convert the direct current (DC) generated by the PV modules into alternating current (AC). The main characteristics them are that there is no requirement to have a transformer, the maximum efficiency is 97,2% (European efficiency: 96,1%), the nominal output capacity of the inverter is 1,5 kW and the maximum input tension is 600 V.

Currently, only two inverters are being used: SB2 is being used for the solar panels at the bottom, and SB3 for the solar panels at the top.
An extract of the datasheet of SB can be found in Attachment 6 to provide the necessary information for SIMIEN.

III. Sunny Island

One battery inverter manufactured by SMA Solar Technology. Model: SI 6.0H-13.
The SI works as a bridge between the main components of the lab. On one hand, connected with the SBs within alternating current (AC), it provides the energy in direct current (DC) to the battery that will store it. On the other hand, when the energy provided by the PV modules is not enough, it will get energy in AC from the generator.
Moreover, it is connected to the monitors of energy in the house. Providing the energy required in AC for the electronic devices of the house and the electric car charger point.
This SI includes a switcher for protection.

IV. Battery

One battery produced by TESVOLT. Model: TS25 – 14.4kWh

This lithium storage system is connected to Sunny Island that provides the energy to it in direct current (DC) from the solar panels. The energy capacity of the battery is up to 14,4 kWh, it stands as a 1-phase connection and its continuous power is 1C.

When the level of the battery is <=20%, the generator starts providing energy and it stops when the charge of the battery reaches 30%. In case of an exceeding of the maximum level of the battery (around 97%), the solar panels will stop working.

V. Generator

The auxiliary generator provides the energy demand that the solar panels can't cover. This generator is located in the university of HVL and is connected to the grid.

VI. Car charger station

Currently there is no real car charger station, however, a heater is being used to obtain the quantity of electricity that can be provided for the car charger station to select the most appropriate one.

This car station can be used as a battery that provides energy back to the house when the energy price is too high. This could be achieved with a bidirectional charge or a V2G (Vehicle-to-Grid).

2.5.2. Monitoring and management devices

I. Energy meter

Two energy meters manufactured by SMA Solar Technology.

This meter calculates the exact amount of electricity consumed by the electric devices of the house and by the charger car station. The values measured are communicated by Ethernet in the local network. Therefore, all the data can be transmitted to SMA systems to have complete control of the system.

II. Home manager

One home manager fabricated by SMA Solar Technology.

The Sunny Home Manager monitors and optimises the energy flow of the entire building.

III. Tigo CCA

A Tigo Cloud Connect Advanced (CCA) registers the data of the energy flow of the main components of the house to guarantee a good monitoring.

IV. Component connections

All the components are connected via Ethernet with a router and its switch (GS108E manufactured by NETGEAR). Moreover, a Raspberry Pi 3 is being used to ensure good monitoring.

V. Pyranometer

The pyranometer type is SMP11-V manufactured by OTT HydroMet and KIPP&ZONEN.
This instrument measures the solar radiation.

2.6. Energy loads

2.6.1. Office equipment

The current SolarLab includes 1 monitor, 1 keyboard, 3 laptops, 1 router, and 1 raspberry.

All the instruments are being used 24h/day except the laptops which are used only if it is required in the work context.

2.6.2. Other equipment

Apart from the office equipment, there are different plugs outside and inside allowing any device to connect to the electricity of the house.

Moreover, each equipment has protection switchers and there are 3 firefighter switchers from Samon.

2.6.3. Lighting

To analyse the energy consumption due to the lighting of the building it is necessary to evaluate different factors:

a) <u>Orientation, location, shadows, and natural light.</u>
All these factors can be studied together as the natural light is determined by the shadows produced by the buildings and obstacles that surround the building. As well as this, the orientation of the building will determine how much natural light enters the building through the window. All this information can be found in the previous chapters.

b) <u>Number, type, and location of the lights.</u>
The house is equipped with 8 LED lights well distributed in both rooms to ensure the lighting of the building.

c) <u>Sensors and regulation</u>
The light intensity can be adjusted by a regulator of the intensity.

d) <u>Installed power</u>
The power of the 8 lights in their maximum level of intensity is 121 Wh.

e) Occupancy and activity indoors

The building is designed to be used as a small office and a laboratory. Therefore, the quantity of light needed must allow the workers to do all the possible tasks inside: read, write, use the computer, do measurements, experiments, etc.

f) Usage time

The number of hours that the lights are switched on depends on the weather conditions and the month of the year. However, it is necessary to understand that the maximum number of hours the light could be switched on will be 7h according to the timetable of occupancy (view 2.8. considerations).

From March to May 2024, the data has been collected directly from the hours that the light has been switched ON/OFF.

For the rest of the months, as there is no available data on the time light usage, the direct sunlight available each day of the year will be obtained with ShadeMap ([ShadeMap - Simulate sun shadows for any time and place on Earth]). To introduce the data in SIMIEN, it will be considered one average day for each month:

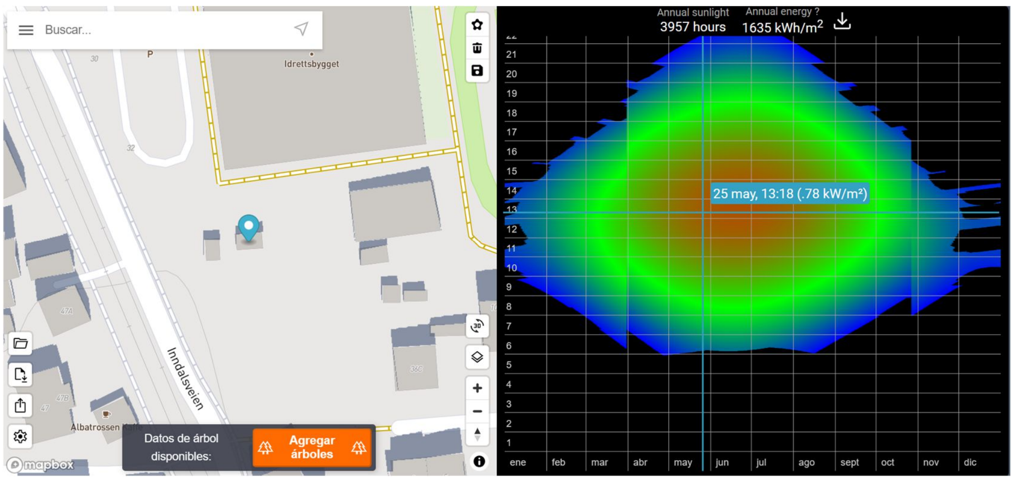


Figure 12. Annual sunlight in SolarLab (ShadeMap)

The total number of hours of direct sunlight in a year in the specific location of the SolarLab is 3957 hours. Considering one average day of each month, we obtain the number of hours of direct sunlight per average day:

Table 4. Annual sunlight in SolarLab.

DIRECT SUNLIGHT	JANUARY	FEBRURARY	MARCH	APRIL	MAY	JUN
Entire hours	4h 13min	8h 2 min	10h 48 min	13 h 58 min	16h 1min	16h 44min

DIRECT SUNLIGHT	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Entire hours	16h 19min	14h 55min	11h 56min	9h 2min	5h 56min	1h 49min

Source: Own work, adapted from Shade Map.

This data is an approximation of the real data, as, the building next to the passive house building doesn't exist nowadays (Figure 12). Nevertheless, the shadows that it produces are despicable since it only affects for a few minutes during the sunset. Even so, there are some other considerations to remark, as there is a small hill on the west of the passive house and the south that can derivate into more shadows.

As well as these observations, it is necessary to understand that ShadeMap calculates the time that the building can receive sun without any other building producing shadows. However, it doesn't consider the influence of the weather conditions, and this is not negligible, given that Bergen is well known for the number of rainy days it has, with an average of 232 rainy days [23] (63,56% of the year). These days, the sky will be covered by clouds [24], therefore, the natural light received will be less than expected by ShadeMap.

Nonetheless, to keep it simple as the main goal is to estimate the number of hours that the lights are switched on, we will work with the data available in ShadeMap considering the sunrise and sunset of each month [25] and considering the worst scenario in terms of the weather conditions: rainy days. Considering the first day and the last day of each month to have the longest and the shortest day, an estimation can be done. Therefore, we obtain that the hours that the light will be switched on are:

Table 5. Annual timetable lights switched on in SolarLab.

LIGHTS. ON	JANUARY	FEBRURARY	MARCH	APRIL	MAY	JUN
Before break	9:00-12:00	9:00-11:30	9:00h-11:00	-	-	-
After break	13:00-17:00	14:00-17:00	15:00-17:00	15:30-17:00	-	-

LIGHTS. ON	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Before break	-	-	9:00-10:00	9:00-10:00	9:00-11:00	9:00-11:30
After break	-	-	15:30-17:00	14:30-17:00	14:30-17:00	14:00-17:00

Source: Own work

2.7. Solar panels

The main goal of the SolarLab is to be a grid-off system, consequently, it has 12 solar panels installed to generate energy for the passive house. These solar panels are 6 monocrystalline solar panels of the company Astronergy of 285 Wp [Attachment 3, 4] and 6 polycrystalline solar panels of REC group of 275 Wp [Attachment 5], completing in total 3,36 kWp.

Each array of solar panels is connected to one Sunny Boy of 1,5 kVA and 1,5 kW [Attachment 6]

2.7.1. Structure and basement

The structure, responsible for supporting the solar modules, provides the proper inclination for them to receive the maximum amount of radiation, thereby increasing their efficiency.

The monocrystalline solar panels are supported by a metal structure anchored to the top of the south wall of the house leaving the bottom of the solar panel at a height of 2,06m above the ground. The polycrystalline solar panels are supported by a metal structure anchored to a concrete base on the ground that elevates it 24cm.

Both structures are rigid keeping a fixed angle, however, the anchors can be moved allowing the change of the angle of the solar panels. The structure ensures resistance against extreme loads due to adverse weather conditions such as snow and wind.

This structure will be called from now on “table”. The distribution of the tables is:

- Number of tables: 4
- Number of rows: 2
- Number of columns: 2
- Number of modules/tables: 3 (vertical position)
- Number of supports: 2

2.7.2. Orientation and inclination

Norway is located in the northern hemisphere; therefore, the solar panels must be oriented to the south to increase the radiation and efficiency.

Analysing the radiation in Sun Path it can be confirmed that the most suitable orientation due to the location is the south as the sun’s path is the next one:

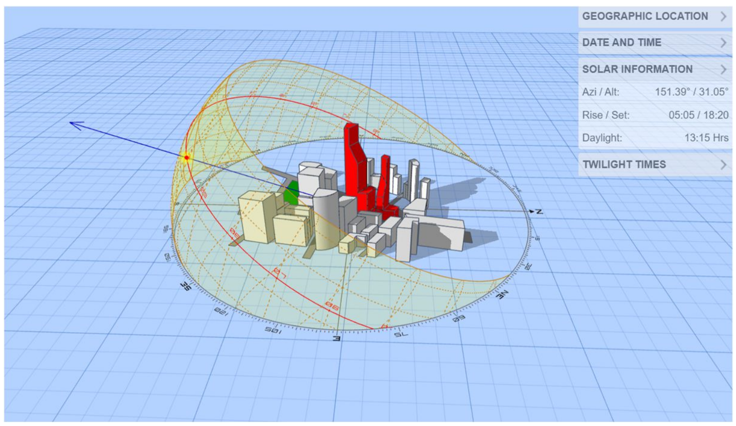


Figure 13. Sun path in Bergen (Sun Path).

Once the orientation is evaluated, it is necessary to analyse the angle of inclination of the solar panels. In this case, the tool PVgys will be used.

The situation of the solar panels can be resumed with the next single-line diagram:

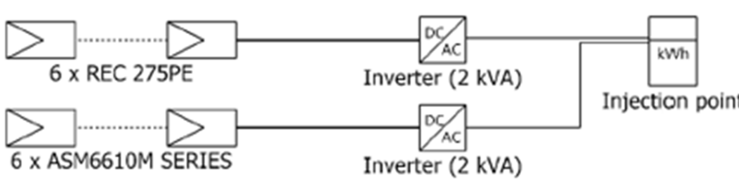


Figure 14. Photovoltaic diagram [Attachment 7].

With PVsyst, we can obtain the energy produced by the solar panels in a year: 986,96 kWh/year with a performance ratio (PR) of 77,01%. Moreover, we can obtain, for each month, the different types of energy produced:

Table 6. PVsyst solar panel production.

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	6.4	5.21	2.32	3.71	3.61	10.2	5.1	0.406
February	19.9	14.56	2.04	10.24	9.97	30.7	23.9	0.694
March	51.8	29.58	3.51	21.02	20.47	64.2	53.8	0.761
April	91.7	51.68	6.97	37.19	35.59	112.2	98.9	0.792
May	139.1	76.01	10.56	68.55	64.06	203.0	185.4	0.805
June	140.3	79.59	13.01	75.66	70.83	222.2	203.6	0.801
July	127.1	77.28	15.97	67.62	63.63	196.4	178.2	0.785
August	102.6	64.88	15.48	49.15	46.51	142.5	127.4	0.771
September	59.8	37.15	12.36	26.09	25.26	77.0	65.4	0.746
October	30.0	20.19	8.61	14.51	14.13	42.6	33.8	0.693
November	9.8	7.63	5.02	5.46	5.32	15.4	9.4	0.511
December	4.1	3.32	3.17	2.25	2.19	6.0	2.2	0.290
Year	782.4	467.08	8.29	381.44	361.57	1122.6	987.0	0.770

The real amount of energy that the solar panels inject to the passive house is 987 kWh (E_grid). This value is calculated multiplying the PR that are the losses of the system, such as the losses due to the temperature, the inefficiency of the inverter, the cabling, shadows…, per the value of energy obtained in the solar panels (EArray). This last energy is obtained as well considering the area of the panel and the global effective irradiation (GlobEff), which is the irradiation that reaches the panels considering the inclination and orientation (GlobInc) and considering the efficiency of them.

Analysing the values, we can see the global incident irradiation in the collector plane is considerably low, this may indicate that the inclination of the solar panels is not the most suitable one to produce the most quantity of energy. As well as this, the performance ratio with the global incident ratio strengths the hypothesis of the bad inclination as the low values indicate that the solar panels are not working with the maximum efficiency possible.

We can analyse the losses of the entire process to understand which are the main points of improvement:

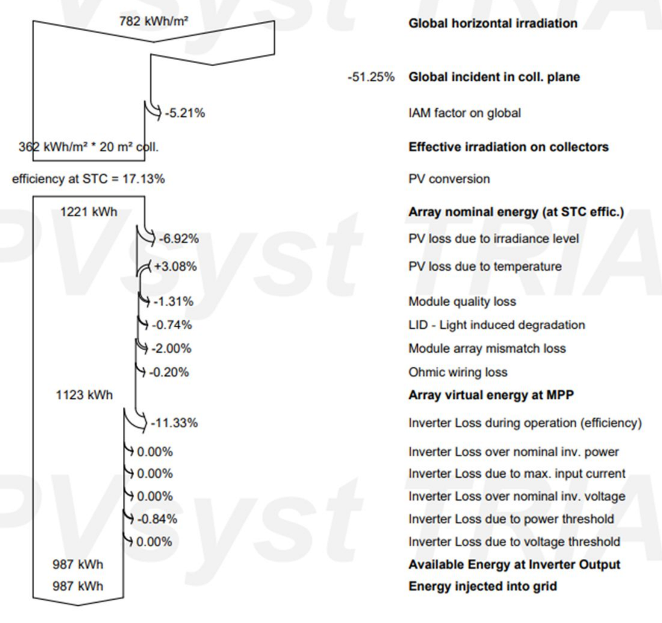


Figure 15. PVsyst Loss diagram.

As the losses diagram shows, the energy lost due to the inclination is the 51,25%. Considering the sun path in Bergen and the difference between the height of the sun in the summer and the winter months, it indicates that the inclination is not the most suitable one.

Therefore, we must analyse which inclination could be the most efficient for the situation of the passive house. Configuring the PVSyst, we propose two different inclinations during the year for the fixed solar panels of the passive house:

Grid-Connected System

PV Field Orientation

Seasonal tilt adjustment	
azimuth	0 °
Summer Tilt	20 °
winter	50 °
Oct.-Nov.-Dec.-Jan.-Feb.-Mar.-	

Figure 16. PVsyst new solar panels' inclination.

This inclination is adjusted for two seasons: summer and winter. Changing two times a year the fixed inclination is totally plausible as it can be done easily, and it is related with the two solstices when the sun is in its maximum and minimum height avoiding intermediate seasons that may not result in a big difference of benefits and PVsyst can offer accurate data of only two different inclinations.

Moreover, analysing both angles of inclination, both are coherent as in summer the sun is higher, and the panels will obtain more irradiation if they are more horizontal, and it happens the opposite in winter as the sun is lower.

By adding these new changes, the new production of the solar panels is 2610,86 kWh/year and the performance ratio is 83,66%. Therefore, the increase in production is 37,8%, that reflects the need of applying the propose made.

If we analyse the new values of energy obtained per month now:

Table 7. PVsyst solar panel production with new inclination.

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	6.4	5.21	2.32	14.6	14.5	46.6	41.6	0.846
February	19.9	14.56	2.04	36.7	36.2	117.3	108.4	0.880
March	51.8	29.58	3.51	80.2	78.8	250.1	233.8	0.868
April	91.7	51.68	6.97	107.0	104.1	327.1	306.6	0.853
May	139.1	76.01	10.56	147.8	143.7	443.9	417.0	0.840
June	140.3	79.59	13.01	144.7	140.5	428.9	402.1	0.827
July	127.1	77.28	15.97	132.1	128.5	387.5	362.0	0.816
August	102.6	64.88	15.48	112.3	109.1	331.9	310.1	0.822
September	59.8	37.15	12.36	71.3	69.0	213.0	197.2	0.823
October	30.0	20.19	8.61	49.8	49.0	151.3	139.5	0.834
November	9.8	7.63	5.02	20.1	19.8	63.1	56.7	0.840
December	4.1	3.32	3.17	12.4	12.2	39.5	36.0	0.868
Year	782.4	467.08	8.29	928.8	905.3	2800.3	2610.9	0.837

All the values have increased, obtaining a better efficiency of the system. As well as this, the losses of all the process have been reduced and now, the global incident in collector plane have increased:

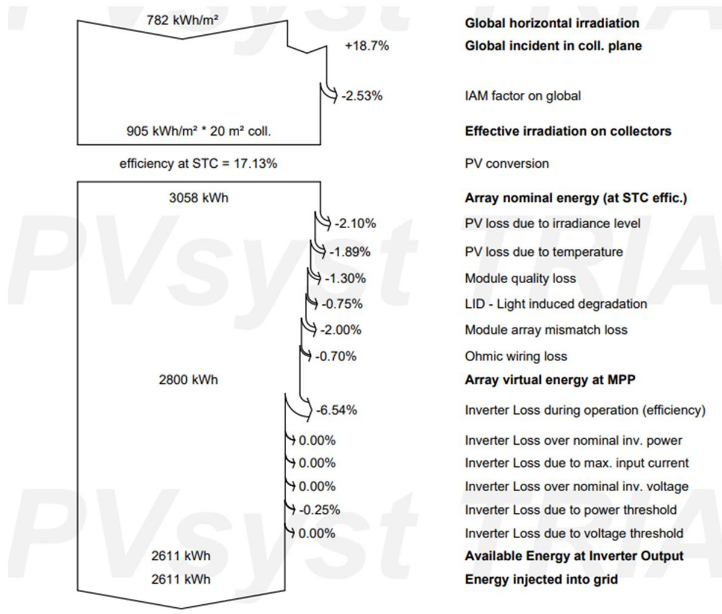


Figure 17. PVsyst Diagram loss with the new inclination.

Therefore, this new propose will result in a better efficiency of the process and a more beneficial system as the balance of the production and the energy demand of the passive house will be improved.

The solar panels production can be evaluated as well with the Sunny Portal web (Sunny Portal powered by ennexOS). This program monitories the photovoltaic system of the passive house considering the 2 SB, the 12 solar panels, the battery, and the home manager. It shows the energy flow with the consumption of the house, the energy production, the battery state of charge and the demand of the grid. This program can be used to analyse if the methodology employed in the PVsyst software has been done correctly. Nevertheless, since the previous months some experiments have been done to understand the function of the system, in this case, it can only be used as an indicative production.

2.8. Other considerations

2.8.1. Air tightness

For the leakage number of air changes (ACH) with a pressure different than 50Pa for the SolarLab, it will be considered that it accomplishes the requirement for the passive houses: 0.6 h^{-1} [26, 27].

2.8.2. Weather forecast

The wind rose of Bergen reflects how the wind comes from the north-east and the rest comes from the south-west.

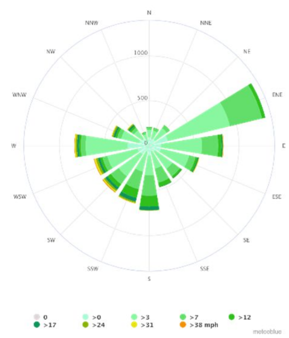


Figure 18. Wind Rose from Meteoblue.

Therefore, despite the small hill that surrounds the building and the building on the east side of the building, it will be considered that there's more than one façade exposed to the wind.

The wind rose has been extracted by meteoblue.com [28] and can be compared to the UIB information [29].

2.8.3. Water system

In the building, there's not a water system.

2.8.4. Heating system

There is no room heating system in the building. The unique device employed to heat the SolarLab is the ventilation system with the auxiliary battery.

2.8.5. Energy sources

Apart from the solar panels, the energy comes from the electricity from the grid.

2.8.6. Use and occupancy

The building is currently being used as a laboratory to analyse the function of it:

- Days of work: workdays from Monday to Friday respecting the 8 weeks of holidays in the year.
- Timetable work indoors: 9:00 - 17:00 h
  Timetable break: 12:00-13:00 h
- Level of occupancy: 1 person

Consequently, the number of times that the door will be open will be between 5/6 times a day. This will influence in the air exchange and the temperature of the building.

However, the equipment and the system it is considered to work every day even in holidays, while the light will be only working when there's someone working inside. This will lead in some inaccuracies when introducing the data on SIMIEN as it can be only established one timetable of work for both aspects. Therefore, it will be simulated as if it works every day and in case of the light, it will be done a second simulation as it only works in the timetable of the occupancy described.

Moreover, the building is lightly furnished: it only has 3 desks and the equipment mentioned above.

2.9. Energy price

The energy price in Bergen, Norway is determined by Nord Pool. This energy market facilitates the trading of electricity in real-time and for the future in the Nordic countries, as well as in other regions of Europe. Since Bergen is located in the west of Norway, according to these criteria, it will be part of the NO5 section.

The price data collected in 2023 is the following:

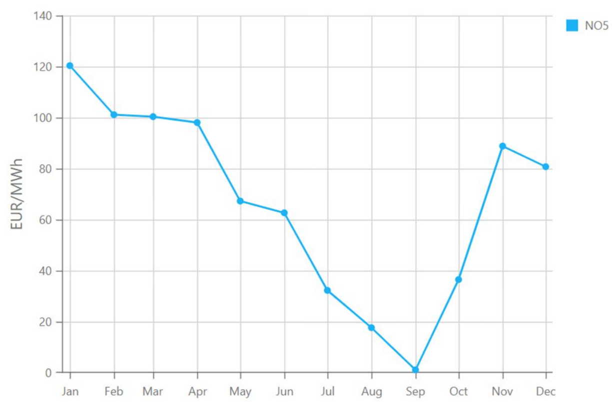


Figure 19. Annual energy price in Bergen from Nord Pool.

Table 8. Annual energy price in Bergen.

Delivery Date Start	Delivery Date End	NO5 (EURO)	NO5 (NOK)
01/12/2023	31/12/2023	80,91	935,86
01/11/2023	30/11/2023	88,82	1 047,80
01/10/2023	31/10/2023	36,47	426,87
01/09/2023	30/09/2023	0,97	11,11
01/08/2023	31/08/2023	17,58	200,76
01/07/2023	31/07/2023	32,49	372,08
01/06/2023	30/06/2023	62,61	732,29
01/05/2023	31/05/2023	67,4	789,86
01/04/2023	30/04/2023	98,18	1 129,05
01/03/2023	31/03/2023	100,35	1 130,41
01/02/2023	28/02/2023	101,18	1 108,02
01/01/2023	31/01/2023	120,41	1 287,62

Source: Own work adapted from Nord Pool, Day ahead prices.

Therefore, the energy price average in 2023 was 0,067 €/kWh. Nevertheless, this value doesn't include the fees and taxes related to the object of study of this project. Therefore, the value used will be 0,14 €/kWh (1,63 NOK/kWh). [30]

3. Results SIMIEN analysis

By introducing all the data of the SolarLab in the software of SIMIEN we can obtain an entire energy model of this passive house.

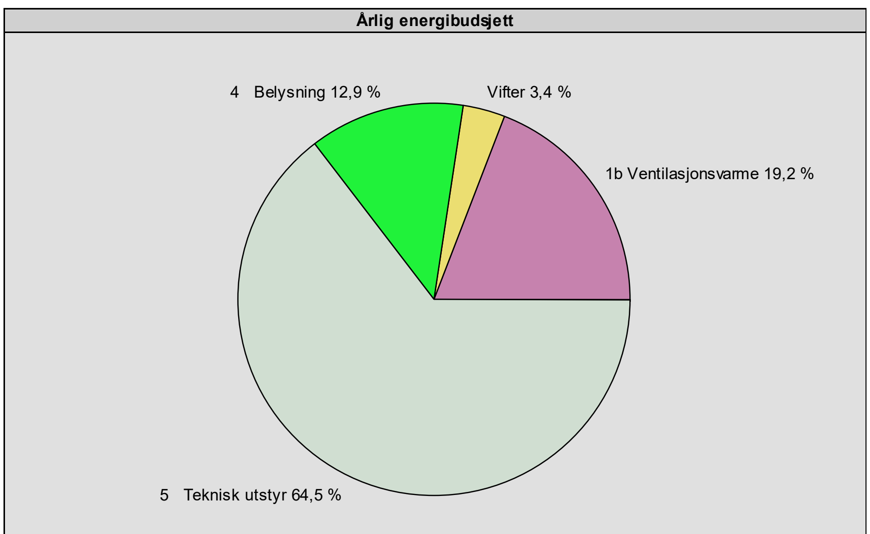
3.1. General energy simulation

3.1.1. Energy sources

As established in SIMIEN, the only sources available are the electricity of the grid and the solar panels. For the electricity, we have considered the default values of the software except from the heating room and heating tap water, that to consider them as inexistent, the minimum value we can add in the program is 0,1. In this case, this electricity will be used exclusively when the solar panels can't reach the energy demand of the building.

3.1.2. Energy consumption

The distribution of the energy consumption in the SolarLab is:



1a Romoppvarming	0 kWh
1b Ventilasjonsvarme (varmebatterier)	186 kWh
2 Varmtvann (tappevann)	0 kWh
3a Vifter	33 kWh
3b Pumper	0 kWh
4 Belysning	125 kWh
5 Teknisk utstyr	625 kWh
6a Romkjøling	0 kWh
6b Ventilasjonskjøling (kjølebatterier)	0 kWh
Totalt netto energibehov, sum 1-6	969 kWh

Figure 20. SIMIEN Annual Energy Budget.

The only points of consumption are the ventilation system with the heating battery (*Ventilasjonsvarme*) with 186 kWh, the ventilation's fans (*Vifter*) with 33 kWh, the light (*Belysing*) with 125 kWh and the equipment of the building (*Teknisk utstyr*) with 625 kWh.

As we can observe, the light has a very few consumptions due to the efficient technology employed. Even we have considered that the lights are being used in their maximum level of intensity which is 121 W (therefore, maximum level of consumption to analyse the worst scenario) the consumption is still very low. This yearly approach is considering the different hours of use depending on the months. To be more accurate, we need to consider that the lights are only used when there's occupancy inside the building, therefore, we can obtain a more plausible value as well for the light consumption doing a small simulation. We obtain the value of 89 kWh.

Regarding the ventilation system, by analysing the consumption of the passive house, we have previously obtained a consumption of approximately 438Wh per day. By introducing this value in SIMIEN, we obtain a total consumption per year of 186 kWh. This value is very low comparing with other ventilation systems; therefore, it reflects the high efficiency of the system.

Finally, the equipment of the Solar Lab has the maximum consumption. This value may vary depending on the weather condition, needs, and other considerations. However, we have previously obtained a total amount of approximately 125 kWh per month, that corresponds to a power of 71W, and SIMIEN's results show us the energy consumed per year by this factor: 625kWh. This value is very high because of the energy demands of the industrial devices.

We can obtain the monthly net energy demand as well:

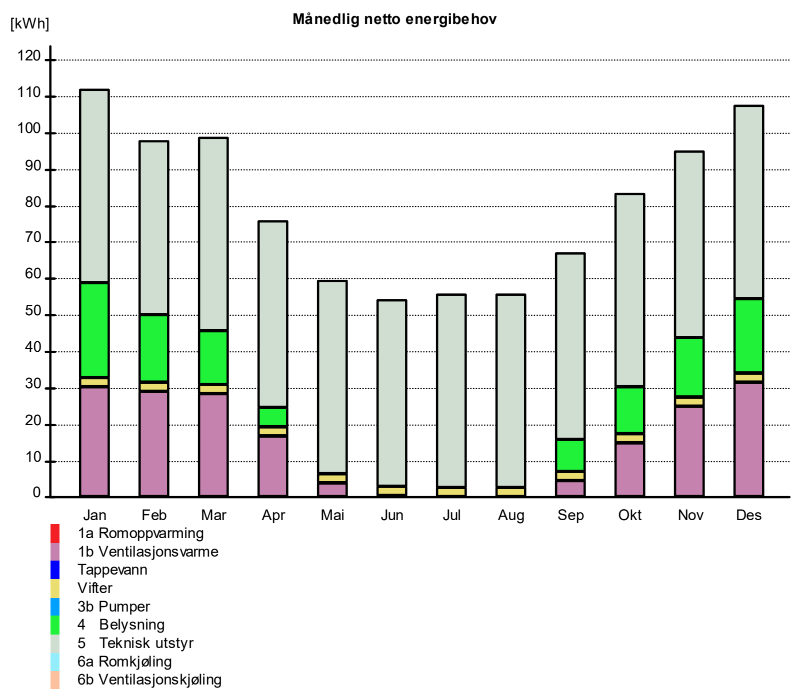


Figure 21. SIMIEN graph monthly net energy demand.

As the graphic shows, on the months from May to August the consumption due to the light is it null. However, in the winter's moths the consumption increase.

Regarding the ventilation consumption, in the summer moths it decreases since the difference between the temperature of the outside of the building and the temperature configured for the inside is very small. Therefore, the heating battery is not needed, and the rotor is being used exclusively for the air exchange, and this results in a less energy demand. However, in the coldest months, the ventilation consumption is much higher due to the big temperature difference which requires a major power from the heating battery.

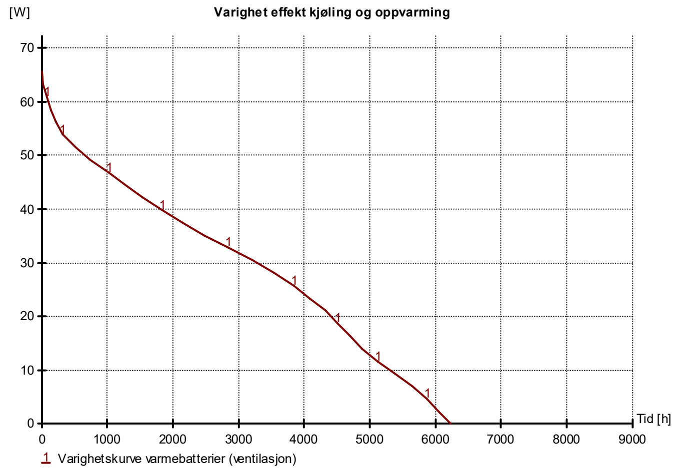


Figure 22. SIMIEN graph duration effect heating

The graph reflects the number of hours of the year that the different levels of power of the heating battery of the ventilation system is needed. Thus, it shows how the maximum capacity of the heating battery is only needed few hours during the year, and approximately 6000h the required power is practically zero. This indicates that during this period (almost more than 2/3 of the year), the exterior conditions are such that no additional heating is needed to keep the indoor thermal comfort. This justifies why the demand that comes from the heating battery of the ventilation system it's zero or very low in summer and in the adjoining months.

In this case, although the consumption's fan is related with the ventilation system, the fans work even in the summer since the ventilation system still works even if the heating battery is not working.

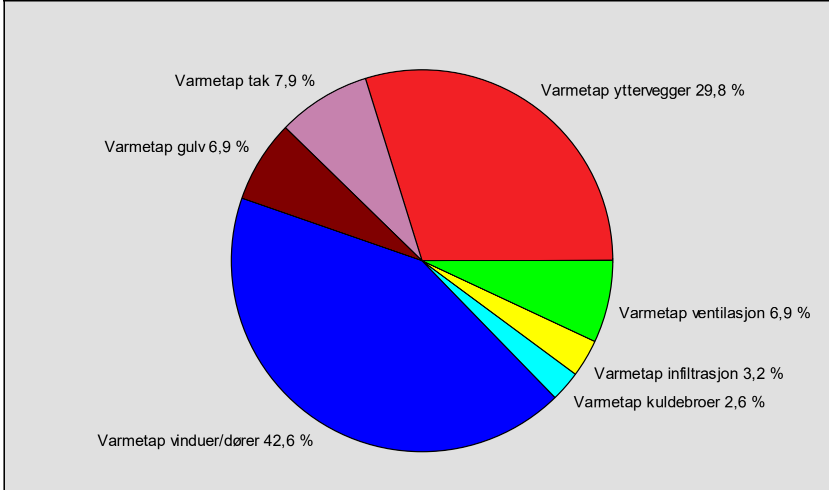
Meanwhile, the equipment consumption remains almost the same at the equipment it's never switched off.

3.1.3. Heat balance

Regarding the heat balance, we consider the heat losses and gains.

On the one hand, the heat losses are due to infiltrations in the building:

Varmetapsbudsjett (varmetapstall)



Varmetapstall yttervegger	0,35 W/m²K
Varmetapstall tak	0,09 W/m²K
Varmetapstall gulv på grunn/mot det fri	0,08 W/m²K
Varmetapstall glass/vinduer/dører	0,50 W/m²K
Varmetapstall kuldebroer	0,03 W/m²K
Varmetapstall infiltrasjon	0,04 W/m²K
Varmetapstall ventilasjon	0,08 W/m²K
Totalt varmetapstall	1,16 W/m²K

Figure 23. SIMIEN heat loss budget

The losses due to roof (*tak*), the floor (*gulv*) and the thermal bridge (*kuldebroer*) are logical as the values obtained are the ones established in the SN 3700. Moreover, the value related with the infiltration (*infiltrasjon*) and the value of the ventilation system (*ventilasjon*) are coherent as they reflect how efficient are the systems since the coefficient of thermal transference obtained are very low, what ensures a good insulation with few heats transference.

However, in terms of the insulation of the walls (*yttervegger*) and the windows and doors (*glass/vinduer/dører*), the values are very high.
In case of the outdoors walls, even that the data introduced reflects how good insulated is the building the result doesn't agrees the data introduced. The data introduced, for example, for the North facade has been the following one:

Table 9. SIMIEN Facade Data Introduced.

Inndata fasade/yttervegg	
Beskrivelse	Verdi
Navn:	North Facade (fasade)
Totalt areal	15,2 m²
Retning (0=Nord, 180=Sør)	0°
Innv. akkumulerende sjikt	Trepanel/treplate 15 mm Varmekapasitet 4,6 Wh/m²K
Konstruksjon	48 mm dobbeltveggkonstr, 350 mm isolasjon Uverdi: 0,12 W/m²K

As the table 9 shows, the value of the thermal coefficient transference corresponds to the maximum value reflected in the requirements of the passive house for the walls, therefore, the building is well insulated. The high volume obtained may be because some other data wrongly introduced.

In case of the windows and the door, the value obtained is higher. Most of the problem comes from the bad insulation of the door. It is a standard door with a double-glazed window; therefore, the U-value is very high:

Table 10. SIMIEN Door Data Introduced

Inndata ytterdør	
Beskrivelse	Verdi
Navn:	Door (ytterdør)
Areal inkl. karm/ramme	1,8 m²
Dørtype	Middels isolert dør Uverdi: 1,60 W/m²K

However, even if we don't consider the losses due to the bad insulation of the door, the windows' U-value remains very high (0,20 W/m^{2}K) and the windows are very well insulated:

Table 11. SIMIEN Window Data Introduced

Inndata vinduselement	
Beskrivelse	Verdi
Navn:	Window 2 (Vindu(er) på East Facade)
Antall vinduer	1
Høyde vindu(er)	1,20 m
Bredde vindu(er)	1,20 m
Karm-/ramme faktor	0,30
Karm/rammekonstruksjon	U-verdi: 0,90 W/m²K Kuldebroverdi: 0,03 W/mK
Vindustype	Trelags glass, argongass, 2 lavemisjonsbelegg Uverdi: 0,60 W/m²K
Konstant (fast) solskjerming	Tre lag glass, hvorav to er energispareglass Total solfaktor: 0,45

To understand the background of the problem a detailed evaluation with a thermal camera should be done to identify the potential points of improvement.

On the other hand, the heat gains depend on the internal loads such as the equipment, the light, and the occupancy. As well as the sun's contribution and the energy coming from the ventilation system.

Therefore, the heat balance is:

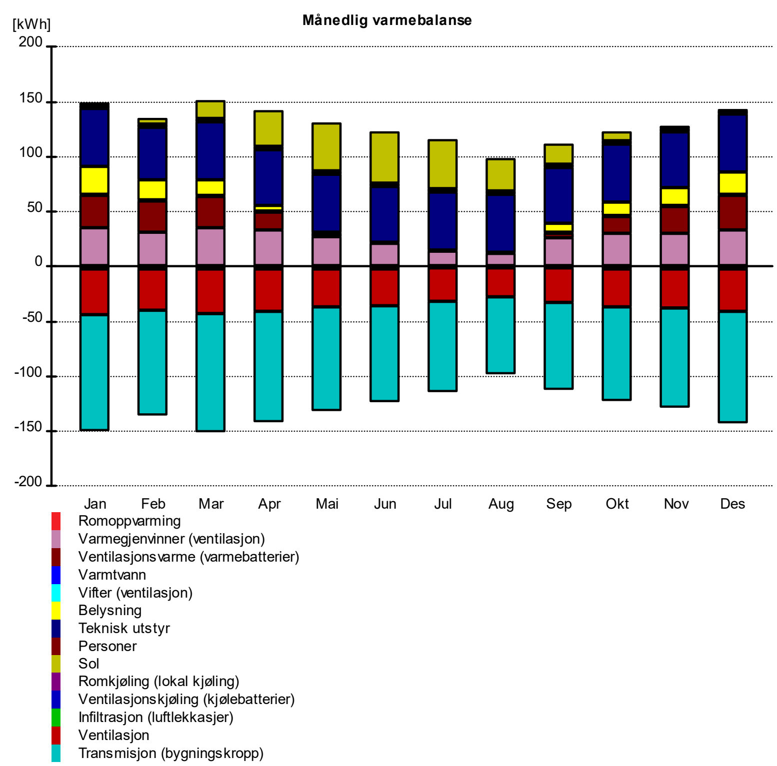


Figure 24. SIMIEN Heat Balance.

In the figure 24, we can see that the main heat losses are due to the building insulation (*transmisjon*) and the ventilation. Meanwhile, the main heat gains are due to the heat battery of the ventilation system and the technical equipment.

3.1.4. Solar panel

The solar panels of the passive house are the main energy source in most of the months of the year:

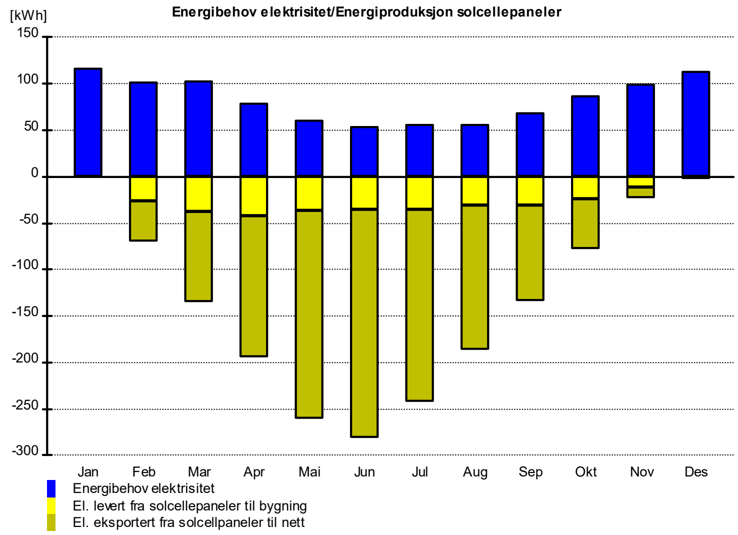


Figure 25. SIMIEN Energy demand electricity and Energy production.

In the summer months it not only covers the heating demand, but also produces and excess of energy that charges the battery of the solar passive house. This excess of energy is the one that is being used for the future charging station car. However, on the month of January and half of the month of December, we have stablished that the solar panels are covered by the snow, considering the year 2023-2024 as a reference, therefore, the production is zero. On

Analysing the values of energy production for each month by each panel, we obtain:

Table 12. SIMIEN Monthly Energy Production.

Energiproduksjon solceller [kWh]													
Panel	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des	Totalt
Produsert PV1 Top Mono	0	5	11	16	22	24	20	16	11	6	2	0	134
Produsert PV2 Top Mono	0	5	11	16	22	24	20	16	11	6	2	0	134
Produsert PV3 Top Mono	0	5	11	16	22	24	20	16	11	6	2	0	134
Produsert PV4 Top Mono	0	5	11	16	22	24	20	16	11	6	2	0	134
Produsert PV5 Top Mono	0	5	11	16	22	24	20	16	11	6	2	0	134
Produsert PV6 Top Mono	0	5	11	16	22	24	20	16	11	6	2	0	134
Produsert PV1 Bottom Poly	0	6	11	16	22	23	20	16	11	7	3	0	136
Produsert PV2 Bottom Poly	0	6	11	16	22	23	20	16	11	7	3	0	136
Produsert PV3 Bottom Poly	0	6	11	16	22	23	20	16	11	7	3	0	136
Produsert PV4 Bottom Poly	0	6	11	16	22	23	20	16	11	7	3	0	136
Produsert PV5 Bottom Poly	0	6	11	16	22	23	20	16	11	7	3	0	136
Produsert PV6 Bottom Poly	0	6	11	16	22	23	20	16	11	7	1	0	135
Sum produsert	0	71	136	196	262	283	244	188	135	79	25	3	1624
Levert til bygning	0	27	38	43	37	36	37	31	32	25	13	3	321
Eksportert til nett	0	45	98	153	225	246	208	157	103	54	12	0	1302

Comparing these results with the PVsyst, we identify some differences in the production obtained. This may be due to some inaccuracies in the process of introducing the data in the software. However, we will keep the information from the PVsyst as it offers a detailed analysis of the passive house production.

Nevertheless, the results obtained in the SIMIEN model will be used to understand the balance of energy demand and energy produced, since it reflects how the solar panels can provide enough energy during the summer months to cover the demand and to produce and excess of energy, while in the winter months, the electricity from the grid will be needed to cover the passive house energy demand.

4. New scenarios definition

The SolarLab is not adapted for residential use. Therefore, in this chapter, different occupancy scenarios will be described to convert the energy model of the passive house to an energy model for a tiny house adapted to the living.

For that, several factors will be evaluated such as the main daily activities, the level of occupancy, the lifestyle conditions, and the energy associated with all these aspects.

4.1. Daily activities

First of all, we will describe the main activities that can be held in a residential building. We consider the essentials as well as the most common ones:

Table 13. Household activities.

CATEGORY	ACTIVITY	APPLIANCE	FRECUENCY OF USE PER PERSON
House-caring	LAUNDRY	Washing machine	3 times/week
		Dryer machine	3 times/week
	CLEANING	Vacuum	1 time/week
Kitchen	COOKING	Stove	3 times/day
	HEATING FOOD	Oven	2 times/week
		Microwave	2 times/day
	COOLING FOOD	Fridge	24h/day
		Freezer	24h/day
	WASHING	Sink	8 times/day
Bathroom	FLUSHING	Toilet	5 times/day
	BATHING	Shower	4 times/week
	DRIYING	Hairdryer	4 times/week
Thermal Confort	HEATING	Heating element	Winter season
	COOLING	Cooling Element	Summer season
Visual confort	LIGTHING	Light	8h/day
Others	CHARGING	Telephone Charger	1 time/day
		Laptop Charger	1 time/day
	INTERNET CONNECTION	Router	24h/day

Source: Own work

4.2. Domestic appliances models proposed

For this scenario where we are describing a household, a study of the different domestic appliances in the market has been done to propose the most efficient devices for not compromising the energy demand. The main criteria for this have been searching for the best rated efficiency (A, A+, A++…) or the Energy Star efficiency. The models selected are:

- LAUNDRY
  Both washing machine and dryer can be combined in only one domestic appliance to save space in the tiny house. After an evaluation of the current models in the market, we can propose a device model for the passive house: considering the economy, the space and the energy

efficiency, the most suitable model could be EW7W4858OB 914610115 manufactured by Electrolux [31]. The main details are:

- Dryer capacity: 5 kg
- Washing machine capacity: 8 kg
- Dimension: 85x60x57
- IEEw= 51,8 (A)
- IEEwD=66,8 (D)
- Consumption/cycle: 2,653 kWh/cycle

▪ CLEANING

The cleaning of the building will be limited to a vacuum for the house. In this case, the one chose is: Conga ThunderBrush 520 Vertical Vacuum 360º produced by Cecotec [32] as it is one of the most efficient and it can be used vertical or handle, perfect for a tiny house situation. Its characteristics are:

- Vertical and handle vacuum
- Rated efficiency: A+
- Power: 600W

▪ COOKING

For cooking, we have chosen an inductive hob instead of a radiant or a halogen hob as has lower heat losses and they're more efficient with more heating speed and better temperature control. Moreover, it is more secure for the tiny house since it has automatically switch off and sensor of vessel to start heating.

In this case, the induction hob selected is the Bolero Squad I 2001 manufactured by Cecotec [33].

- Two different size zones
- Power: 1500/2000 W
- 9 different levels of power
- Heat sensor

▪ HEATING FOOD

The kitchen will have a microwave for heating the food apart from the induction hob. The microwave considered is Microwave Grill LG 20 L MH6042D.BBKQEUS [34]:

- Inverter Technology
- Power: 700 W
- Volume: 20 L

▪ COOLING FOOD

We have selected a unique device that combines the fridge and the freezer. The model selected is Fridge combi Erie 3014W UBF2214-20 Universal Blue No Frost F manufactured by Universal Blue [35] as its economic price and its height does not compromise the efficiency:

- Rated efficiency: A
- Power: 3014 W

▪ DRYING

Since the location is set up in Norway, we consider that the hair dryer is a very common electronic device. The hair dryer selected is BaByliss PRO TT Tourmaline Titanium Travel Dryer [36], since is a device with low wattage, therefore, lower energy demand:

- Power: 1000W
- Far-infrared heat
- Superior heat conductivity

▪ HEATING AND COOLING

For the first instance, we will consider that the ventilation system remains the same as the established in the passive house: Flexit Spirit Uni2.

- LIGHTING
  The lighting will be the same as the one in the SolarLab: 8 LED lights with a total consumption of 121Wh and with a light intensity controller. However, the time usage will change for the new lifestyle of the building, as it will be the opposite of the passive house: the Solar Lab is used as an office and now it will be used as a residential building.

- INTERNET CONNECTION
  The internet connection will remain the same as the starting model.

- CHARGING
  For mobile phones, we select a fast charger of 33 W.
  For computers, we select a charger of 45 W.

4.3. Scenarios of occupancy

Tiny houses are adapted to give the perfect living conditions for few levels of occupancy; therefore, it will be considered two different scenarios of occupancy:

a) <u>SCENERIO A: One person living</u>

<u>Occupancy</u>

We will consider one employed person who works outside the home or a student living in the building. Thus, the number of hours that the person is inside the house will be less considering the need to go to work or the university, therefore, the person will spend around 16 hours inside the house:

- Morning: 00:00 - 08:30 h
- Afternoon/night: 17:30 - 00:00 h

<u>Lighting</u>

Considering the same methodology to obtain the number of hours that the light is being used and considering the lifestyle explained, the use of light is:

Table 14. Timetable lights switched on.

LIGHTS. ON	JANUARY	FEBRURARY	MARCH	APRIL	MAY	JUN
Before break	7:00-8:30	7:00-8:30	7:00-8:30	7:00-8:30	-	-
After break	17:30-23:00	17:30-23:00	18:00-23:00	19:30-23:00	20:30-23:00	-

LIGHTS. ON	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Before break	-	-	7:00-8:30	7:00-8:30	7:00-8:30	7:00-8:30
After break	-	-	19:30-23:00	18:30-23:00	17:30-23:00	17:30-23:00

Source: own work

<u>Energy demand</u>

In order to obtain the energy demand of the internal loads, we consider that the average energy consumption per households and year for a person is 15165 kWh [37].
This consumption is the sum of the different activities in the households that demands energy, the distribution that we will consider is:

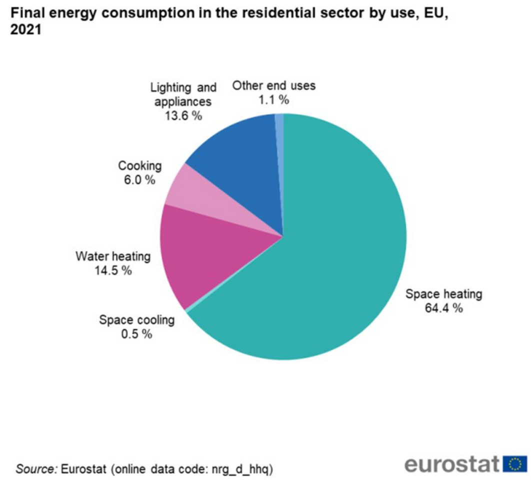


Figure 26. Household activities Energy Distribution Eurostat [38]

Therefore, the consumptions for one person will be:
- Space heating: 9.766,26 kWh
- Water heating: 2.198,925 kWh
- Lighting and appliances: 2.062,44 kWh
- Cooking: 909,9 kWh
- Other end uses: 166,815 kWh
- Space cooling: 75,825 kWh

In case of space heating and cooling system, we will keep the ventilation system from the first model since, in a first approach, it is very efficient. Therefore, the energy demand devoted to this activity will be assumed as the one from the ventilation system: 438 Wh/dia.

Regarding the lighting and appliances, we will consider that the maximum light consumption is 121W. Considering the number of hours that the lighting is switched on, the lighting consumption will be approximately 195kWh/year. Thus, the consumption due to the appliances is approximately 1.867,44 kWh, that we will consider simultaneously with the "Other end uses". Therefore, the complete demand of energy due to appliances will be 2034,355 kWh.

For the water heating, we will assume that we use a water heater standardized in SIMIEN and all the energy needed to obtain heat water will be provided by the electricity of the grid or from the solar panels.

In this case, the number of hours that the equipment is working will depend on the activity since it will not work as a timetable. We must consider that the equipment of the first model will remain the same (inverters, battery, computers, etc) and we will add the new consumption due to one person living in the building. Therefore, the number of hours for the equipment of the first model will still be 24h, meanwhile, in this new case, we will establish approximately the hypothesis of the hours considering the power of the proposed devices:
- General Domestic Appliances' hours of use: 2034,355 kWh/ 7,314 kW = 278,15 h/year = 1 h/day, 365 days.
- Cooking Appliances' hours of use: 909,9 kWh/ 2 kW= 454,95 h/year = 1,24 h/day

These hypothesis are exclusively done to adapt the situation to the SIMIEN data requirements.

<u>Other features</u>
The building is fully furnished as it will have the basic requirements of a household plus the equipment of the photovoltaic system.

Regarding the rest of the characteristics, the building structure and the construction characteristics will remain the same as well as the requirements of the passive house established in the first model.

b) SCENERARIO B: Two people living

Occupancy

Tiny houses can hold even two people living; therefore, it will be considered this possibility as well. The lifestyle will be considered the same: 16 hours inside the building on a regular day. It can be even considered a pet or a baby in this scenario of occupancy.

Lighting

The lighting will be considered the same as in the Scenery A.

Energy demand

In this case, some changes will be implemented as the building will be shared. Thus, some activities will have double consumption while others will be shared.

We consider that the average energy consumption per households and year for two people is 21154 kWh [37].

Considering the same distribution as in the Scenery A, the consumptions will be:

- Space heating: 13.623,18 kWh
- Water heating: 3.067,33 kWh
- Lighting and appliances: 2.876,94 kWh
- Cooking: 1.269,24 kWh
- Other end uses: 232,69 kWh
- Space cooling:105,77 kWh

For the appliances, in this case, the consumption will be 2.618 kWh plus "other end uses".

The rest of the contemplations made in the Scenery B remain the same.

Proceeding with the same criteria, we obtain the number of hours of use in this case for each activity will be:

- General Domestic Appliances' hours of use: 2850,69 kWh/ 7,314 kW = 389,76 h/year = 1h 30min/day, 365 days.
- Cooking Appliances' hours of use: 1.269,24 kWh / 2 kW= 634,62 h/year = 1 h 50 min/day

Other features

Same assumptions as the Scenario A.

5. New model simulation

By introducing all this data in the software of SIMIEN we can obtain the contribution of energy demand and heating that a person living in the building could cause.

5.1. Scenario A.

5.1.1. Energy resources

In this case, the energy resources needed remain the same: the electricity from the grid and the production of the solar panels. However, in this case we will need electricity to heat the water of the building, this will result in an increase of the energy demand and therefore, in a increase of the electricity that will be supplied.

5.1.2. Energy consumption

Adding the domestic appliances to the building system result in an increase of the energy demand, obtaining the same amount of energy needed by the existing equipment but with a new contribution due to the new devices introduced.

Simulating the new model in SIMIEN we obtain that the new demand of the "general appliances" is 2674 kWh, and the demand of the hob is 728 kWh. Therefore, introducing these elements will suppose a demand of 3402 kWh.

Moreover, we will have a new demand due to heat water. In this case, it will suppose an energy demand of 334 kWh.

Finally, these new contributions will have an influence on the ventilation system and the ventilation energy demand since it will suppose a new heat contribution that the ventilation system will need to counter. This new energy demand will be 156kWh.

Therefore, the new distribution will be approximately:

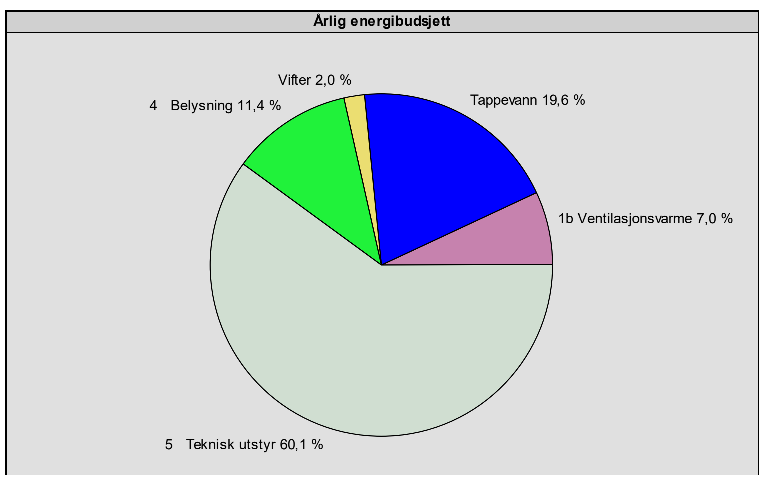


Figure 27. SIMIEN Annual Energy Budget

Without considering the existent equipment due to the solar panels of the passive house.

Meanwhile, the balance will be during the months will be approximately:

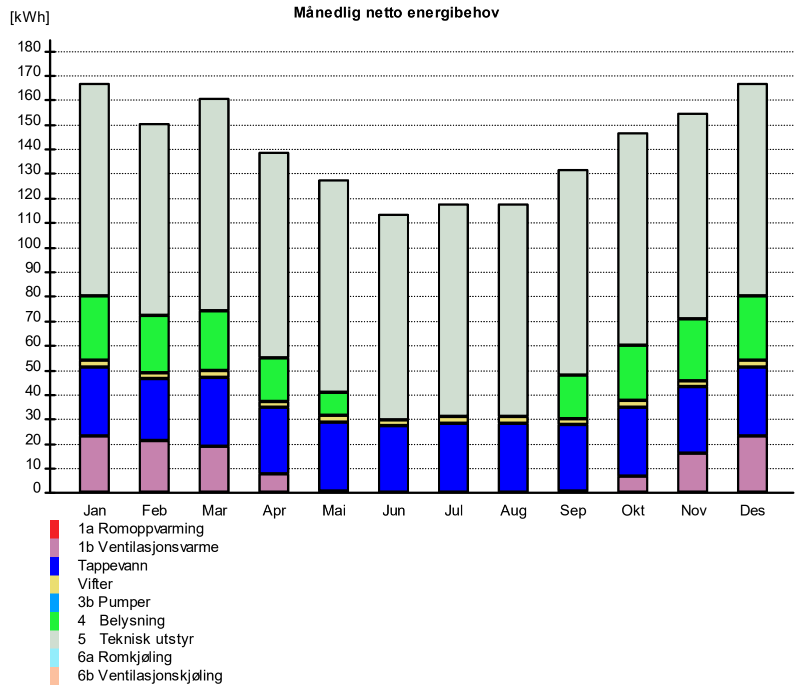


Figure 28. SIMIEN graph monthly net energy demand

In this case, comparing with the firs model, we are introducing the demand of the heat water. Meanwhile the rest of the demand structure remain the same: no light and no ventilation energy demand in the months of summer, while in the rest of year there is a consumption due to them. Regarding the heat water, we have assumed that the energy demand will always be the same in the year, however, we could make a difference between summer and winter months since the weather conditions have an influence on the heat water needed.

Both graphs are a model of the situation to have a better understanding of how the new situation will affect the balances of the first model. However, it remains as an approximation as the data can't be detailed introduced in the software of SIMIEN since we are missing some demand of the solar panel's equipment.

5.1.3. Heat balance

Regarding the heat balance, the losses due to the structure will remain the same, but the total balance will change.

However, there will be an increase in the heat gains due to the new domestic appliances:

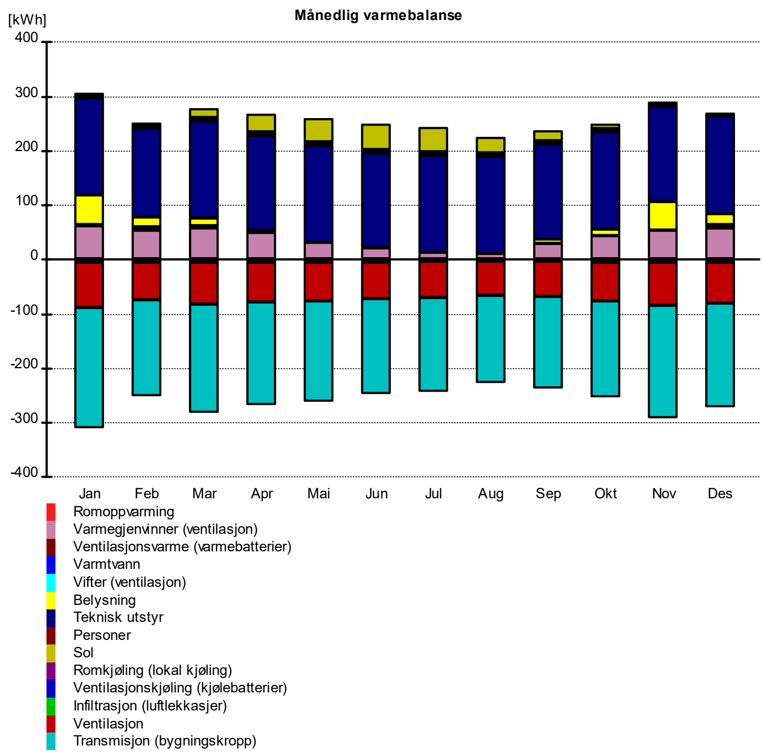


Figure 29. SIMIEN Heat Balance

As we can observe in the graph, the heat gains due to the equipment has increased considerably as now the number of electronic devices existent in the building has increased.

This will suppose a change in the temperature of the building that will result in a new demand of the ventilation system as mentioned before. Moreover, this may cause a need of employing a new heating room system to obtain the comfort temperatures for the occupancy level. As well as this, this may cause a need on changing the configuration of the current ventilation system.

5.1.4. Solar panels

In this case, we will continue with the same configuration of the solar panels, however, now the solar panels will not produce and excess of energy since the demand has increased.

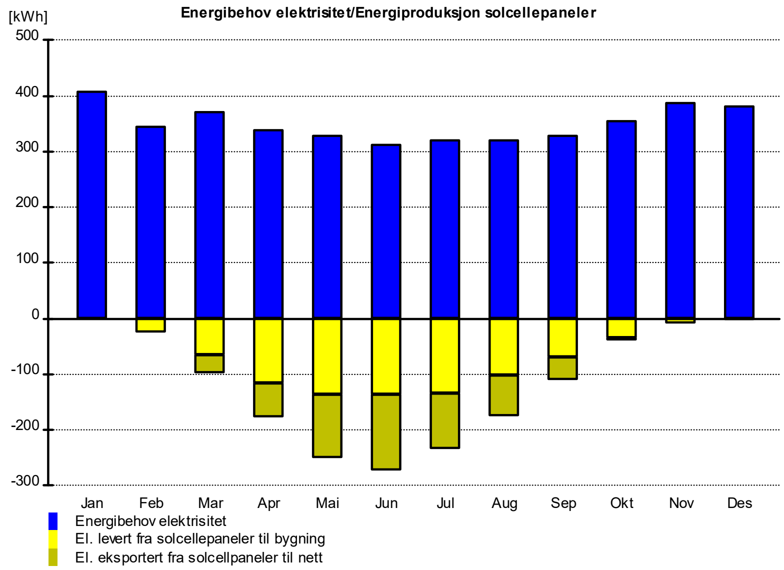


Figure 30. SIMIEN Energy demand electricity and Energy production.

The graph shows how now the solar panels can't cover the energy demand of the system. We need to consider that the solar energy production is not the real one comparing with the PVsyst. This may cause that in some months such as the summer months, the demand is in reality covered by the solar panels. However, this graph can be used as a reference of how the energy demand has been increased, and, therefore, how the new proposal of the angle inclination of the solar panels may result in a beneficial situation as the production will cover most of the months the energy demand.
Nevertheless, we must keep in mind that the electricity grid demand will be necessary since we are keeping the same energy flow model of the first SIMIEN simulation. In order to be self-sufficient in terms of energy, we must consider new changes, or we must evaluate new renewable energy sources after the change of the solar panel's inclination.

5.2. Scenario B.

5.2.1. Energy resources

In this case, the energy resources needed remain the same: the electricity from the grid and the production of the solar panels. However, comparing with the scenery A the energy demand will be higher as well as the electricity supplied to the house.

5.2.2. Energy consumption

Regarding the energy consumption, comparing with the scenario A, we observe how the total amount of energy demand is half doubled. As mentioned, not all the activities are doubled as some of them are shared, however, the energy demand has considerably increased.

5.2.3. Heat balance

The heat balance change considerably as well, since the energy demand increases and therefore, the heat gains increase. This ends up influencing the ventilation system that will require a bigger energy demand as the temperature will increase.

5.2.4. Solar panels

In this aspect, the situation of the scenario A gets worse as the energy demand is higher and the solar panels will not be enough to cover it.

The same proposes as reflected in the scenario A will help to improve the situation to be more self-sufficient.

6. Conclusion

This bachelor thesis has focused on the simulation of a passive house using SIMIEN software to analyse the energy flow and evaluate how the incorporation of people living in the building affects the energy needs of the house. Through the implementation of two different scenarios: one single person living or two people living, we have been able to identify the direct impact that the increase of the occupancy has on energy consumption, especially in terms of the use of additional appliances and the demand of a new hot water system.

The results of the simulations have shown that the energy flow model of the passive house can indeed adapt to changes in occupancy without compromising its efficiency. In the single occupant scenario, energy demand remained well within the limits of what the house's renewable energy system could support. When introducing a second occupant, while energy consumption increased, mainly due to more frequent use of appliances and increased demand on the hot water system. However, the results have reflected the need of introducing some improvements in the current model to cover the new energy demand. Several proposes have been made to improve the current model: change on inclination, employing efficient devices, etc. This must be considered in order to develop a good energy flow model that can cover the energy demand of people living in the building.

This study underlines the importance of designing energy flow models withing the architectural design of the buildings to cover the energy demands due to people living and to allow the self-sufficient energy living.

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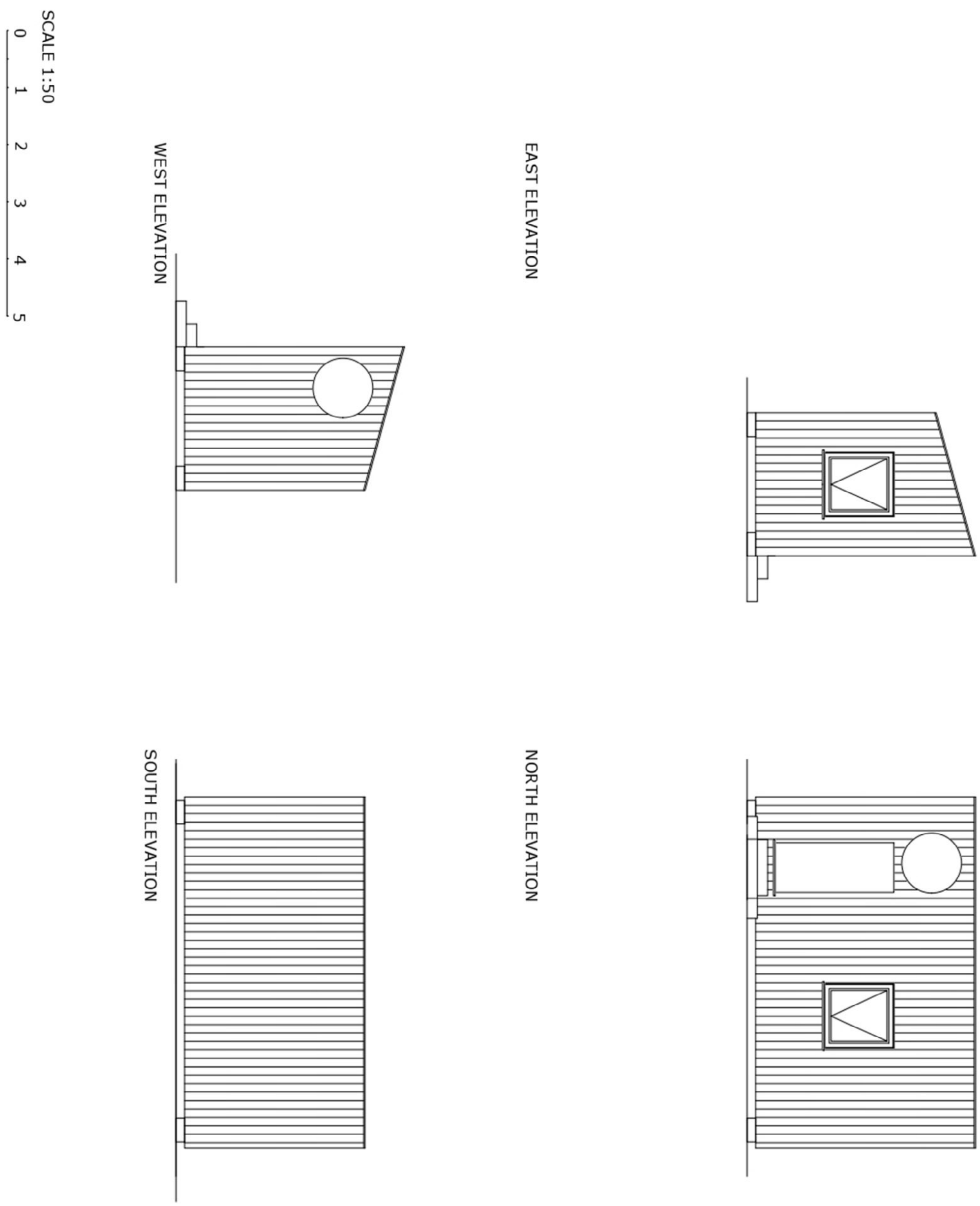
8. Attachments

Attachment 1

AutoCAD plane: Buildings surrounding the passive house

Attachment 2

AutoCAD plane: Views of the passive house



Attachment 3

Datasheet solar panel.

VIOLIN™

Crystalline PV Module ASM6610M Series

- With innovational 4-busbar cells
- Reducing cell series resistance
- Increasing cell efficiency
- More power output

275 | 280 | 285 | 290 | 295 | 300

EN

ELECTRICAL SPECIFICATIONS [1]						
STC [2] rated output (P_{max})	275 Wp	280 Wp	285 Wp	290 Wp	295 Wp	300 Wp
Standard sorted output			-0/+3%			
Warranted power output STC ($P_{nominal}$)	275Wp	280 Wp	285 Wp	290Wp	295 Wp	300 Wp
Rated voltage (V_{mpp}) at STC	31.45 V	31.55 V	31.65 V	31.75 V	31.85 V	31.95 V
Rated current (I_{mpp}) at STC	8.86 A	8.98 A	9.09 A	9.21 A	9.32 A	9.44 A
Open circuit voltage (V_{oc}) at STC	38.05 V	38.15 V	38.25 V	38.35 V	38.45 V	38.55 V
Short circuit current (I_{sc}) at STC	9.40 A	9.50 A	9.60 A	9.70 A	9.80 A	9.90 A
Module efficiency	16.81%	17.12%	17.42%	17.73%	18.03%	18.34%
Rated output (P_{mpp}) at NOCT [3]	205.6 Wp	208.9 Wp	212.2 Wp	215.6 Wp	219.0 Wp	222.4 Wp
Rated voltage (V_{mpp}) at NOCT	28.93 V	29.02 V	29.11 V	29.20 V	29.30 V	29.39 V
Rated current (I_{mpp}) at NOCT	7.11 A	7.20 A	7.29 A	7.38 A	7.47 A	7.57 A
Open circuit voltage (V_{oc}) at NOCT	35.17 V	35.26 V	35.35 V	35.44 V	35.54 V	35.63 V
Short circuit current (I_{sc}) at NOCT	7.60 A	7.68 A	7.76 A	7.84 A	7.92 A	8.00 A

Temperature coefficient (P_{mpp})	- 0.442 % / K
Temperature coefficient (I_{sc})	+0.042 % / K
Temperature coefficient (V_{oc})	- 0.329 % / K
Normal operating cell temperature (NOCT)	46 °C ±2 °C

Maximum system voltage	1000 V_{DC}
Number of diodes	3
Reverse current loadability (IR)	20 A
Maximum series fuse rating	15 A

[1] Measuring uncertainity Pmpp: +/−3 %; Tolerance for Voc, Isc, Vmpp and Impp: +/−10 %
[2] Standard test conditions that are defined as follows:
1.000 W/m² irradiation at a spectral density of AM 1.5 and a cell temperature of 25° C,
[3] Nominal operating temperature of the cell at 800 W/m² irradiation, 20°C ambient temperature, wind speed of 1 m/s
[4] Manufactured in an ISO9001/14001 certified facility

Made in Germany

A CHNT COMPANY

ASTRONERGY

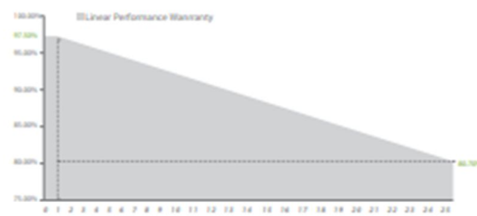
Attachment 4

Second Datasheet solar panel

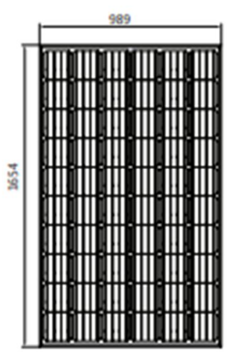
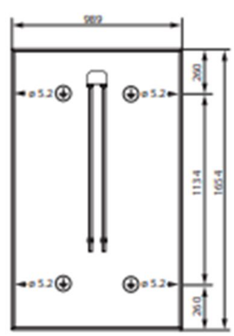
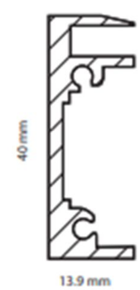
RELATED PARAMETERS	
Cell type	Monocrystalline cell, 4-busbar technology
Number of cells / cell arrangement	60 / 6 x 10
Cells dimension	157 x 157 mm²

MECHANICAL SPECIFICATIONS	
Outer dimensions (L x W x H) [5]	1654 x 989 x 40 mm
Frame technology	Aluminum, silver anodized
Module composition	Glass / EVA / Backsheet (white)
Weight (module only)	18.2 kg
Front glass thickness	3.2 mm
Junction box IP rating	IP 67
Cable length	1000 mm
Cable diameter	4 mm²
Maximum load capacity [6]	6000 Pa
Fire class (IEC 61730)	C
Connector type	MC4 pluggable

QUALIFICATION AND LINEAR WARRANTIES	
Product standard	IEC 61215 Ed. 2, IEC 61730
Extended product warranty [7]	12 years
Performance warranty [7]	Linear performance warranty
Year 1	>97.5% of warranted output power
Year 25	>80.7% of warranted output power



MODULE DIMENSION DETAILS

Front view	Side view	Rear view	Frame cross section
			

○ No mounting holes on the frame.

[5] Dimensional tolerance: +/−2 mm
[6] In accordance with IEC 61215 Ed. 2
[7] According to the current warranty conditions of Astronergy Solarmodule GmbH

www.astronergy.com Astronergy ASM6610M_TD_ EN_2016-02-18

Attachment 5

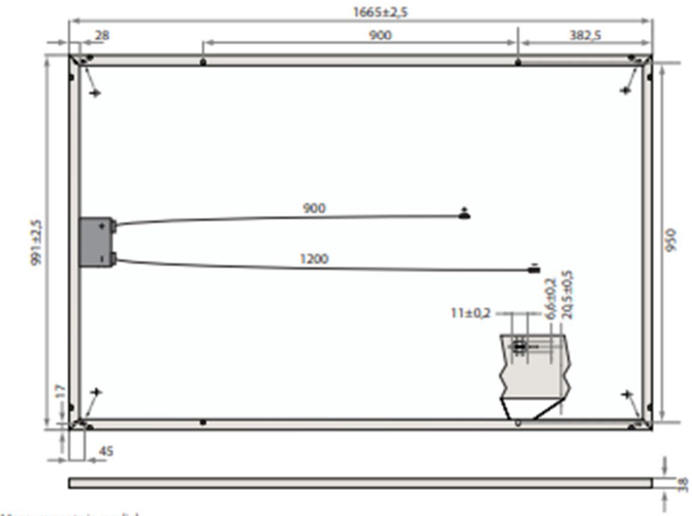
Datasheet solar panel

REC PEAK ENERGY SERIES

16.7% EFFICIENCY

10 YEAR PRODUCT WARRANTY

25 YEAR LINEAR POWER OUTPUT WARRANTY



Measurements in mm [in]

GENERAL DATA	
Cell type:	60 multicrystalline cells 3 strings of 20 cells in series
Glass:	3.2 mm solar glass with anti-reflection surface treatment
Backsheet:	Highly resistant polyester
Frame:	Anodized aluminum (silver / black)
Junction box:	3 bypass diodes, IP67 rated in accordance with IEC 62790
Cable:	4 mm² solar cable, 0.9 m + 1.2 m in accordance with EN 50618
Connectors:	Stäubli MC4 PV-KBT4/PV-KST4 (4 mm²) Tonglin TL-Cable01S-FR (4 mm²) in accordance with IEC 62852, IP68 only when connected
Origin:	Made in Singapore

ELECTRICAL DATA @ STC	Product Code*: RECxxxPE					
Nominal Power - P_{MPP} (Wp)	250	255	260	265	270	275
Watt Class Sorting - (W)	-0/+5	-0/+5	-0/+5	-0/+5	-0/+5	-0/+5
Nominal Power Voltage - V_{MPP} (V)	30.2	30.5	30.7	30.9	31.2	31.5
Nominal Power Current - I_{MPP} (A)	8.30	8.42	8.50	8.58	8.66	8.74
Open Circuit Voltage - V_{OC} (V)	37.4	37.6	37.8	38.1	38.4	38.7
Short Circuit Current - I_{SC} (A)	8.86	8.95	9.01	9.08	9.18	9.25
Panel Efficiency (%)	15.2	15.5	15.8	16.1	16.4	16.7

Values at standard test conditions (STC: air mass AM 1.5, irradiance 1000 W/m², temperature 25°C), based on a production spread with a tolerance of V_{OC} & I_{SC} ±3% within one watt class. At low irradiance of 200 W/m² at least 95.5% of the STC module efficiency will be achieved.
*Where xxx indicates the nominal power class (P_{MPP}) at STC indicated above, and can be followed by the suffix BLK for black framed modules.

MAXIMUM RATINGS	
Operational temperature:	-40 ... +85°C
Maximum system voltage:	1000 V
Design load (+): snow Maximum test load (+):	367 kg/m² (3600 Pa)* 550 kg/m² (5400 Pa)
Design load (-): wind Maximum test load (-):	163 kg/m² (1600 Pa)* 244 kg/m² (2400 Pa)
Max series fuse rating:	25 A
Max reverse current:	25 A

*Safety factor 1.5

ELECTRICAL DATA @ NMOT	Produkt Code*: RECxxxPE					
Nominal Power - P_{MPP} (Wp)	183	187	190	193	196	202
Nominal Power Voltage - V_{MPP} (V)	27.8	28.0	28.2	28.4	28.6	28.8
Nominal Power Current - I_{MPP} (A)	6.58	6.68	6.74	6.80	6.86	7.02
Open Circuit Voltage - V_{OC} (V)	34.7	34.8	35.0	35.3	35.7	36.0
Short Circuit Current - I_{SC} (A)	7.11	7.18	7.23	7.29	7.35	7.40

Nominal module operating temperature (NMOT: air mass AM 1.5, irradiance 800 W/m², temperature 20°C, windspeed 1 m/s).
*Where xxx indicates the nominal power class (P_{MPP}) at STC indicated above, and can be followed by the suffix BLK for black framed modules.

TEMPERATURE RATINGS*	
Nominal Module Operating Temperature:	45.7°C (±2°C)
Temperature coefficient of P_{MPP}:	-0.40 %/°C
Temperature coefficient of V_{OC}:	-0.27 %/°C
Temperature coefficient of I_{SC}:	0.024 %/°C

*The temperature coefficients stated are linear values

CERTIFICATIONS

IEC 61215, IEC 61730 & UL 1703; MCS 005, IEC 62804 (PID)
IEC 62716 (Ammonia Resistance), IEC 60068-2-68 (Blowing Sand)
IEC 61701 (Salt Mist level 6), UNI 8457/9174 (Class A), ISO 11925-2 (Class E)
ISO 9001: 2015, ISO 14001: 2004, OHSAS 18001: 2007

take-e-way WEEE-compliant recycling scheme

WARRANTY

10 year product warranty
25 year linear power output warranty
(max. degression in performance of 0.7% p.a.)
See warranty conditions for further details.

MECHANICAL DATA	
Dimensions:	1665 x 991 x 38 mm
Area:	1.65 m²
Weight:	18 kg

Specifications subject to change without notice.

Ref: NE-05-05-01Rev- 23 07.18

Founded in Norway in 1996, REC is a leading vertically integrated solar energy company. Through integrated manufacturing from silicon to wafers, cells, high-quality panels and extending to solar solutions, REC provides the world with a reliable source of clean energy. REC's renowned product quality is supported by the lowest warranty claims rate in the industry. REC is a Bluestar Elkem company with headquarters in Norway and operational headquarters in Singapore. REC employs more than 2,000 people worldwide, producing 1.5 GW of solar panels annually.

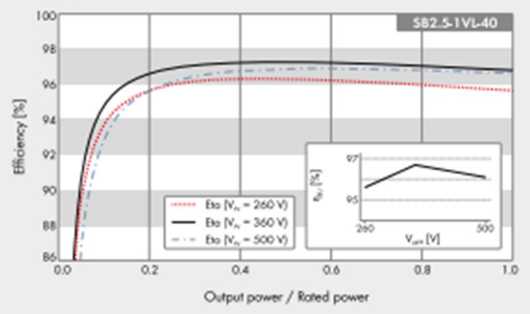
REC

www.recgroup.com

Attachment 6

Datasheet inverter.

Efficiency curve



● Standard features ○ Optional features – not available
Data in nominal conditions
Last updated: 07/2021

Technical Data	Sunny Boy 1.5	Sunny Boy 2.0	Sunny Boy 2.5
Input (DC)			
Max. PV array power	3000 Wp	4000 Wp	5000 Wp
Max. input voltage	600 V	600 V	600 V
MPP voltage range	160 V to 500 V	210 V to 500 V	260 V to 500 V
Rated input voltage	360 V		
Min. input voltage / initial input voltage	50 V / 80 V		
Max. input current per string	10 A		
Max. short-circuit current per string	18 A		
Number of independent MPP inputs / strings per MPP input	1 / 1		
Output (AC)			
Rated power (at 230 V, 50 Hz)	1500 W	2000 W	2500 W
Max. apparent power AC	1500 VA	2000 VA	2500 VA
Nominal AC voltage	220 V / 230 V / 240 V		
Nominal AC voltage range	180 V to 280 V		
AC grid frequency / range	50 Hz, 60 Hz / −5 Hz to +5 Hz		
Rated grid frequency / rated grid voltage	50 Hz / 230 V		
Max. output current	7 A	9 A	11 A
Power factor at rated power	1		
Adjustable displacement power factor	0.8 overexcited to 0.8 underexcited		
Feed-in phases / connection phases	1 / 1		
Efficiency			
Max. efficiency / Euro-eta	97.2 % / 96.1 %	97.2 % / 96.4 %	97.2 % / 96.7 %
Protective Devices			
DC side disconnection point	●		
Ground fault monitoring / grid monitoring	● / ●		
DC reverse polarity protection / AC short circuit current capability / galvanically isolated	● / ● / –		
All-pole-sensitive residual-current monitoring unit	●		
Protection class (according to IEC 61140) / surge category (according to IEC 60664-1)	I / III		
Reverse current protection	Not required		
General Data			
Dimensions (W / H / D)	460 / 357 / 122 mm (18.1 / 14.1 / 4.8 inches)		
Weight	9.2 kg (20.3 lbs)		
Operating temperature range	−40 °C to +60 °C (−40 °F to +140 °F)		
Noise emission, typical	< 25 dB		
Self-consumption (at night)	2.0 W		
Topology	Transformerless		
Cooling concept	Convection		
Degree of protection (according to IEC 60529)	IP65		
Climatic category (as per IEC 60721-3-4)	4K4H		
Max. permissible value for relative humidity (non-condensing)	100 %		
Features			
DC connection / AC connection	SUNCLIX / connector		
Display via smartphone, tablet, laptop	●		
Interfaces: WLAN / Ethernet	● / ●		
Communication protocols	Modbus (SMA, Sunspec), Webconnect		
Integrated shade management SMA ShadeFix	●		
Warranty: 5 / 10 / 15 years	● / ○ / ○		
Certificates and permits (more available upon request)	AS4777, C10/11, CE, CEI0-21, DIN EN 62109-1/IEC 62109-1, DIN EN 62109-2/IEC 62109-2, EN50438, G83/2, IEC61727, IEC62116, NBR16149, NEN-EN50438, NRS097-2-1, RfG compliant, VDE-AR-N4105, VDE 0126-1-1, VFR2014		
Country availability of SMA Smart Connected	AU, AT, BE, CH, DE, ES, FR, IT, LU, NL, UK		
Type designation	SB 1.5-1VL-40	SB2.0-1VL-40	SB2.5-1VL-40

Attachment 7

PVsyst: photovoltaic diagram