Master's thesis

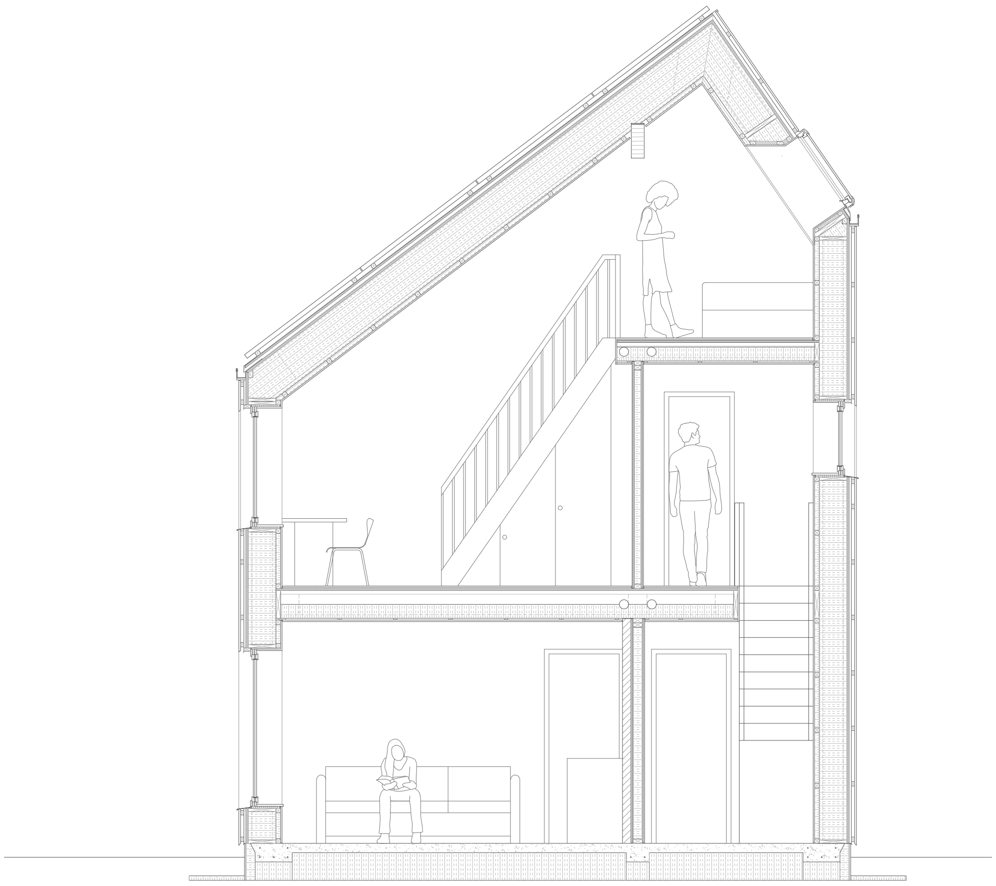
NTNU
Norwegian University of
Science and Technology
Faculty of Design and Architecture
Department of Architecture and Technology

Émilie Chartrand

Zero-emission low-rise student housing at Haugenhuset

Master's thesis in Master of Science in Sustainable Architecture
Supervisor: Tommy Kleiven

Trondheim, June 2020



NTNU
Norwegian University of
Science and Technology

Émilie Chartrand

Zero-emission low-rise student housing at Haugenhuset

Master of Science in Sustainable Architecture
Supervisor: Tommy Kleiven

Trondheim, June 2020

Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Architecture and Technology

NTNU
Norwegian University of
Science and Technology

ABSTRACT

In response to the need for student housing in Trondheim, Sit is expected to further expand its building stock. As being one of the main developers for student housing in the area, Sit has the opportunity and responsibility to contribute to lowering the emissions from its existing and new buildings by implementing low-carbon strategies. The potential of reducing the climate footprint of student housing is demonstrated in this thesis through the design of a set of five low-rise buildings at Haugenhuset, in Moholt Studentby. The buildings were designed based on the principles of zero-emission building and integrated energy design. The design was done on three levels, from the building, the neighbourhood, to the landscape.

The energy and environmental analyses were conducted from the preliminary stage of the design, informing the shape and layout. The roof plays a big role in the design concept, as it was shaped to optimize the on-site electricity generation, while providing space for a mezzanine. The simple and compact shape houses between five and eight students. The use of passive strategies are reflected in the orientation and configuration of the buildings. The configuration is inspired from the neighbouring brick buildings. A common outdoor space at the center of the site features a greenhouse made from reused bricks and windows from the existing building on-site.

The buildings generate enough renewable electricity to offset the emissions from operation. Consequently, this thesis showcases the potential of integrating such strategies in the design of low-rise student housing.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

CAV	CONSTANT AIR VOLUME
CO_2	CARBON DIOXIDE
CO_{2EQ}	CARBON DIOXIDE EQUIVALENT
DF	DAYLIGHT FACTOR
DHW	DOMESTIC HOT WATER
EPD	ENVIRONMENTAL PRODUCT DECLARATION
EPS	EXPANDED POLYSTYRENE
GHG	GREENHOUSE GAS
HRV	HEAT RECOVERY
kW	KILOWATT
kWh	KILOWATT-HOUR
LCA	LIFECYCLE ASSESSMENT
PV	PHOTOVOLTAIC
COP	COEFFICIENT OF PERFORMANCE
SCOP	SEASONAL COEFFICIENT OF PERFORMANCE
Sit	STUDENT WELFARE ORGANIZATION IN TRONDHEIM
SPF	SPECIFIC FAN POWER
TEK17	BYGGTEKNISK FORSKRIFT
U-value	THERMAL TRANSMITTANCE
XPS	EXTRUDED POLYSTYRENE
ZEB	ZERO-EMISSION BUILDING
ZEB-O	ZERO-EMISSION BUILDING IN OPERATION
ZEB-OM	ZERO-EMISSION BUILDING IN OPERATION AND MATERIALS

I:
INTRODUCTION

INTRODUCTION

BACKGROUND

The building and construction sector accounts for 39 percent of the total carbon emissions worldwide, with operational energy emissions accounting for 28 percent and embodied carbon emissions for the remaining 11 percent (World Green Building Council, 2019). In the transition to decarbonizing the sector, the construction of additional buildings should be limited and low carbon alternatives should be adopted. Limiting the construction of new buildings in the student housing sector is however a challenge since there is high demand for student housing in Trondheim. In 2019, over 3,000 students were on the waiting list to get housing with the Student Welfare Organization in Trondheim (Sit) (NTB, 2019). To reply to the demand, Sit is expected to build new student housing units in the upcoming years. With new projects comes the need to address and the opportunity to contibute the decarbonization of student housing construction by implementing low-carbon solutions as part of the rehabilitation and new construction process.

Sit is in charge of the welfare of the students in Trondheim. Housing is one of the main responsibilities of Sit and it houses around 6,400 students at the moment. The corporate social responsibility of Sit within sustainability and the environment is defined by the UN's sustainability goals. In terms of housing development, this translates in providing a high-quality living environment in an economically sustainable way, while reducing the climate footprint as much as possible. In an effort to understand the effectiveness and viability of different sustainable strategies, Sit wants to develop a living lab. The scale of the project is four to eight detached houses for one to two people. This lab would serve as testing for a set of solutions that could then be scaled up across other housing developments. The project would also provide inputs on the students' preferences and behavior under different solutions, therefore contributing to the state-of-the-art of sustainable student housing. Sit has targeted Haugenhuset as being the future living lab. Haugenhuset is located in Moholt, the largest student housing village in Trondheim. The site is 2,592 square meters and currently houses one residential detached building of 250 square meters built in the 1970s. The house is expected to be demolished and it is one of Sit's objectives to investigate the potential of reusing the materials from this house. Sit is open to different design solutions to achieve their sustainability goals.

SCOPE

The scope of this thesis is to design a set of low-rise student housing units at Moholt based on the principles of zero-emission building (ZEB) and integrated energy design. The design is done at different levels: single building, collection of buildings and landscape. One of the goals for the project is to reach ZEB-OM, which means that a building generates enough renewable energy to offset the greenhouse gas (GHG) emissions from its materials and operational energy over a lifetime of 60 years (Fufa et al., 2016). Complementary goals are to provide students with a high-quality environment both inside and around the buildings.

The main focus will be on the built form since the potential of reaching ZEB-OM is closely linked to the integration of energy and other technical analyses in the design of the building shape. Also, the building form has a larger impact on the building performance for small buildings. The efficiency and architectural quality of the space will also be accounted for in the design of the form. In addition to the form, other passive strategies will be looked into. The possibility to reuse some of the materials from the existing building will be investigated to reduce waste from building materials.

Overall, this thesis is a proposal of how to design student housing in a more sustainable way. There are different visions to sustainability and in this thesis, it is translated into limiting the GHG emissions from the construction and operation of new buildings. On a social perspective, it also means to increase the attractiveness of the common spaces for students to gather together and therefore limit loneliness.

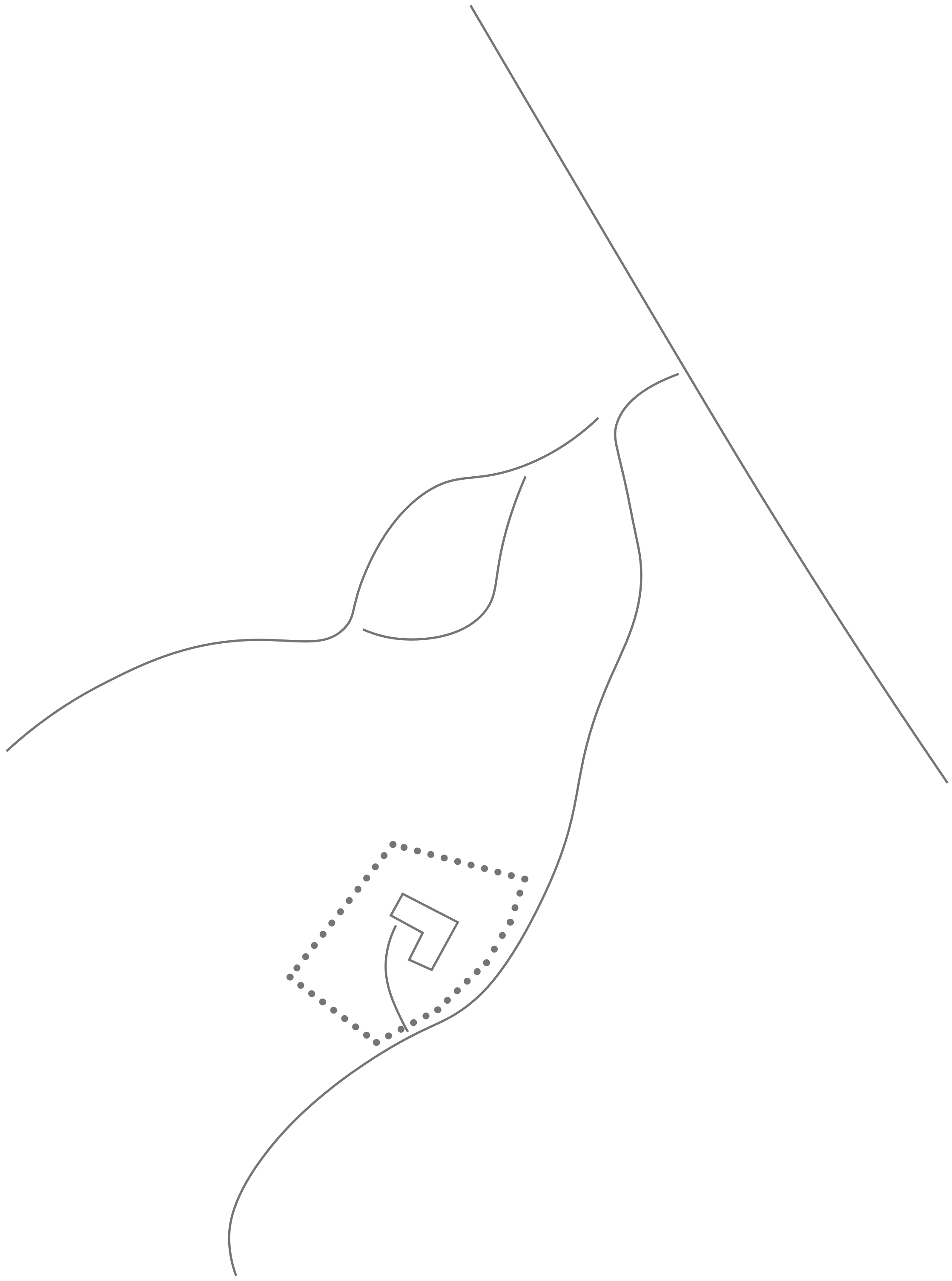
METHODOLOGY

Different steps were followed to complete the design of the buildings on site. First of all, documentation was gathered to get a better understanding of the site and the needs of Sit. Two meetings were held with Sit Bolig where they explained their vision and expectations of the project. A site visit was also done during the first visit to have a look inside the existing building as well as the surroundings. The progress was discussed every other week with the project's supervisor to get some feedback and ensure that the project is going in the right direction. Secondary research was done throughout the process to inform the design. Byggforsk (SINTEF, 2020) was consulted at many instances for building details and regulations. The ZEB pilot projects' documentation was also used for tips on how to achieve a zero-emission building.

1. The design started with the internal layout to have an idea of the size of the buildings and the number of students that could live in them.
    - Sketching was done, especially in the early stages of the project, to put on paper ideas and concepts.
    - AutoCAD was the main drawing tool used throughout the project.
2. An analysis of the roof shape was then perfomed to optimize the living space and the solar radiation on the roof, while minimizing the energy need.
    - The buildings were modelled in Rhino and the solar radiation simulations were conducted with Grasshopper.
    - The energy demand was obtained from energy simulations in SIMIEN.
3. Once the building form was set, the number of buildings and their placement was analyzed taking into account the terrain, solar radiation on the roof, sunlight duration on the common outdoor space, density, privacy and regulations.
    - A site model was laser cut to get a sense of the topography and the surrounding volumes. Styrofoam was used to represent the new buildings on the site model.
    - The sunlight and radiation simulations were conducted with Grasshopper.

4. Going back to the building scale, passive strategies were investigates. The window size and placement was determined, taking into account daylighting, natural ventilation and overall look on the facades. An overheating analysis and the effect of adding thermal mass was also done.
    - The interior of the buildings was modelled in Rhino and the daylight factor simulations were run with Grasshopper.
    - Airflow through natural driving forces were calculated with the use of Bernoulli's equations.
    - SIMIEN was used for the overheating analysis and for the thermal mass effect.
5. The building also relies on active strategies to provide a comfortable indoor environment. A simple design of the mechanical ventilation, space heating and domestic hot water systems was done. The energy sources available to the site were also looked at. The electricity output from the photovoltaic (PV) panels was also determined.
    - The heating demand was obtained through SIMIEN.
    - The renewable electricity produced from the PV panels was obtained through simulations on Grasshopper.
6. Going into more details, the building structure, foundations and acoustics was designed. The materials selection for each building component was also done.
    - Most of the design choices are based on the recommendations from Byggforsk.
    - Materials were selected based on their proximity to the site and their emission factor.
7. Zooming out to the site scale, the landscaping on site was designed, including the access, vegetation and common outdoor space.
    - Sketching and AutoCAD were used to come up with the landscaping design.
8. Once the design was almost completed, the emissions from operational energy and materials were calculated. The avoided emissions from PV panels were also calculated and then the ZEB balance calculations were done.
    - Emissions from operational energy was based on the energy simulation from SIMIEN.
    - Embodied emissions from materials were calculated based on a lifecycle assessment (LCA) of the buildings. The Environmental Product Declarations (EPD) from the Norwegian library were used as much as possible.
    - The ZEB balance calculations were done in the ZEB Tool developed by NTNU and Sintef.
9. The final design step was to produce the final drawings and illustrations.
    - AutoCAD was the main drawing tool used.
    - Adobe Photoshop was used to colour drawings and Adobe Illustrator was used to created illustrations.
10. In the end, reporting and presentation of the project was done.
    - Adobe InDesign was used to create the report and presentations throughout the project.

The report is divided in six main chapters: i) Site and context; ii) Concept and form; iii) Placement, access and landscaping; iv) Passive and active strategies; v) Materials and details; vi) ZEB balance. Finally, the main findings, limitations and further work is discussed.



II:
SITE &
CONTEXT

SITE & CONTEXT

MOHOLT STUDENTBY

Moholt Studentby was established in the 1960s and first welcomed students in the fall of 1964. Moholt was originally an agricultural land known to be 'rural' and 'green'. The first construction phase consisted in about 50 red-brick blocks of four storeys designed by architect Herman Krag. Krag won an architectural prize from Trondhjeim Bys Vel for the design of Moholt Studentby in 1974 (Brønmo, 1998). The student village expanded over the years, with the most recent expansion in 2015 with Moholt 50|50 to underline its 50 years of activity. Moholt 50|50, designed by MDF Arkitekter, features 632 accommodation units in five towers, a library and a kindergarten. The buildings were designed in cross-laminated wood elements.

Being the largest student village in Trondheim, Moholt offers several services in proximity to students. The site location and main services around are shown in Figure 1. The Folkebibliotek is at the center of the village. In addition to offer a space for students to borrow books and study, it has a cafe run by Sit and an activity space called Loftet on the second floor. Loftet is where events are held on the village, including quiz, game, music and movie nights. There is also a kids section on the first floor. Bunnpris is the closest grocery store on the village, but there is also Rema1000 across the street, as well as an Asian store called Bamboo on the village. The laundry is located on the ground floor of one of the towers and would serve the new buildings. Two student organizations have their quarters at Moholt: NTNUI Bumerang which rent out outdoor equipment to students free of charge and ReStore which collects and stores furniture from students moving out and giving it away for free to students moving in the next semester. Both organizations contribute to the village's sustainability by reducing goods waste and limiting consumption. There is an indoor gym, an exterior climbing wall and a beach volleyball field. Other services include a medical center and a hairdresser salon. Moholt is halfway between Gloshaugen and Dragvoll campuses, being around 30-minute-walk away from each.

BUILDING SITE

The site is located on top of a small hill along Moholt Alle, connecting the site to the intersection with Jonsvannsveien where the bus stops are. The area of the site is about 2,592 square meters. The site is bordered to the east by mature trees following the street line, and to the west by Moholt Barnahagen. A car parking lies between the site and the kindergarten. The proximity of the parking to the site is one of the project's weaknesses and special attention should be put in creating a transition between the parking and the buildings on site. There is currently garbage and recycling bins alongside the parking lot. Those could either be moved on the other side of the parking or bordered with vegetation to create a barrier with the new buildings.

The site is quite open and barely shaded from the surrounding buildings. Although there is a significant height difference between the plot and the waste disposal facility located to the north of it, the terrain is more or less even on the plot itself. The main feature is the height difference created by the retaining wall of Haugenhuset. There is currently an entrance path connecting Moholt Alle to Haugenhuset. That entrance path creates a drop in the terrain height: it is about one meter lower. The terrain slope slightly increases on each side of the entrance path.

SITE LOCATION
1:2000

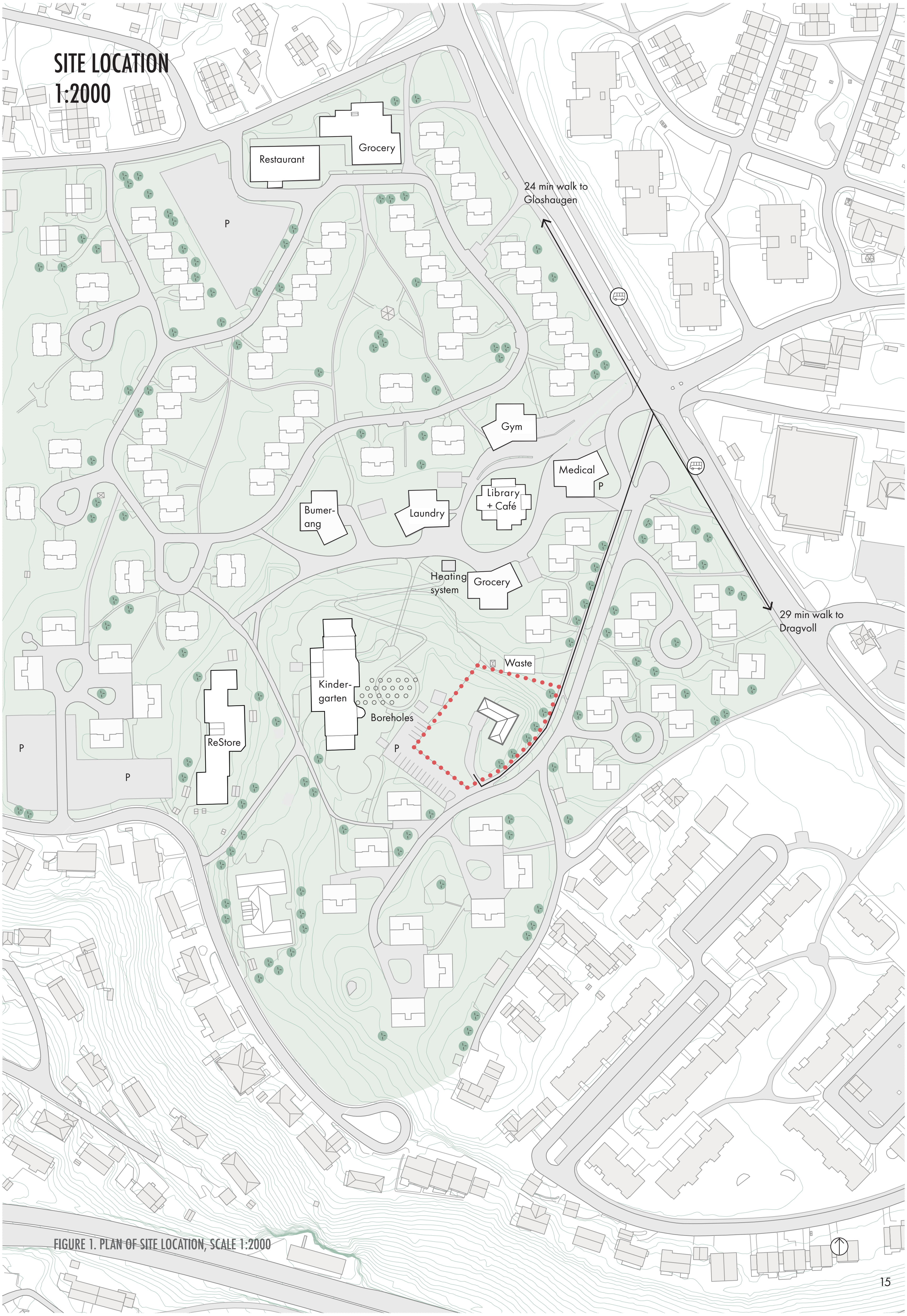


FIGURE 1. PLAN OF SITE LOCATION, SCALE 1:2000

HAUGENHUSET

The site houses a 250-square meter bungalow, Haugenhuset, built back in 1969. It is currently vacant and Sit is planning on demolishing it to create space for additional housing units on the village. The building structure is in concrete, covered with red bricks and wood cladding on the exterior. The roof structure is in wood and the cladding consists of red tiles. The L-shape building does not appear to have undergone major renovation work since its construction.

Original drawings of the house were provided by Sit. New drawings were created based on the original ones. The elevations of Haugenhuset are shown in Figure 2. The drawings were redone to easily estimate the quantity of each material that could possibly be reused in the project.

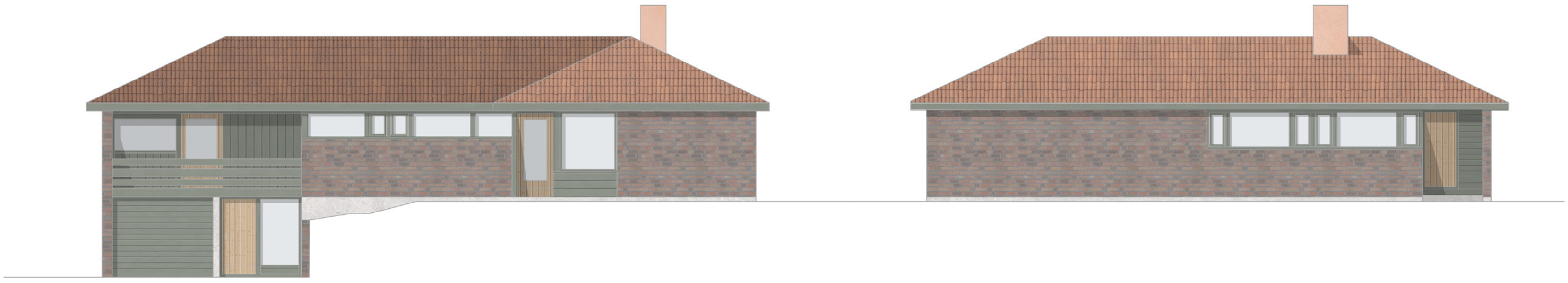
The main material featured in the building is red brick, covering about 136 square meters. Brick is a traditional material that has been used for years, especially for wall applications. It is a durable material that has a good thermal mass properties. Considering the higher carbon content of bricks, it is however usually not included as a new material in a zero-emission building project. Reused bricks on the other hand is a low-cost and low-carbon material to be integrated in the new buildings. Having bricks is also esthetically pleasing when installed indoors. The possibility of having a brick wall in the common area of the buildings is discussed in Chapter V. If there are bricks left, then they could be integrated in the landscaping. More information is provided in Chapter IV.

Wooden windows and doors have a long lifetime and can be use for other purposes when removed from their original location. Used wooden windows can also be part of new construction projects as it is the case with the experimental housing at Svartlamoen (Nøysom Arkitekter, 2017). For a Passive House building, used windows however don't have the required thermal resistance value and would result in higher heat loss. It was decided not to use the old windows for the main buildings but rather to reuse them to build a common greenhouse at the center of the site. Another option for reusing the windows would be to use them as a veranda or winter garden on the south side of the buildings. The greenhouse design is discussed in Chapter IV.

Further work would need to be done to investigate the potential of reusing the other materials either on the site or elsewhere. If not reused, the materials could be sold on GreenStock.no for example.

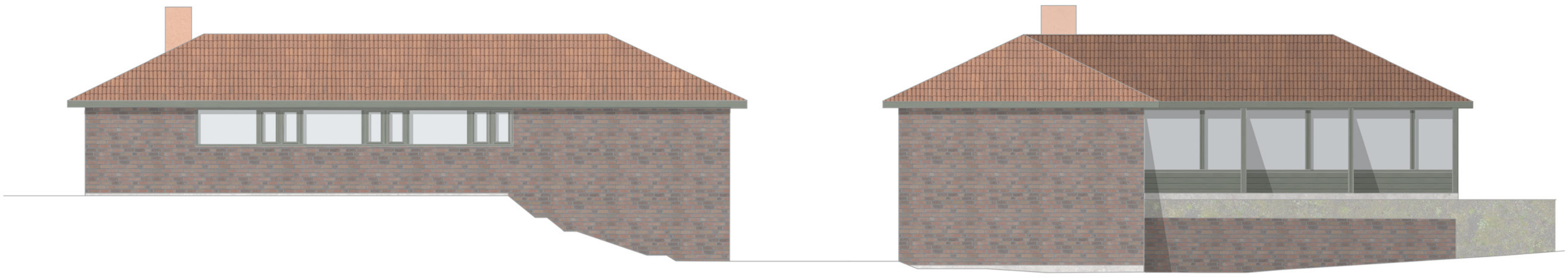
HAUGENHUSET

1:200



SOUTH

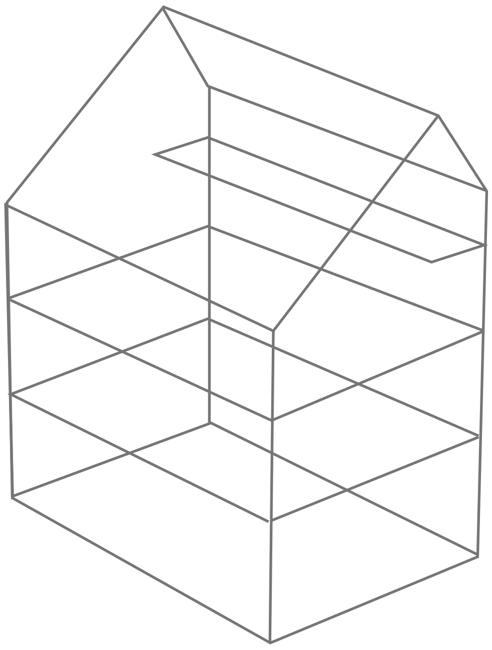
EAST



NORTH

WEST

FIGURE 2. ELEVATIONS OF HAUGENHUSET, SCALE 1:200 (ILLUSTRATIONS BASED ON DRAWINGS FROM 1970s)



III:
CONCEPT & FORM

CONCEPT & FORM

SCALE

The room program guidelines provided by Sit included a set of five to eight detached small houses, housing between one to two people. Building smaller-scale buildings enables Sit to test out solutions at a reasonable price range.

Following this approach, the building size was kept small, but large enough to house four to eight students, which is more representative of a typical collective in student villages.

ACCESSIBILITY

Accessibility was another requirement provided by Sit based on TEK17 guidelines (Direktoratet for Byggkvalitet, 2017). As stated in §1-3 (6), at least 20 percent of the housing units must meet the accessibility requirements in §12. This translates into having one accessible bedroom per collective, regardless of the number of bedrooms in the collective. The common area and bathroom must also be designed for accessibility purposes.

To limit the need for an elevator, the common area as well as the accessible bedroom were placed on the first floor together with a main bathroom available for all students and their visitors. The first floor is therefore designed to meet the accessibility requirements from TEK17.

BUILDING FOOTPRINT

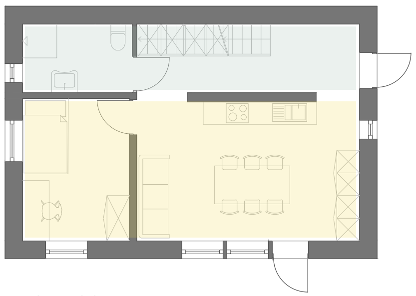
The footprint of the building was designed to fit a common area for four to eight students, a common accessible bathroom and one accessible bedroom. The size of the common area in a student collective varies, it is for example of about: 22 square meters for eight students at Berg studentby and 28 square meters for six students at Lerkendal studentby. The common area was set to about 22 square meters, while the accessible bedroom was set to a standard size of 11 square meters.

This yields to a rectangular building footprint having the capacity to house three bedrooms and a second bathroom upstairs, for a total of four bedrooms in the building.

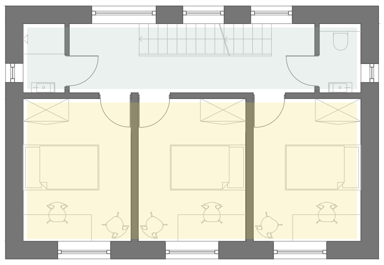
DIVISION

The floor plan is divided in two main distinct sections as shown in Figure 3: i) the service spaces, i.e. corridor, stairs, storage and bathrooms and; ii) the living spaces, i.e. living area, kitchen and bedrooms.

In addition to the bathroom on the first floor, the building also has bathroom services on the second floor. A compromise between having a single bathroom per room and one bathroom per floor was to split the bathroom services into two rooms: i) one with a sink and a toilet and; ii) another with a sink and a shower. This way, the toilet can be used while the shower is occupied, making it more convenient during rush hours, i.e. in the morning. The space under the straight staircase can be used for storage and for mechanical equipment.



FIRST FLOOR



SECOND FLOOR

🟨 Living area - bedrooms, kitchen & living room
▨ Service area - corridor, staircase, storage & bathrooms

FIGURE 3. ROOM DIVISION, SCALE 1:200

CONCEPT & FORM

ORIENTATION

The orientation of the rectangular building was set to maximize solar passive strategies, while limiting overheating.

In solar passive design, it is common practice in residential buildings to having living areas facing south with more fenestration to allow the solar heat to warm up the rooms, and the service areas in the north where the fenestration is less needed, therefore limiting heat losses on the coldest facade.

Although residential buildings can keep a comfortable indoor temperature without mechanical cooling due to the mild Norwegian summers, overheating is becoming more and more of an issue with the global warming phenomenon. Southern fenestration leads to higher risk of overheating.

A bedroom test was done in SIMIEN to assess the impact of orientation on the heating demand and the overheating hours. As expected, a bedroom with window facing south leads to a lower annual energy demand (by 6 percent), but a higher number of hours with indoor temperatures over 26 degrees Celsius (2.6 times) than the same bedroom but with a window facing north. In Trondheim, the number of hours above 26 degrees Celsius should be kept below 100 a year. The bedroom with window facing north leads to almost no overheating, but at an heating demand cost.

Fortunately, there are solutions to overcome overheating such as the use of shading devices and natural ventilation. The overheating and natural ventilation is discussed in Chapter V. Cooling through natural ventilation in Trondheim can prove to be effective in the summer since the outdoor temperatures in night time can go down to ten degrees lower than the peak temperatures in daytime. In Trondheim, the prevailing wind direction in the summer is from south as shown in Figure 4, enhancing single-sided ventilation. Occupancy is lower in the summer in student housing, especially during daytime, where the highest temperatures occur, since students are most probably at work or some other places. It was therefore decided to orient the rectangular building with its longer axis in the east-west direction with living areas facing south and service areas facing north as shown in Figure 5. Having the longer axis in the east-west direction is also beneficial for on-site solar electricity generation.

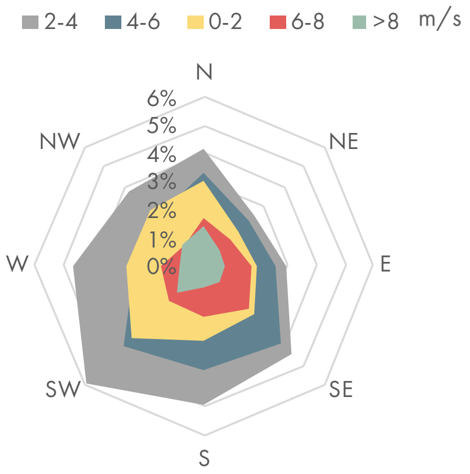
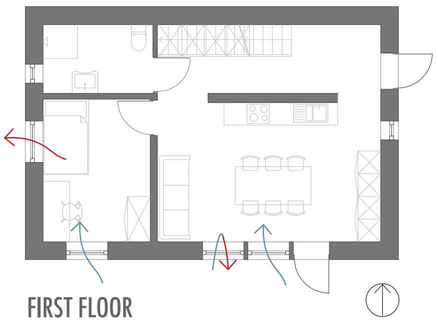
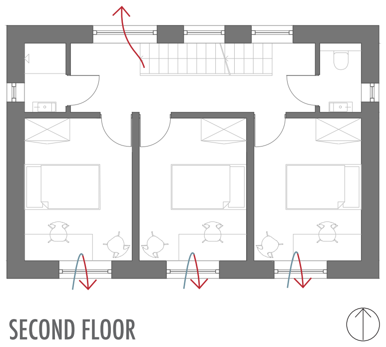


FIGURE 4. AVERAGE ANNUAL WIND SPEED AND DIRECTION FOR TRONDHEIM (DATA FROM EPW FILE)



FIRST FLOOR

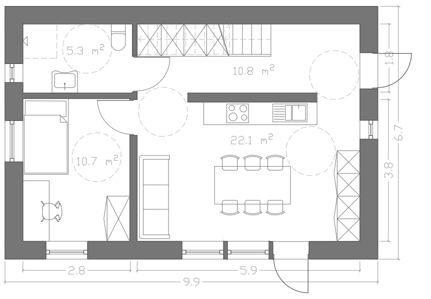


SECOND FLOOR

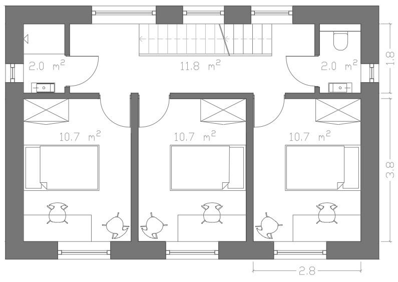
FIGURE 5. BUILDING ORIENTATION, SCALE 1:200

CONCEPT & FORM

4-BEDROOM LAYOUT
1:200



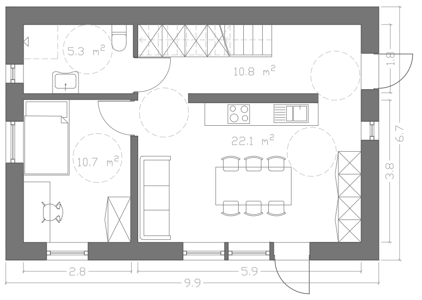
FIRST FLOOR



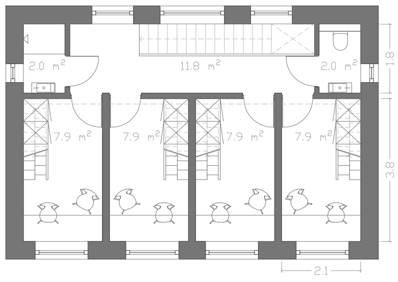
SECOND FLOOR

FIGURE 6. FLOOR PLAN OF FOUR-BEDROOM UNIT, SCALE 1:200

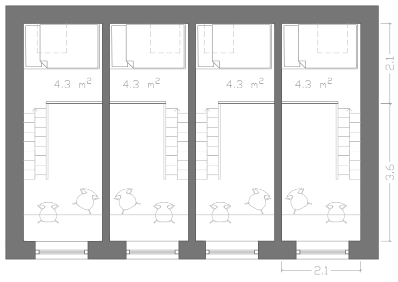
5-BEDROOM LAYOUT
1:200



FIRST FLOOR



SECOND FLOOR



MEZZANINE

FIGURE 7. FLOOR PLAN OF FIVE-BEDROOM UNIT WITH MEZZANINE, SCALE 1:200

SLOPED ROOF & MEZZANINE ROOM

To balance the emissions from construction and operation, zero-emission buildings invest in on-site renewable energy production. Solar photovoltaic panels mounted on the building roof is a common strategy.

The optimal angle for solar radiation in Trondheim is about 40 degrees from the horizon. Tilting the roof can therefore result in higher solar radiation per surface area. Having a sloped roof increases the heated volume, but a larger volume does not necessarily result in higher emissions per heated floor area as there is a possibility to add an extra floor to occupy the volume.

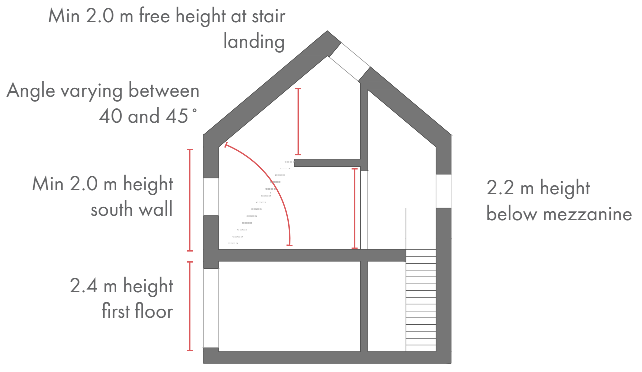
The possibility to arrange the bedrooms on the second floor with a mezzanine was investigated. The mezzanine is used as a sleeping area, whereas the first level of the room is furnished with a desk and sitting area. The space under the stairs can be used for storage and wardrobe. The area of the mezzanine was designed to fit a two-meter long bed that can be placed in both directions.

The width of one bedroom can be reduced from 2.8 to 2.1 meters by adding a mezzanine, creating space for an extra bedroom on the second floor. Although the volume and heated floor area increase with a sloped roof and mezzanine, the volume and heated floor area per student decreases, making the building more compact.

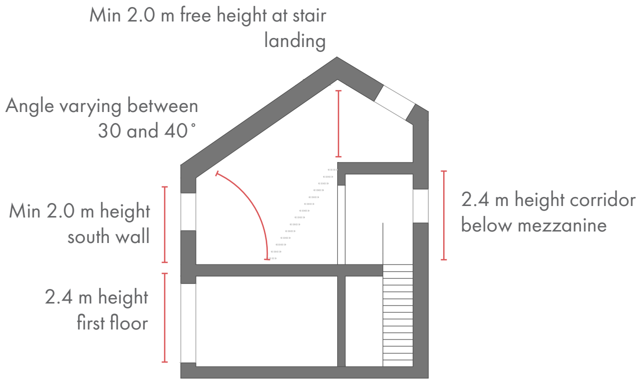
SLOPING ANGLE ANALYSIS

A more detailed analysis of the roof inclination was conducted to assess which shape is best suited for this project. A set of building models were tested out. Four types of sloped roof models were analyzed: i) symmetrical roof; ii) asymmetrical roof with peak at stair landing (asymmetrical 1); iii) asymmetrical roof with pitch at start of bed (asymmetrical 2) and; iii) monoslope roof. A roof angle of 30, 35 and 40 degrees was used for asymmetrical and monoslope roofs, while an angle of 40 and 45 degrees was used for the symmetrical roof. All building models have the same footprint, the flat roof model houses four students, while the sloped roof models house five students. A free height of 2.0 meters was used at the stairs landing up to the mezzanine, as required by TEK17. A minimum height of 1.0 meter was used for the wall on the north side of the mezzanine, while a minimum height of 2.0 meters was used for the wall on the south side on the lower level of the room. At first, the height of the south wall was set to 1.8 meters, but it was found that an extra 0.2 meters led to be better daylight quality. The symmetrical roof was included in the analysis as it represents more traditional roof construction in Norway. In that configuration, the sleeping mezzanine is over the bedroom itself, instead of being over the corridor. A free height of 2.2 meters was kept under the mezzanine.

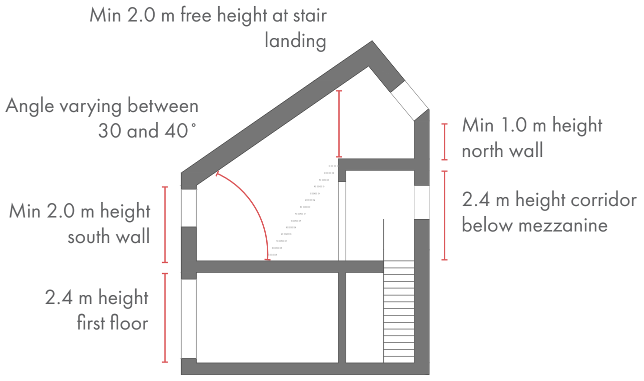
Design parameters for the tested building models are summarized in Figure 8 and the 12 building models are presented in Figure 9.



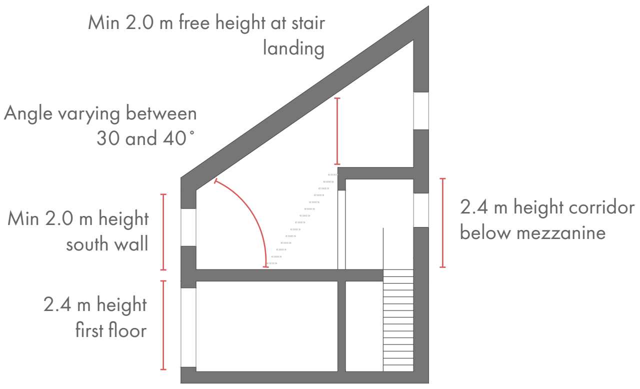
A) SYMMETRICAL



B) ASYMMETRICAL 1: WITH PEAK AT STAIR LANDING



C) ASYMMETRICAL 2: WITH PEAK AT START OF BED



D) MONOSLOPE

FIGURE 8. TYPES OF ROOF SHAPE TESTED AND DESIGN CONSTRAINTS, SCALE 1:200

CONCEPT & FORM

The energy need, the exterior surface of materials, the PV production potential on the roof, as well as the architectural quality of the space were factors accounted for. The exterior surface was used as a simplified indicator of embodied emissions from materials. It is the exterior surface measured from the interior. The energy need was obtained from SIMIEN simulations. It was assume that the entire south roof surface is covered of PV panels in the calculation of the annual radiation. The PV production potential was obtained from multiplying the annual radiation on the roof by an efficiency factor of 15 percent. The PV production was estimated to get an idea whether the surface of the roof is large enough to offset the emissions from operation. The specific energy need and the annual energy need do not take into account the presence of PV panels. The results are compiled in Table1.

Just by looking at the total annual energy need, the flat roof model has by far the lowest need when compared to the other shapes. However, when looking at the energy need per student, the flat roof has a higher need than most sloped roof models. The same conclusion applies for the exterior surface of a flat roof compared to a sloped roof. When it comes to PV production, the flat roof option has a similar output to that of the sloped roof models E and F. However, a higher number of PV panels is needed on the flat roof since the irradiation (solar radiation per square meter) is less on a flat surface. More PV panels result in more embodied emissions. Since the emissions from PV panels are significant, it is best to go for the sloped roof option that has less PV panels for the same output.

Overall, the opportunities created a sloped roof surpass those of a flat roof in this project. Indeed, the sleeping area in the mezzanine creates a nice architectural feature to the bedroom in addition to resulting in higher electricity production from the PV panels on the south-facing roof. It also creates space for an extra room on the second floor.

Now, moving to the comparison between the different sloped roof models. If the objective was solely to limit embodied and operational emissions, then the 'asymmetrical 1' shape or the symmetrical shape would be chosen, with model E being the best option. Indeed, the energy simulations show that, in general, the lower the heated volume, the lower the energy need. However, the PV production does not seem to be large enough to cover the emissions from the energy need, especially for model B. In the case of the symmetrical roof, having the sleeping mezzanine in the bedroom itself rather than over the corridor, like it is the case for the other roof shapes, reduces the quality of the space below the mezzanine. In an aim to reach a ZEB-OM balance, a larger roof is beneficial for maximizing solar production. Moving the pitch of the roof further back, as it is the case for the 'asymmetrical 2' shape, increases the area of the south roof. It also increases the headspace in the mezzanine space, which results in a more comfortable space. That comes at an energy cost, but the additional energy need is not significant when compared to the increase in PV production. Models H and I seems to be two good options that result in higher PV production than energy need. The PV production is at its highest for the monoslope shape since the entire roof area is facing south. On the other hand, this model also has the highest energy consumption due to its higher volume. From the monoslope models, model K seems to be the best compromise between PV production and energy need. The architectural quality of the space must also be accounted for in the selection of the roof shape. Special attention was put to ensure that the additional volume created by the sloped roof is transformed in useful liveable area. Although the monoslope roof leads to the highest PV compensation, the sleeping area it creates is not optimal in terms of space efficiency. Having an 'asymmetrical 2' roof would create a space that is more suited to the function of a sleeping area and adds the possibility to have a skylight rather than a vertical window, enhancing the daylight quality throughout the room.

TABLE 1. ROOF SHAPE ANALYSIS

Roof	Floor area (BRA) m^2	Heated volume1) m^3	Exterior surface2) m^2	Exterior surface / Volume3)	Exterior surface / BRA	South roof area m^2	Irradiation $kWh/m^2/yr$	Radiation kWh/year	PV production4) kWh/year	Specific energy need $kWh/m^2/yr$	Annual energy need kWh/year	Energy need per student kWh/year
A	102.6	231.6	254.0	0.96	2.48	64.2	885	56,776	8,516	79.2	8,124	2,031
B	120.4	295.7	292.7	0.85	2.43	41.9	1,130	47,380	7,107	82.8	9,975	1,995
C	120.4	295.1	292.0	0.86	2.43	45.4	1,127	51,150	7,673	82.7	9,954	1,991
D	120.4	298.8	294.3	0.87	2.43	47.0	1,106	52,031	7,805	82.9	9,986	1,991
E	120.4	288.7	289.0	0.87	2.40	49.3	1,119	55,155	8,273	82.6	9,942	1,988
F	120.4	297.1	293.4	0.86	2.44	52.8	1,130	59,668	8,950	82.9	9,985	1,997
G	120.4	298.8	294.3	0.87	2.44	57.1	1,106	63,196	9,479	83.1	10,006	2,001
H	120.4	292.9	292.7	0.88	2.46	60.1	1,119	67,217	10,083	82.9	9,942	1,997
I	120.4	307.2	304.8	0.87	2.53	65.1	1,130	73,505	11,026	83.8	10,094	2,081
J	120.4	313.1	314.7	0.88	2.61	74.1	1,106	81,949	12,292	85.0	10,230	2,046
K	120.4	308.0	314.6	0.91	2.65	78.1	1,119	87,393	13,109	85.0	10,233	2,047
L	120.4	324.0	329.0	0.89	2.73	83.8	1,130	94,649	14,197	86.4	10,404	2,081

1) excluding partitions 2) measured from the interior 3) including partitions 4) PV production = Radiation * 15%

CONCEPT & FORM

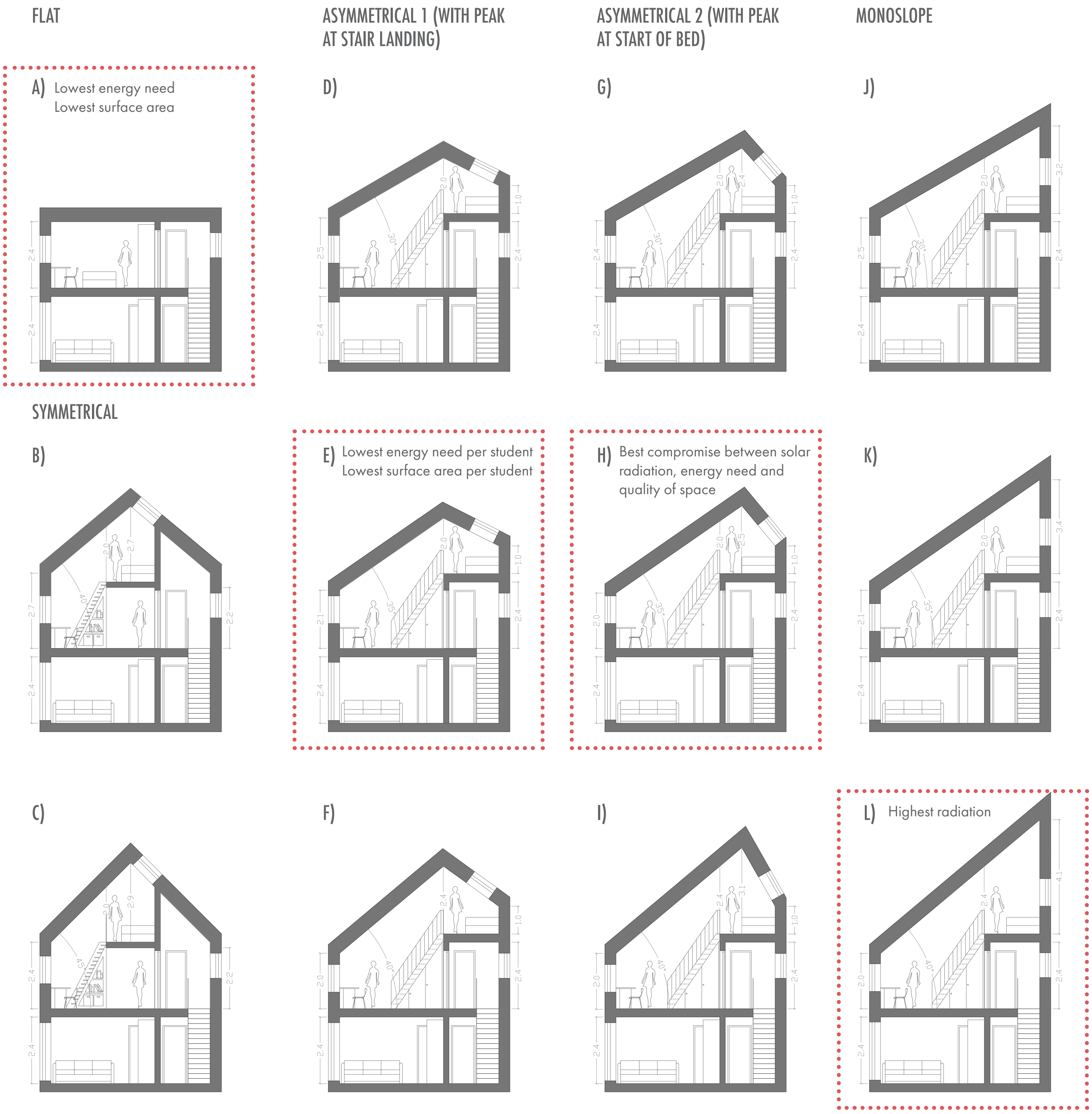


FIGURE 9. SECTION OF DIFFERENT ROOF CONFIGURATIONS, SCALE 1:200

CONCEPT & FORM

FIGURE 10. ELEVATIONS OF DIFFERENT ROOF CONFIGURATIONS, SCALE 1:200

CONCEPT & FORM

To compare the different models in terms of greenhouse gas emissions, a more detailed analysis of the embodied emission for each model would have been needed. Kristjansdottir et al. (2018) conducted a similar roof shape analysis where they accounted for the embodied emissions from materials. The study revealed that 'the extra embodied emissions in the roof and external wall constructions are small compared to the emission benefits of the PV system' when comparing a monoslope roof to a set of different roof constructions. The findings of that study are therefore similar to those obtained in this roof analysis.

Finally, it can be concluded that:

- Asymmetrical 1 (Model E) would be the best option to limit embodied and operational emissions;
- Monoslope (Model K) would be the best option to reach ZEB-OM;
- Asymmetrical 2 (Model H) would be the best compromise between reaching a ZEB building and having a high-quality space in the mezzanine room.

The elevations of all three options are shown in Figure 10.

As a compromise between reaching ZEB-OM and providing an attractive space for students, the roof model with 'asymmetrical 2' sloped roof was chosen. A sloping angle of 35 (model H) to 40 degrees (model I) seems to provide the best room configuration taking into account the design constraints. In the end, it was decided to go for an angle of 37 degrees. Having an angle of 37 degrees instead of 35 degrees enables the south-facing roof to have an additional row of PV panels in portrait arrangement. The chosen roof shape is presented in Figure 11.

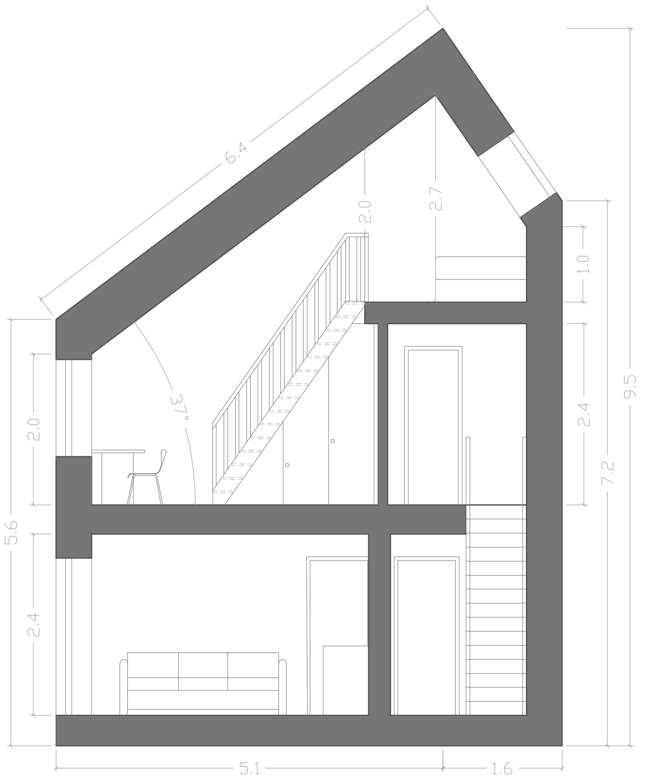


FIGURE 11. 37-DEGREE ROOF SHAPE, SCALE 1:100

CONCEPT & FORM

STAIRS TO THE MEZZANINE

One of the main architectural challenges in the design of the bedrooms with mezzanine was the stairs up to the mezzanine. The design of stairs is regulated by TEK17. According to §12-14, the stairs leading to a measurable area must be compliant to TEK17. On the other hand, stairs to a non-measurable area are exempt from the regulations. A measurable area is defined as a building volume having a free height of 1.9 meters or more on a width of at least 0.6 meter based on §5-4 (2).

Obviously, having a measurable area on the mezzanine would lead to a more comfortable space that could not only be used to crawl in to sleep, but also for standing up and walking around without worrying about the headspace. Reducing the mezzanine space to a non-measurable area would mean to change the roof shape, decreasing the PV collection area as shown in Figure 12a.

A TEK17-compliant staircase requires a width of 0.8 meters and stair run of at least 0.25 meters, occupying a fairly large area of the room as shown in Figure 12b.

Considering that the traffic in the staircase is limited to one person in a compact housing unit, it was decided to go for a samba staircase up to the mezzanine. A samba staircase is a space- and resource-saving construction that would be easy and safe to use, and also fulfill other intentions of the regulations. A width of 0.6 meters was chosen for the samba stairs. Having a samba stairs also gives the opportunity to have a larger desk with space for an extra chair if a visitor is coming (Figure 12a).

The room could still fit a TEK17-compliant staircase as the free height at landing is 2.0 meters, but that would result in less usable space on the lower level. Illustrations of both types of staircases are shown in Figure 12.

INCREASE DENSITY

The possibility of increasing the number of bedrooms in the building was further studied by adding a storey to the building, resulting in a collective for eight students.

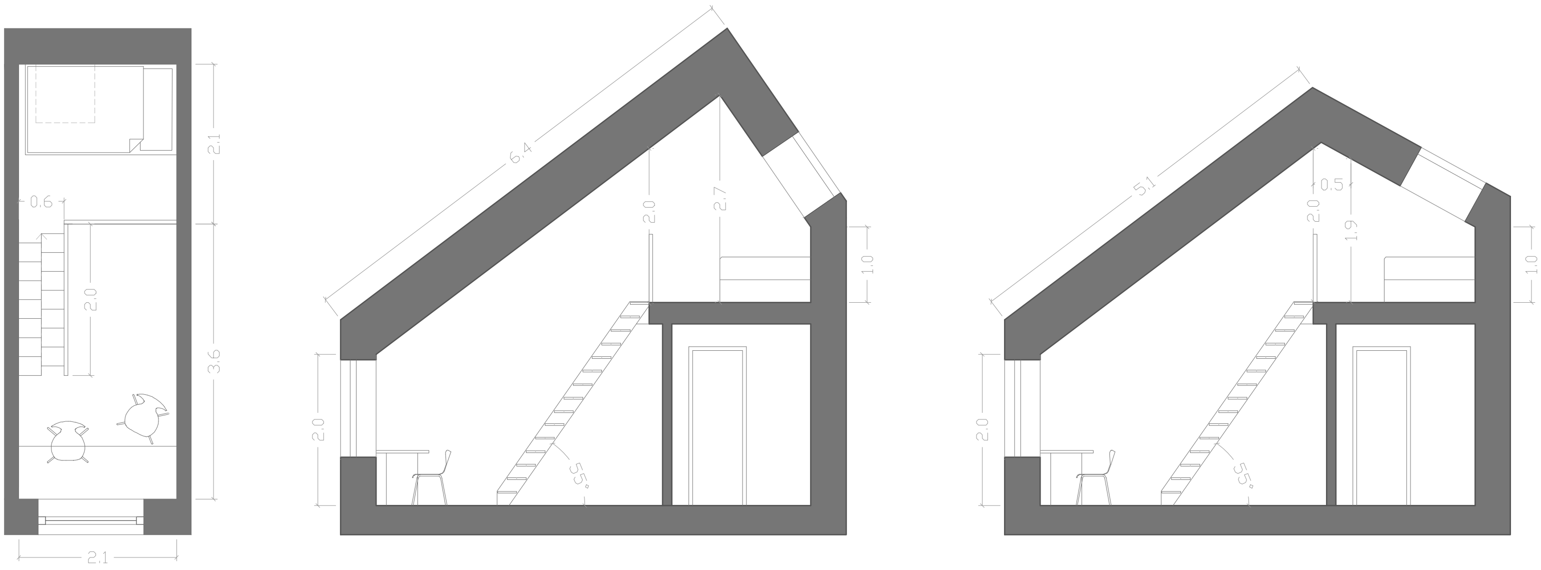
The building has the same footprint as the five-student building and the same layout on the first floor, proving the layout's flexibility to adapt to the number of students. It was deemed reasonable to have a common living area of 22 square meters for eights students, as it is the case at Berg Studentby. The second floor was designed to fit three bedrooms of equal size.

Adding a storey increases the space efficiency as it reduces the volume and floor area per person. It also gives the opportunity to have higher buildings at the north of the site for PV production. Having both two-storey and three-storey buildings on the site also creates some dynamism.

Floor plans and elevations of the two-storey and three-storey buildings are illustrated in Figures 13 to 20.

CONCEPT & FORM

A) SAMBA STAIRS


MEASURABLE AREA ON THE MEZZANINE

NON-MEASURABLE AREA ON THE MEZZANINE

B) TEK17 stairs

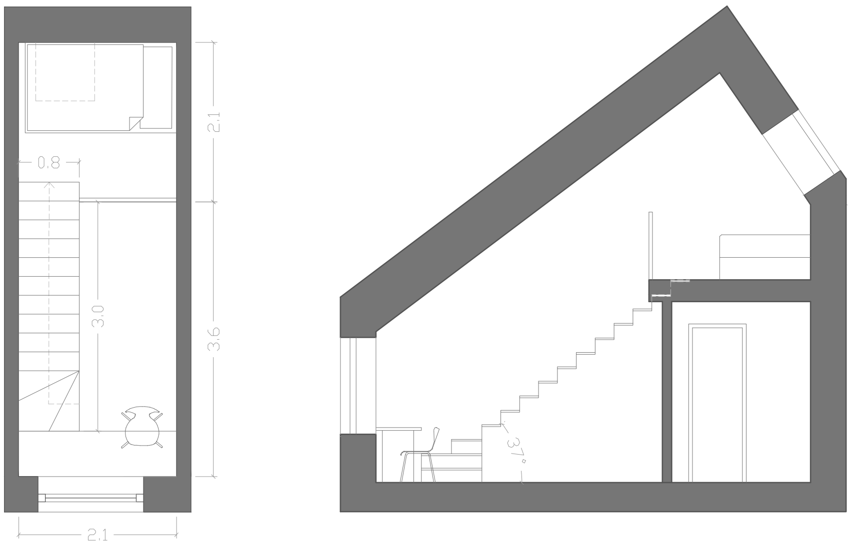
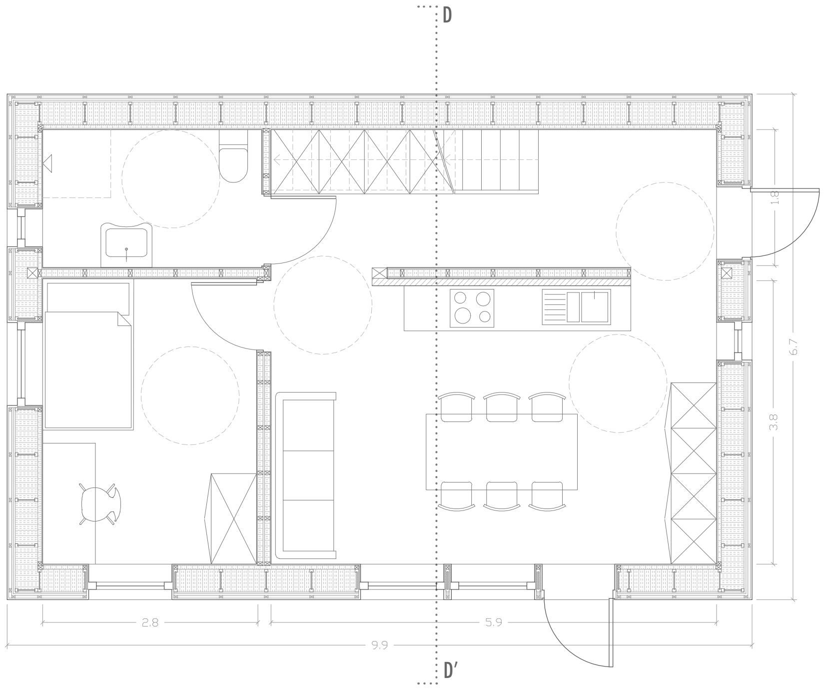
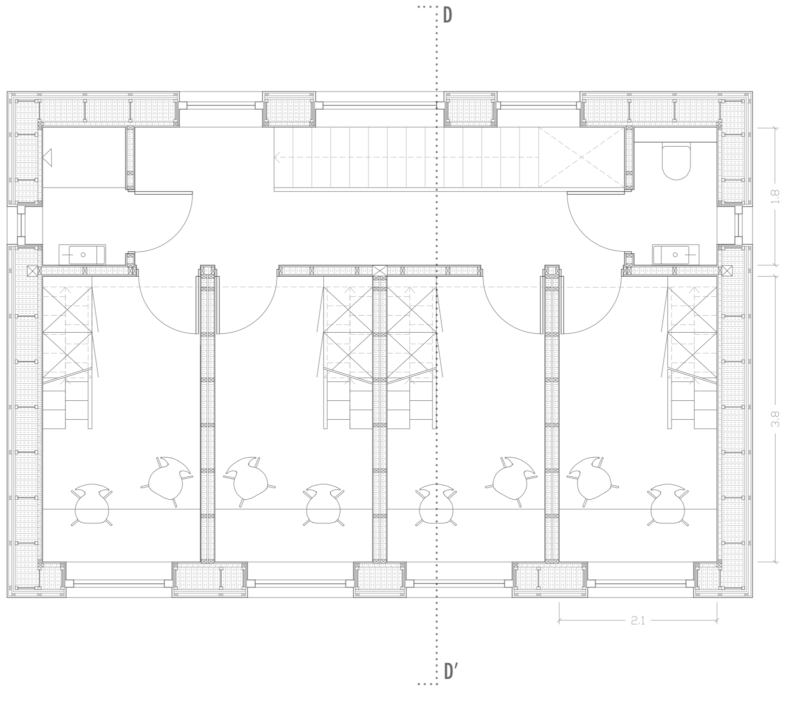


FIGURE 12. PLAN AND SECTION OF DIFFERENT STAIR CONFIGURATIONS, SCALE 1:100

FLOOR PLANS
1:100
2-STOREY BUILDING



FIRST FLOOR



SECOND FLOOR

FIGURE 13. FLOOR PLANS OF THE TWO-STOREY BUILDING, SCALE 1:100

FLOOR PLANS
1:100
2-STOREY BUILDING

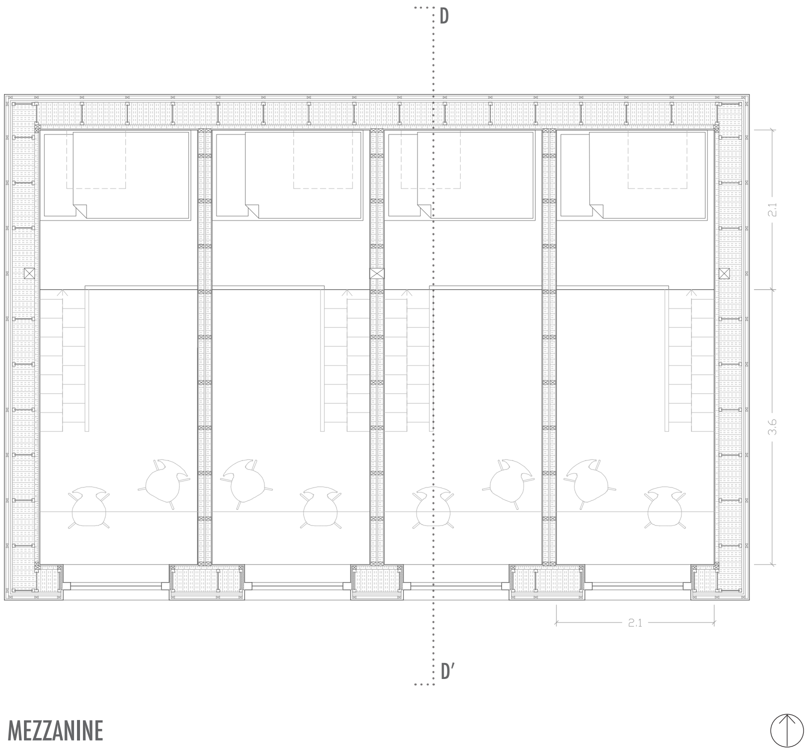


FIGURE 14. FLOOR PLANS OF THE TWO-STOREY BUILDING, SCALE 1:100 (CONTINUED)

ELEVATIONS

1:100

2-STOREY BUILDING

SOUTH

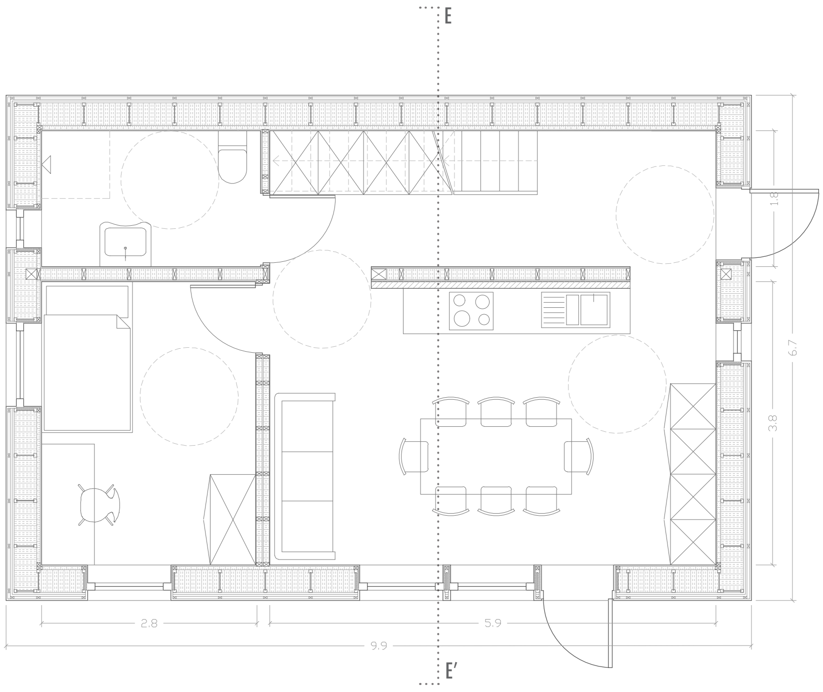
EAST

FIGURE 15. ELEVATIONS OF THE TWO-STOREY BUILDING, SCALE 1:100

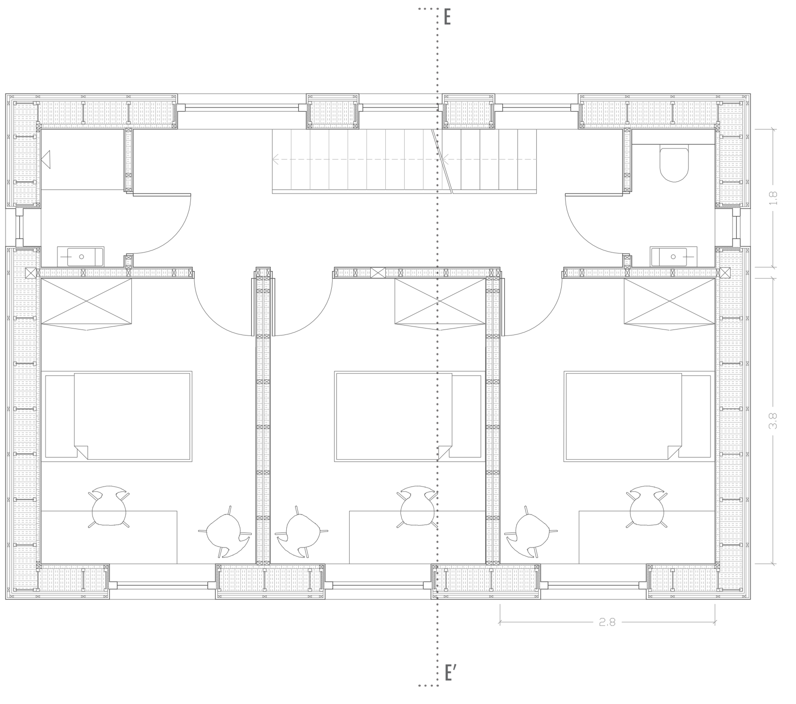
ELEVATIONS
1:100
2-STOREY BUILDING

FIGURE 16. ELEVATIONS OF THE TWO-STOREY BUILDING, SCALE 1:100 (CONTINUED)

FLOOR PLANS
1:100
3-STOREY BUILDING



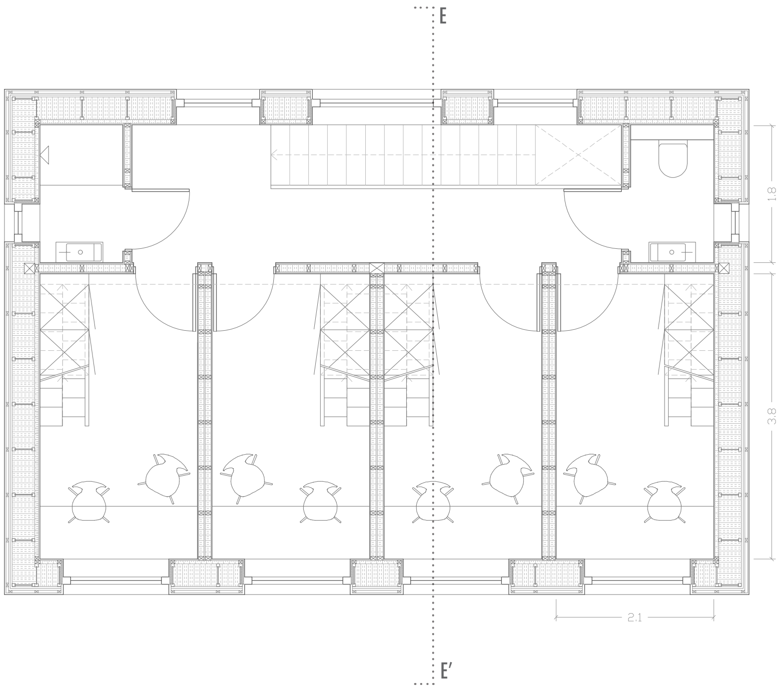
FIRST FLOOR



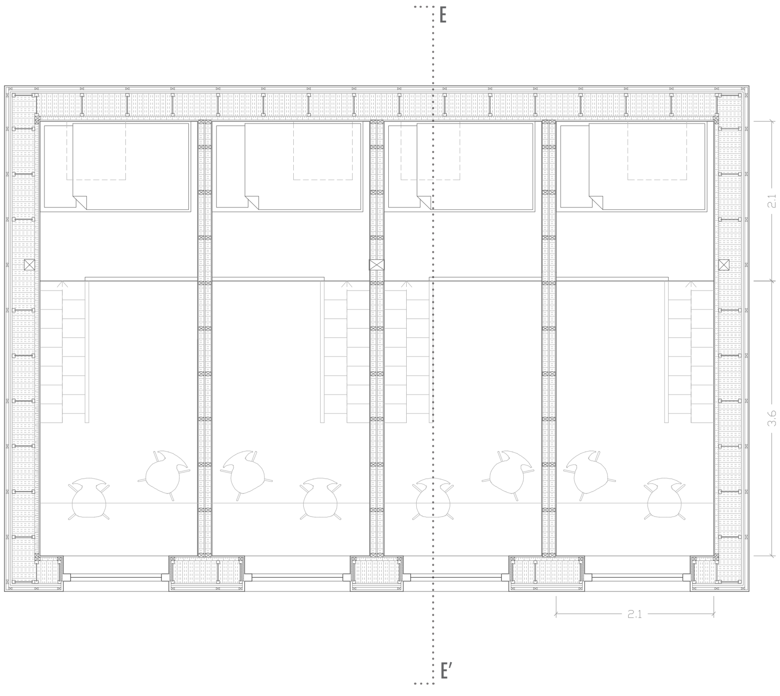
SECOND FLOOR

FIGURE 17. FLOOR PLANS OF THE THREE-STOREY BUILDING, SCALE 1:100

FLOOR PLANS
1:100
3-STOREY BUILDING



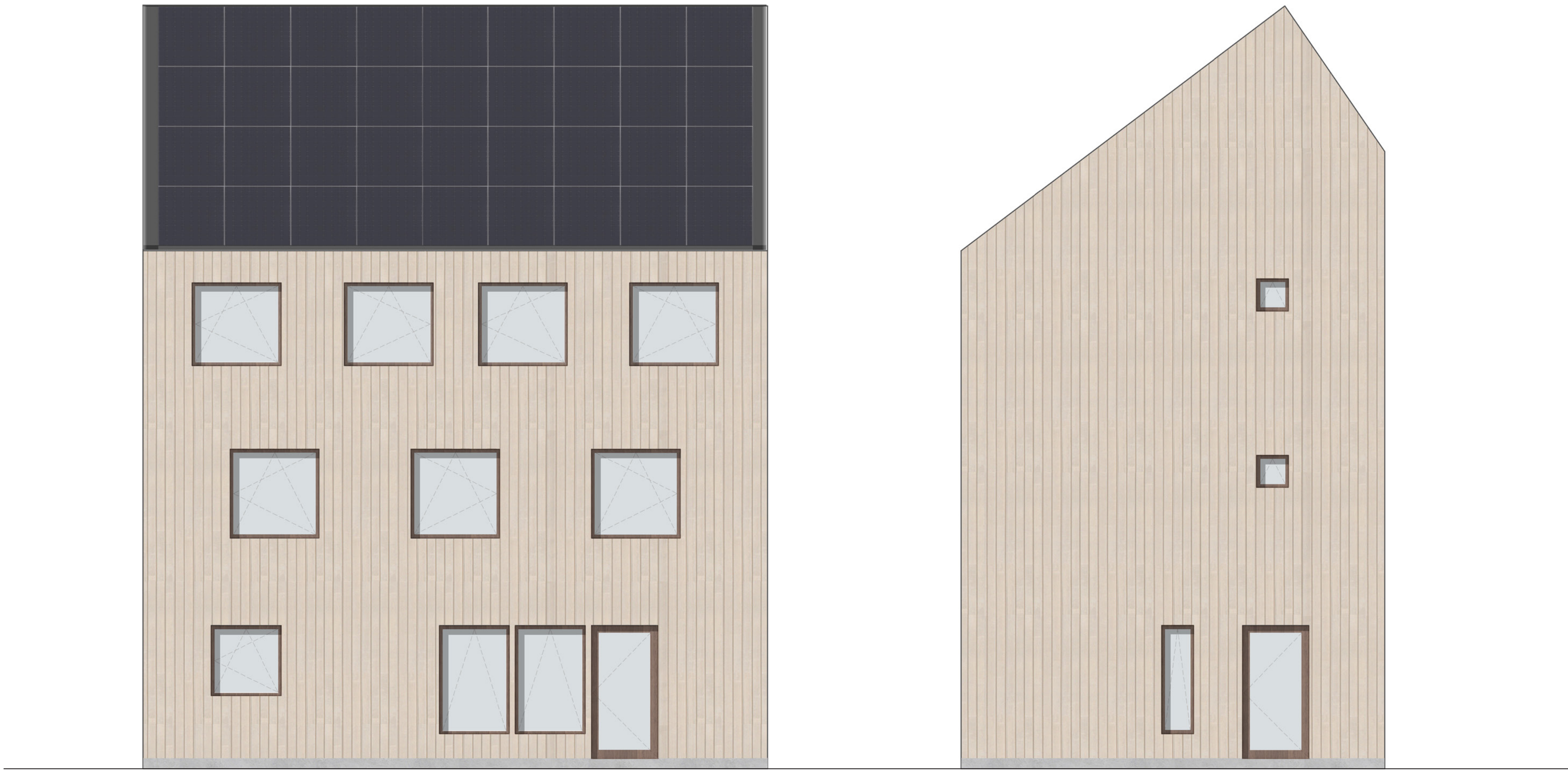
THIRD FLOOR



MEZZANINE

FIGURE 18. FLOOR PLANS OF THE THREE-STOREY BUILDING, SCALE 1:100 (CONTINUED)

ELEVATIONS
1:100
3-STOREY BUILDING



SOUTH

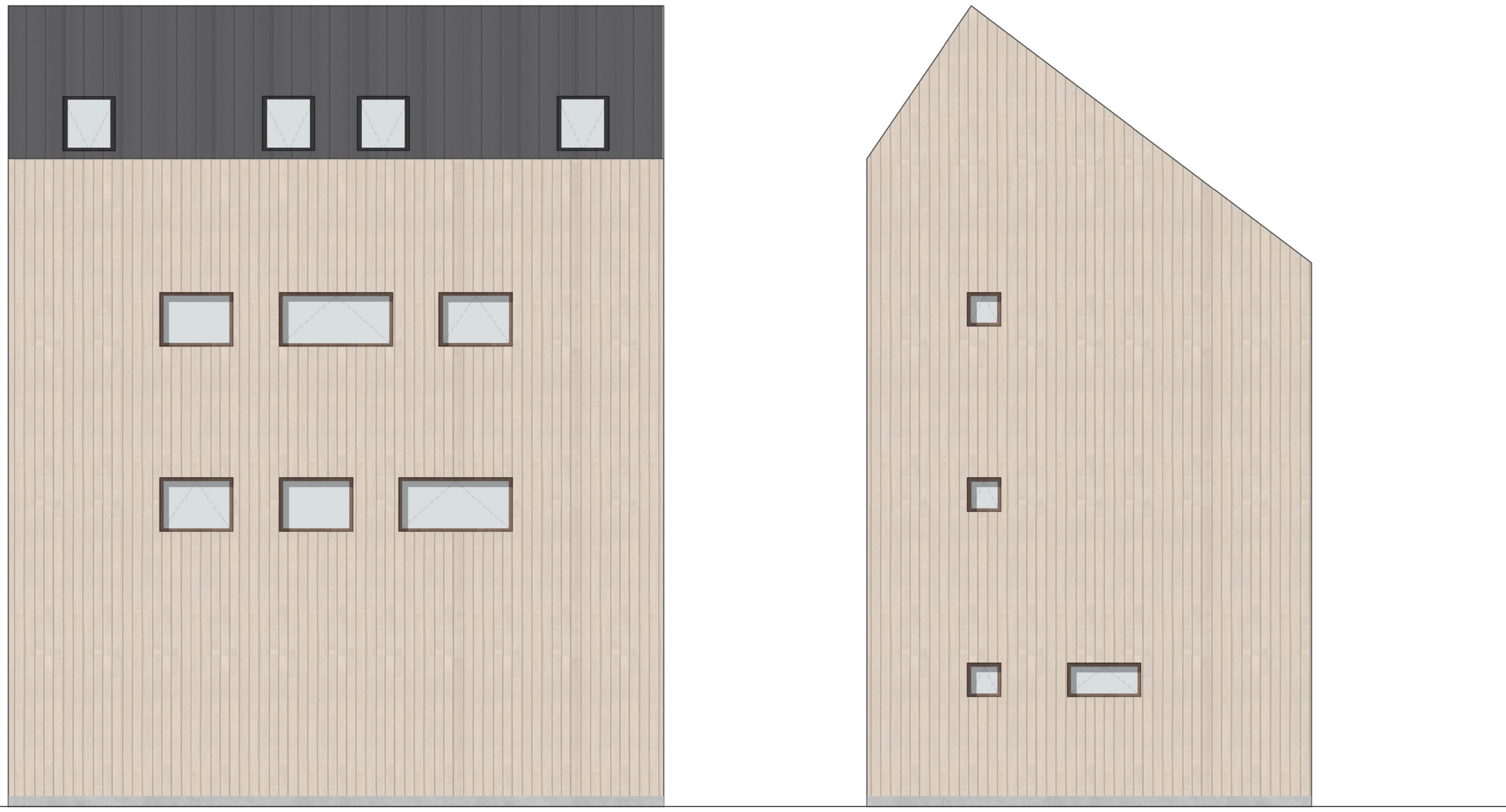
EAST

FIGURE 19. ELEVATIONS OF THE THREE-STOREY BUILDING, SCALE 1:100

ELEVATIONS

1:100

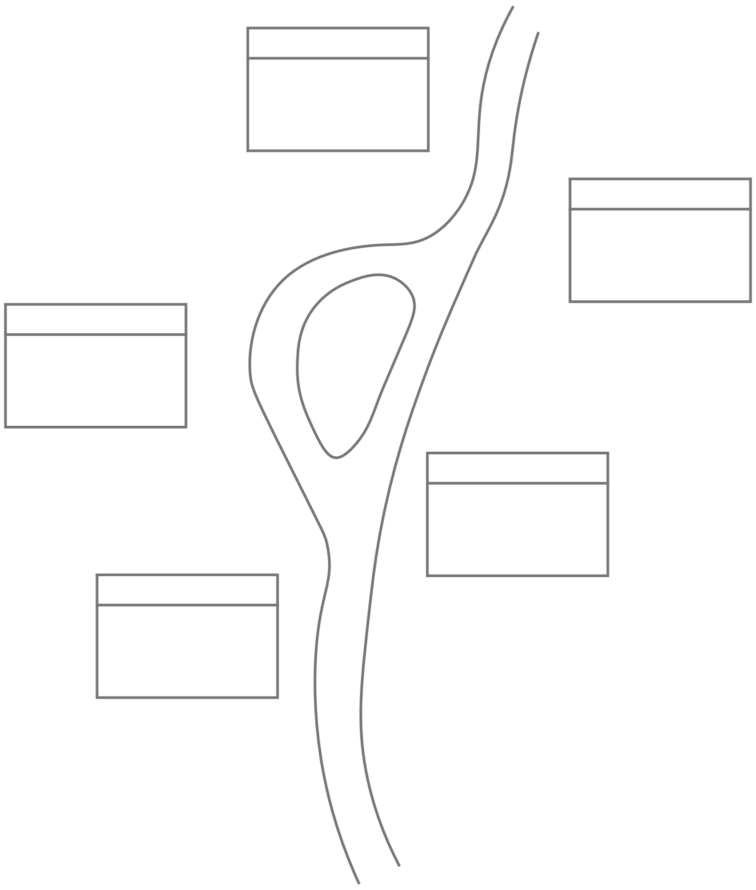
3-STOREY BUILDING



NORTH

WEST

FIGURE 20. ELEVATIONS OF THE THREE-STOREY BUILDING, SCALE 1:100 (CONTINUED)



IV:
PLACEMENT, ACCESS & LANDSCAPING

SITUATION PLAN
1:1000

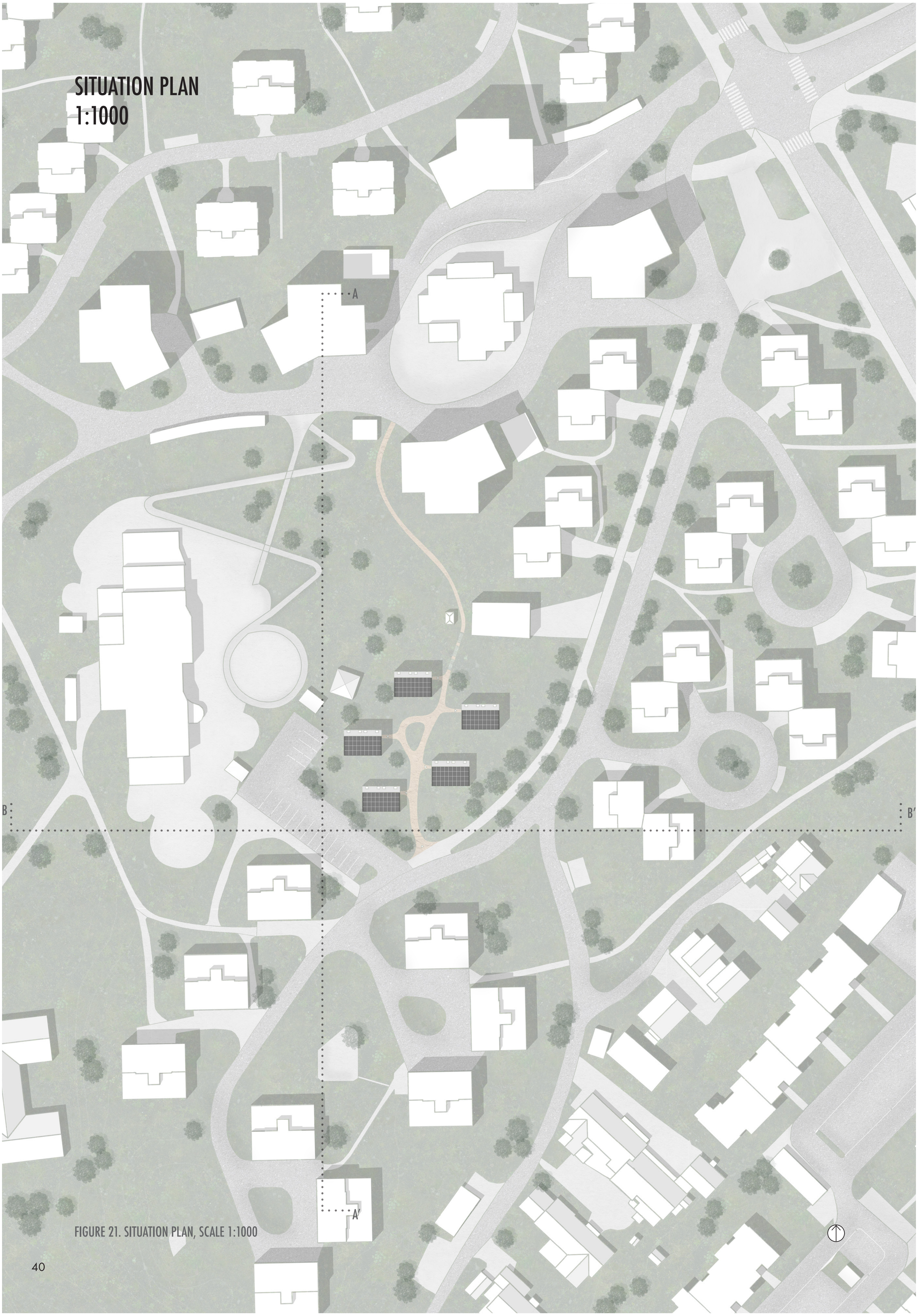


FIGURE 21. SITUATION PLAN, SCALE 1:1000

PLACEMENT, ACCESS & LANDSCAPING

PLACEMENT AND ORIENTATION

A site model was created to get a sense of the topography as well as the volumes of surrounding buildings. The disposition of the buildings in relation to the terrain and existing buildings is shown in pictures of the model (Figure 22) where the new building volumes are those in white. The topography of the terrain clearly defines the site boundary to the north and east, while the kindergarten's fence and parking mark the limit to the west and south. The existing entrance connecting Moholt Alle to Haugenhuset creates a height difference on site, where the entrance is about one meter lower than the ground to the east and west of it. That height difference is visible on the pictures of the site model. The entrance for the new buildings was kept at its actual location and the new buildings were placed on each side of it, within the terrain contour lines. Following the terrain contour lines, two buildings were placed to the east of the entrance, on the highest part of the plot, while three other buildings were placed to the west of the entrance.

Considering the building footprint, there is therefore a possibility to place five buildings within the site boundaries. A minimum distance of eight meters was kept between buildings as required by the measures to prevent the spread of fire between low-rise construction works. The buildings are located at least three meters from the parking lot and the fence of the kindergarten for privacy reasons. Buildings are not aligned in both directions so that each building benefits from a fair amount of daylight.

The buildings were placed around in a circle, creating a space at the center for a common space. This building arrangement is similar to that of the existing buildings around the roundabouts in Moholt as illustrated in the situation plan (Figure 21). The buildings are oriented in line with the north direction, as it is the case for most buildings at Moholt. That is also more beneficial for harvesting solar energy through the PV panels integrated on the roofs. The northernmost building was placed further away from the other buildings to give a more spacious common space at the center.

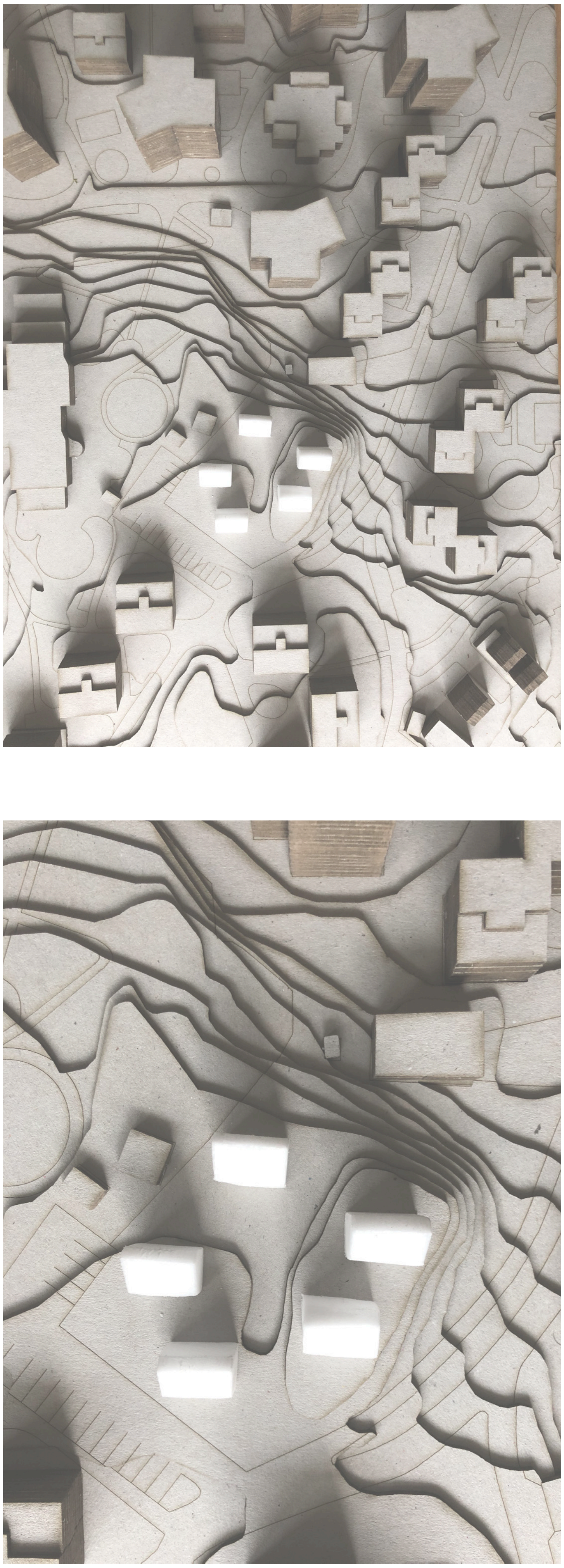


FIGURE 22. PICTURES OF THE SITE MODEL FROM AERIAL PERSPECTIVE

PLACEMENT, ACCESS & LANDSCAPING

HEIGHT

Two types of buildings were designed: a five-bedroom unit over two floors and an eight-bedroom unit over three floors. To determine which type to place where, a shadow and radiation analysis were performed. Five configurations were tested out as shown in Figure 23. The idea was to optimize the solar radiation on the roofs, but also to take into account the target of reaching ZEB-OM as well as the density and daylight quality on site.

The solar radiation results shows that the distance between the buildings is large enough to prevent excess of shading on the south-facing roof. Indeed, the irradiation difference between the most shaded and least shaded parts are of less than 150 kWh per square meter per year. The most shaded parts still receive over 1,000 kWh per square meter per year. That is more than the irradiation on a flat roof without shading, i.e. 885 kWh per square meter per year. Nonetheless, it was found that having lower buildings to the south and higher buildings to the north is beneficial. That is especially the case for the northernmost building (E) which is laid on a lower terrain level than the other buildings. Indeed, the largest radiation gain is going from configuration 1 to 2 as shown in Table 2. It was therefore decided to placed two-storey buildings for the two southernmost buildings (A & B) and a three-storey building for the northernmost one (E). As for the building at the extreme east (D) and extreme west (C), the results show that if they have three storeys they would produce more electricity (configuration 5), but only by a small amount. Other factors were then looked at.

A sunlight hour analysis was conducted for the outdoor common space. Results show that the average annual number of sunlight hours is somewhat similar for all configurations. In general, having lower buildings to the south of the common area results in a slightly less shadowed area. From preliminary energy simulations, it was found that a two-storey building has a higher potential to reach ZEB-OM since it produces the same amount of electricity on-site for less emissions from materials and operation than the three-storey option. On the other hand, having an extra storey enables more students to be part of that new quarter on the village. That highlights one interesting finding about the quest to reaching a zero-emission building. In the end, it was decided to go for three three-storey buildings in the back and two two-storey buildings in the front (configuration 5).

TABLE 2. ANNUAL SOLAR RADIATION AND SUNLIGHT HOURS FOR DIFFERENT BUILDING HEIGHT CONFIGURATIONS

Configuration	Number of two-storey units	Number of three-storey units	Total annual solar radiation on roof kWh/year	Average number of annual sunlight hours in common space h/year
1	5	0	312,325	1,532
2	4	1	315,843	1,532
3	3	2	317,108	1,498
4	3	2	316,864	1,524
5	2	3	318,184	1,490

PLACEMENT, ACCESS & LANDSCAPING

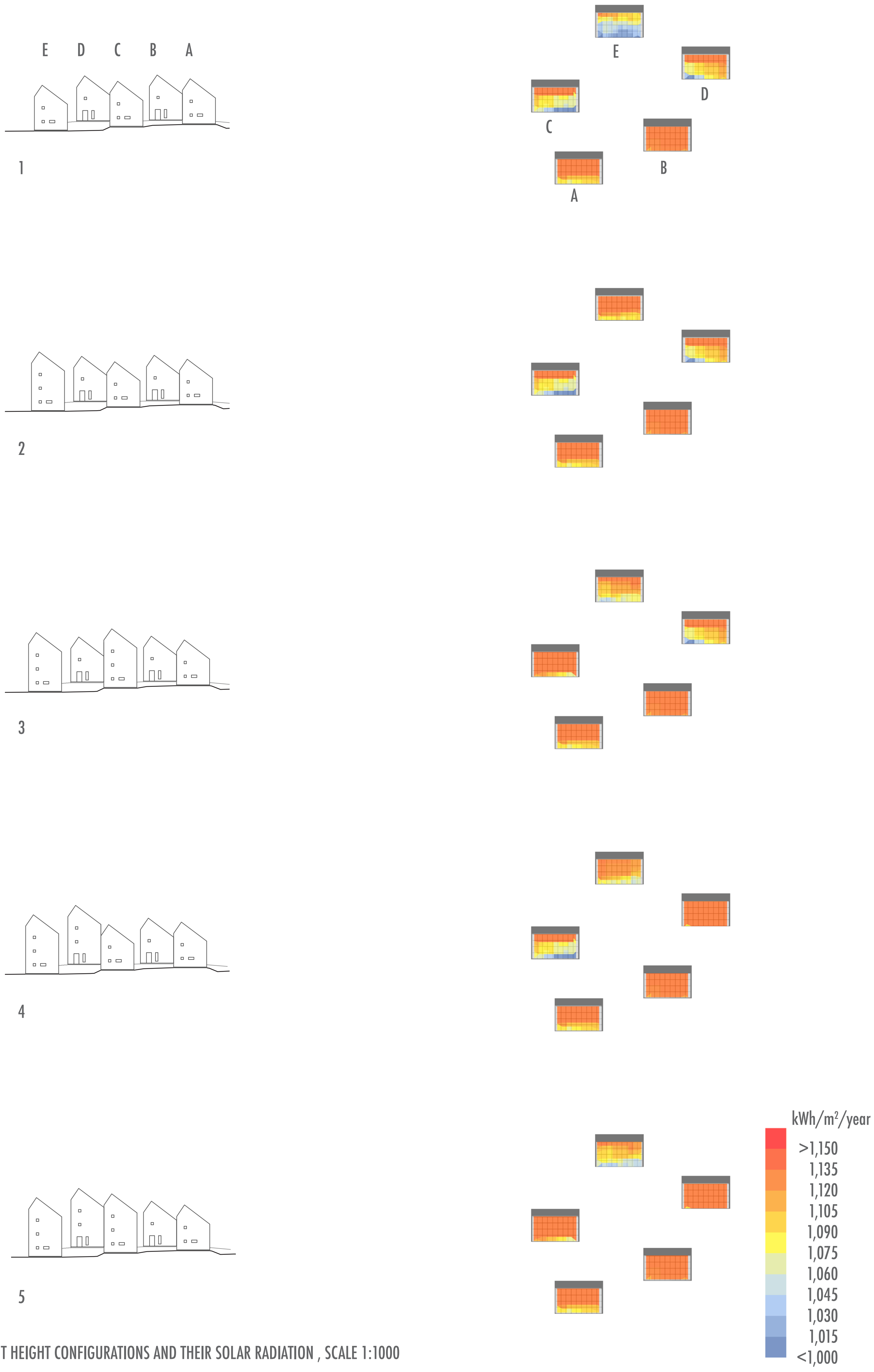


FIGURE 23. DIFFERENT HEIGHT CONFIGURATIONS AND THEIR SOLAR RADIATION , SCALE 1:1000

SITE SECTIONS
1:1000

FIGURE 24. SECTION A-A’, SCALE 1:1000

FIGURE 25. SECTION B-B’, SCALE 1:1000

PLACEMENT, ACCESS & LANDSCAPING

DIVERSITY

The building arrangement together with the terrain level creates a skyline with some variations, breaking the uniformity between buildings. Another way to give personality to each building is to use different exterior wooden cladding patterns. Although all of them have natural wood cladding finish, two of them have horizontal wood chips, while two others have vertical cladding and one has horizontal cladding. The different wooden claddings are illustrated in the site sections (Figure 24 and 25).

SURROUNDING BUILDINGS

When compared to the surrounding buildings, the new buildings blend in well both in terms of height and exterior look. Their natural wooden exterior finish reminds that of Moholt 50|50, i.e. the towers, the library and the kindergarten, while their height is similar to that of the three-storey red brick buildings. Some pictures of the new buildings arrangement on the site model are shown in Figure 26.

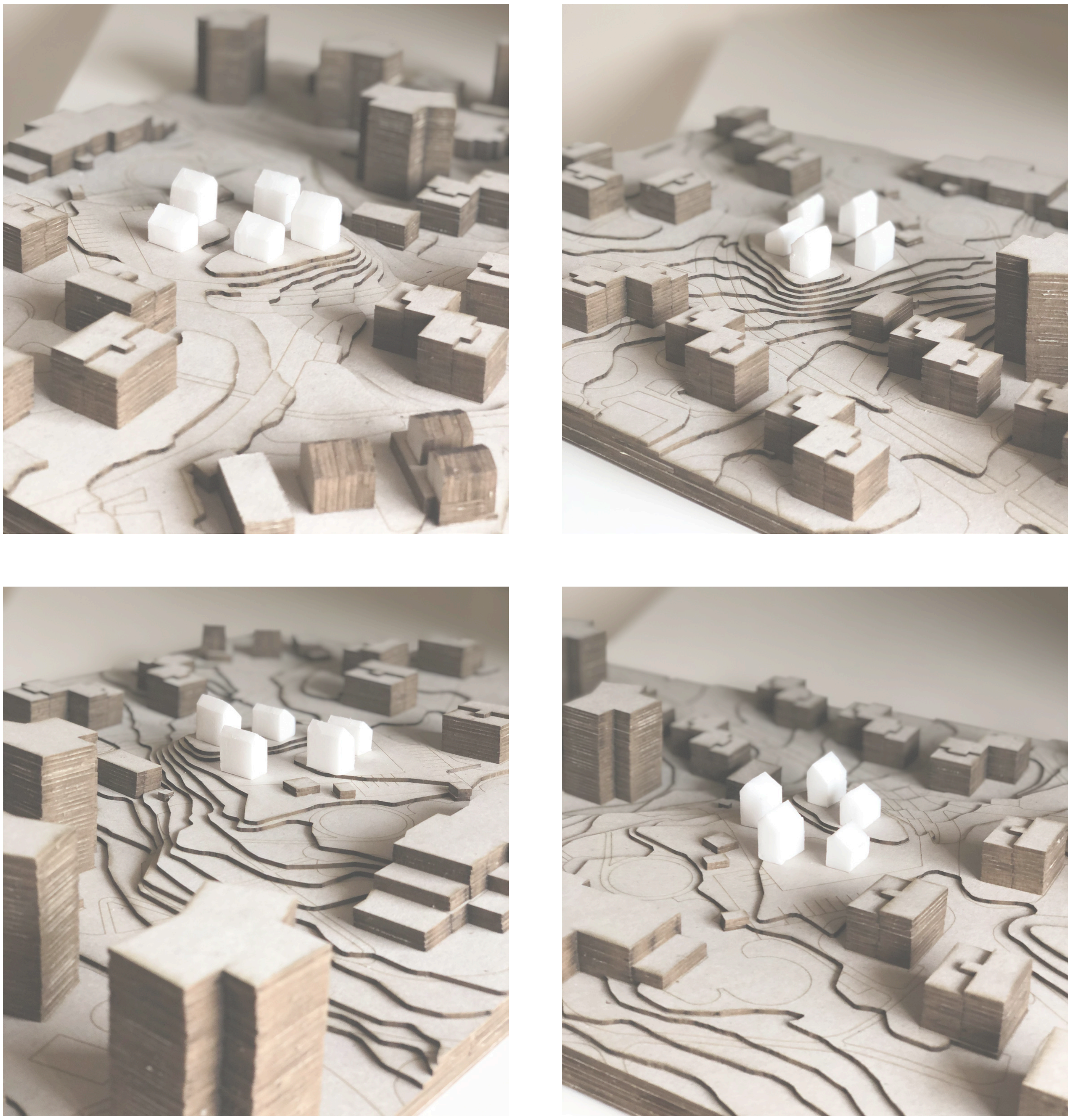


FIGURE 26. PICTURES OF THE SITE MODEL FROM DIFFERENT PERSPECTIVES

SITUATION PLAN
1:500

FIGURE 27. SITUATION PLAN, SCALE 1:500

PLACEMENT, ACCESS & LANDSCAPING

ACCESS TO THE SITE

As previously mentioned, it was decided to keep the entrance to the site in its actual location. In addition to connecting to Moholt Alle, the path was extended to connect the site to the main square where the library is, as seen in Figure 27. Since the height difference is quite important to the north of the site, stairs are needed down to the level of the waste disposal facility. The path then follows the fence of the kindergarten down to the main square. The path widens in a common space at the heart of the site. The shape of the common space is inspired from the spaces created by the roundabouts in Moholt.

A covered bicycle parking could be placed at the entrance of the parking lot. An alternative could be to have individual bicycle racks for each building. That rack could be placed next to the entrance door. The closest parking lot is the kindergarten's, located to the south of the site.

VEGETATION

There are beautiful mature deciduous trees to the east of the site, along Moholt Alle. Those should be kept in place as they represent a strength of the plot. They provide some privacy and also shading in the summer, limiting overheating inside the buildings to the east of the site. There are also smaller and more recently planted trees on the kindergarten site along the fence.

Additional trees should be planted on the site, especially between the new buildings and the parking lot. Some trees or bushes could also be grown around the buildings to create privacy between them and from the public areas.

SITUATION PLAN
1:200

FIGURE 28. SITUATION PLAN, SCALE 1:200

PLACEMENT, ACCESS & LANDSCAPING

BUILDING ENTRANCE

The entrance of each building is facing the path connecting them, as shown in Figure 28. The buildings on one side of the path are therefore mirrored with those on the other side. That mirror effect is however not too strong since the buildings are not aligned.

COMMON SPACE & GREENHOUSE

At the center of the common space lies a greenhouse that could be used for social gathering when the weather is not nice enough to sit outside or on colder summer evenings. An example of glass house used for social gathering is the one at Trondhjems Kooperative Boligselskap (Ramm, 2019). Residents gather there to feast, chat or for music events. The greenhouse could also be used for gardening as it receives a fair amount of daylight considering its position facing south. There is a Studenthage close to Lerkendal Studentby, but there is none in Moholt. Students could grow some vegetables and berries in the greenhouse and outside as well. The gardening equipment could be kept inside the greenhouse. Since the kindergarten is just next door, children and their educators could also take part in gardening activities for educational purposes, especially in the summer when most students are out of the student village.

Windows and glazed doors from Haugenhuset were used to create a 15-square-meter greenhouse. Repurposing windows for a greenhouse is not a new idea. There are numerous examples of greenhouses or glass facades made from used glazed windows. The window frames could be painted in a turquoise colour for example, while colourful pieces of polycarbonate or plexiglass could be inserted between windows to close off the envelope. The smaller windows are operable, and therefore could be used to ventilate the greenhouse on hot summer days. Elevations of the greenhouse are shown in Figure 29. The greenhouse has a double entrance door on its south side. The long side of the greenhouse is aligned with the path so that the long facades are facing the green spaces between the buildings, rather than the buildings themselves for privacy concerns. The floor inside the greenhouse is made out of used bricks from Haugenhuset. Bricks provide both thermal mass and a nice aesthetic feature to the space. The brick paving extends from the entrance of the greenhouse to the path where there are tables and chairs to extend the gathering space outside the greenhouse. The common space is also designed to have picnic tables and a grill area to the west of the greenhouse. The aim of this common space is therefore to not only offer an enjoyable living environment inside the buildings for its residents but also outside for all students on the village. A section of the common space is illustrated in Figure 30.

PATIO SPACE

Each building has an exterior patio space on its south side. That space is accessible from the living room through a patio door. To create some privacy between the patio area and the common space, bushes and trees are used. If additional used windows are sourced, then those could be stacked vertically and used as a wall along the patio for additional privacy.

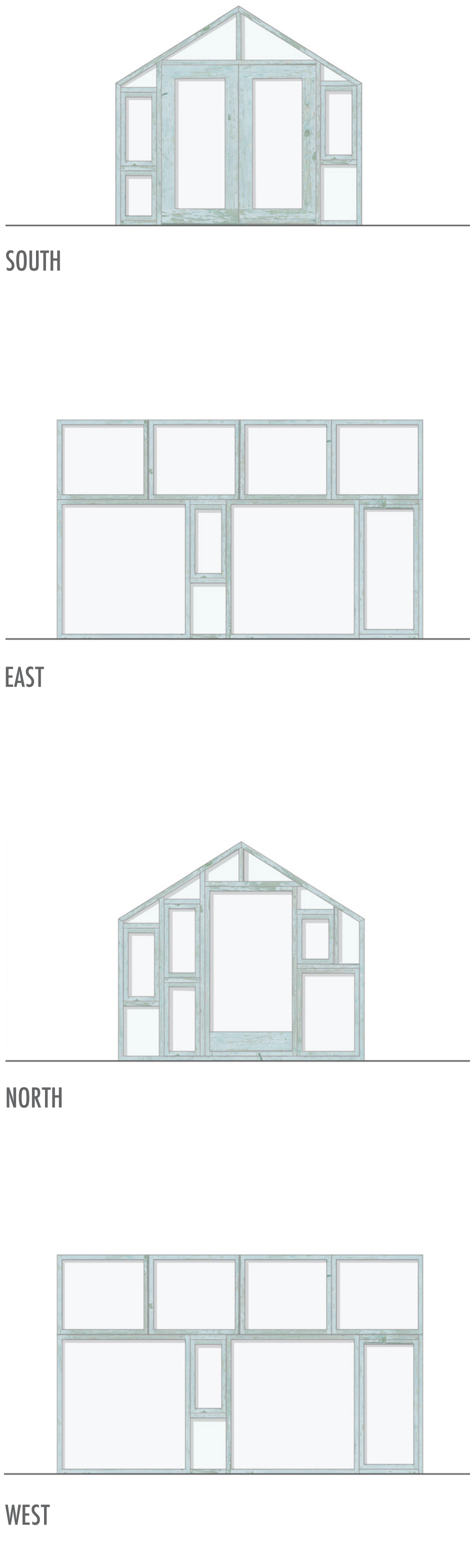


FIGURE 29. ELEVATIONS OF THE GREENHOUSE, SCALE 1:100

SITE SECTION
1:200

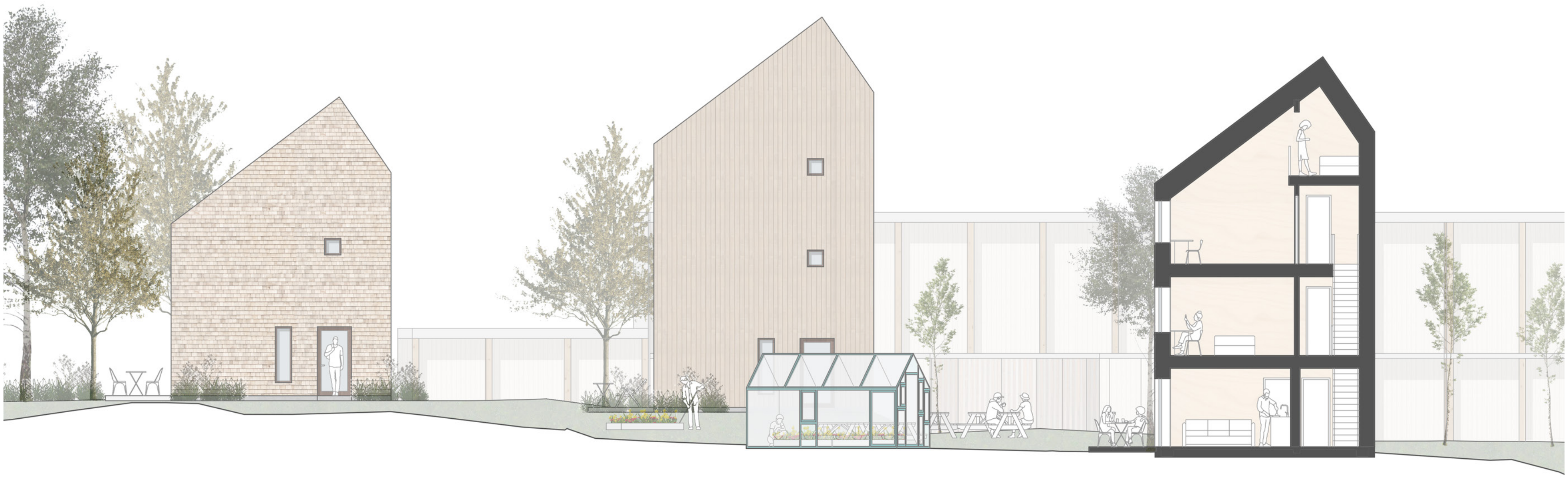
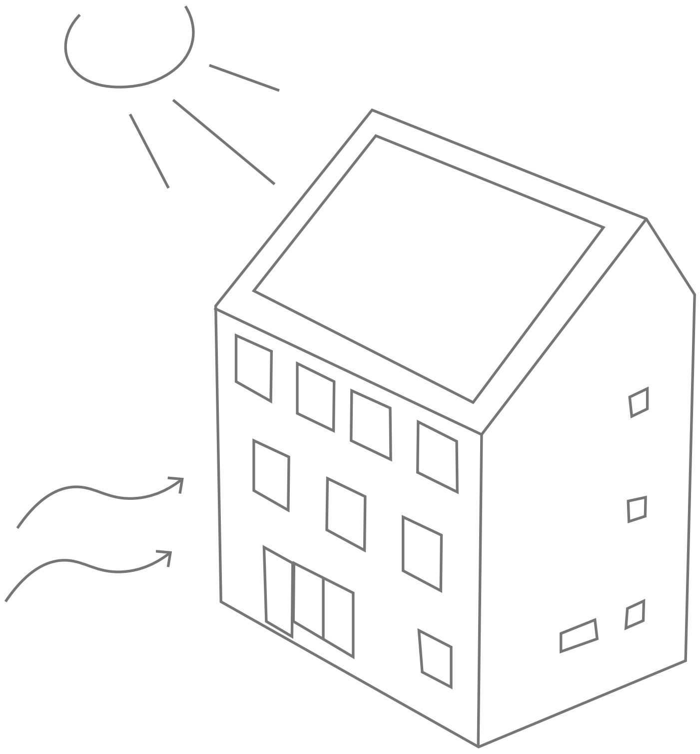


FIGURE 30. SECTION C-C', SCALE 1:200

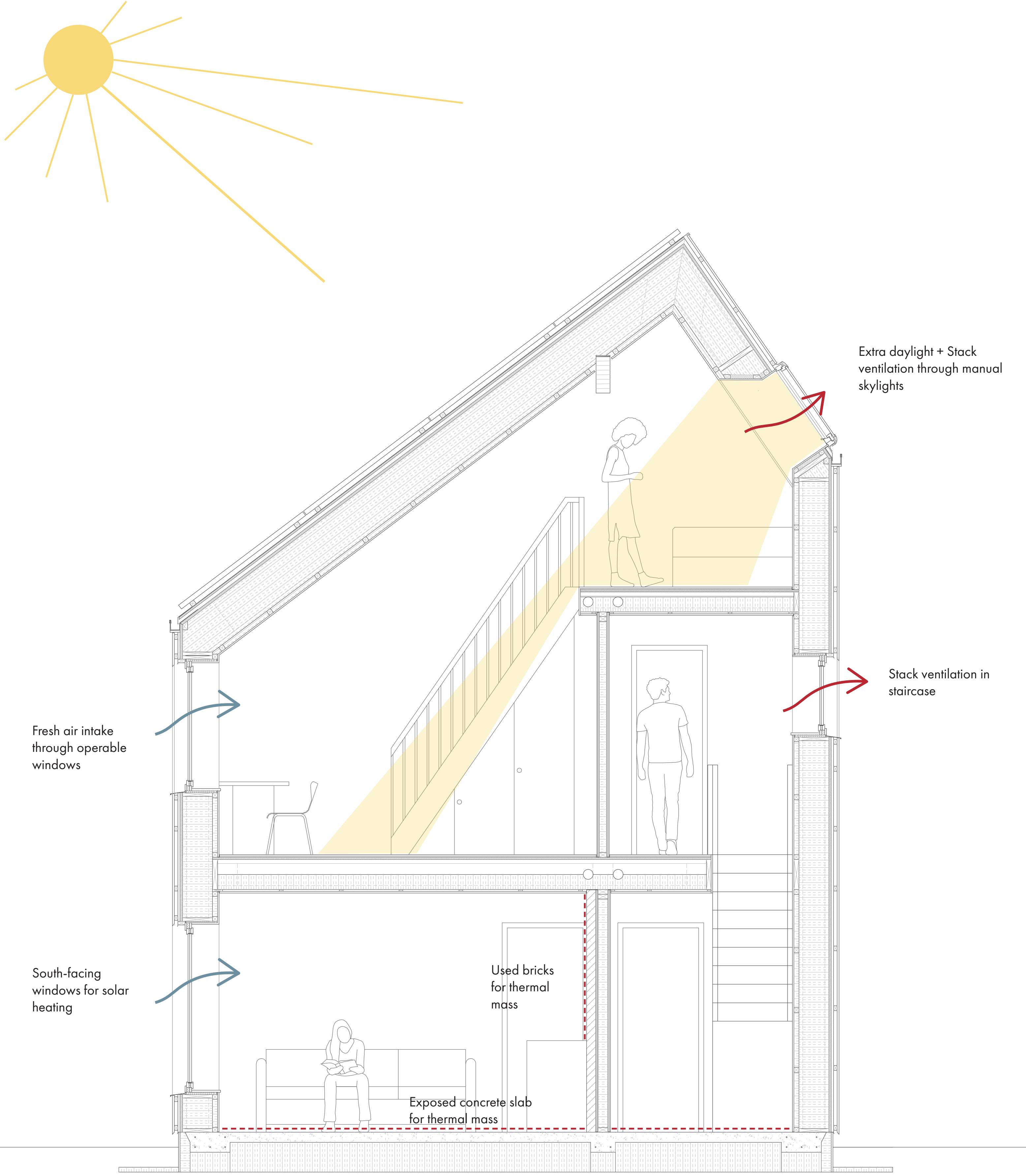


V:
PASSIVE & ACTIVE STRATEGIES

PASSIVE STRATEGIES

1:50

SECTION D-D’



Extra daylight + Stack ventilation through manual skylights

Stack ventilation in staircase

Fresh air intake through operable windows

South-facing windows for solar heating

Used bricks for thermal mass

Exposed concrete slab for thermal mass

FIGURE 31. PASSIVE STRATEGIES ON SECTION D-D’, SCALE 1:50

PASSIVE STRATEGIES

THERMAL MASS

The timber buildings are built on a slab on grade foundation. To benefit from the thermal mass effect of the concrete, the slab is kept exposed. More information on the slab on grade is given in Chapter IV. An exposed concrete slab is one of the most effective ways to increase thermal mass. Thermal mass should be exposed to direct sunlight in the heating season to be most effective. The windows in the common living room run down to 40 cm above the floor to enable the sun rays to enter the room during periods of low sun angle. In summer, thermal mass should be exposed to cooling breezes to limit overheating issues. The thermal mass acts together with natural ventilation to increase thermal comfort. Reused bricks from Haugenhuset are integrated both inside the buildings and outside in the greenhouse. The reused bricks are used in the main room to further increase the thermal mass of the building. The bricks are installed on the kitchen's load-bearing wall facing south, as shown in Figure 31. The bricks cover the entire wall, from floor to ceiling. Above the kitchen counter, there is no kitchen cabinet on the upper part of the wall. Floating wooden shelves are installed instead, leaving the brick exposed and creating a pleasing architectural feature. The brick wall is facing the windows on the south facade and is thereby exposed to the cool summer breeze, which will then rise in the staircase and exit through the windows in the corridor. Although the effect of thermal mass is not as efficient in cold climate as it is in places with a higher diurnal swing, the combined effect of the exposed concrete slab and brick wall reduces the heating demand of the building by 1.4 kWh/m^2 per year when compared with a lightweight construction. Results are based on building energy simulations in SIMIEN.

NATURAL VENTILATION

In addition to daylighting, natural ventilation was also accounted for in the design of windows. All windows can be opened for extra ventilation, except for the windows in the staircase that are not manually reachable. Each room has a window that can be opened both in 'tilt and turn' fashion for single-sided ventilation. In rooms with higher volume or higher expected internal gains, windows were designed to also provide cross-ventilation and stack ventilation. That is the case for the common living area, which has windows on two facades for cross-ventilation and two of the three windows in the corridor can be opened for stack ventilation. The bedrooms with mezzanine also have two windows at different heights to properly ventilate the mezzanine space that could reach higher temperature due to the buoyancy effect in the summer. In summer, the inside temperature can go over 26 degrees, creating overheating problems. Window ventilation is one strategy to reduce overheating hours, especially in Trondheim where the temperature at night can be 10 degrees lower than that during the day. Rooms that are risk of overheating are the bedrooms and the living room, which are all facing south. To determine the effect of window ventilation on the indoor conditions in summer, simulations were run with SIMIEN. The option for window ventilation is available in SIMIEN, but the algorithm it is based on is only applicable for single-sided ventilation (information taken from SIMIEN manual).

The rooms were simulated individually to get more representative results. Without window ventilation or shading device, the number hours exceed largely the annual maximum of 100. The results are shown in Table 4 per room. The most critical room is the living area due its large fenestration on the south facade. Using single-sided ventilation, the overheating hours are significantly reduced. The window ventilation was set to a 25-percent opening. The results show that single-sided ventilation alone is enough to reach acceptable indoor comfort for the bedroom on the first floor. However, it is not sufficient for the other rooms. In that case, external shading device, i.e. screen, manually controlled are required. The single-sided ventilation together with manually-controlled external screen on the south windows reduce the overheating hours to 0 per year across the rooms. The graphs from SIMIEN are shown in Appendix A.

For the mezzanine rooms and the common living area, additional ventilation can be provided through cross- and stack ventilation. The airflow rates for both types were calculated with the use of Bernoulli's equations to show the potential for extra ventilation. On the hottest summer day, the outdoor temperature varies between 15 and 24.5 degrees Celsius. In the room simulation without window ventilation and external shading, the inside temperature is 35 and 45 degrees in the mezzanine room and between 25 and 28 degrees in the living room. The temperature swing in the living room in smaller due to the effect of thermal mass in the exposed concrete and brick wall. Since stack ventilation is based on the temperature difference between inside and outside, it is more efficient at night when the temperature difference is higher. The airflow rate for stack ventilation shown in the table is the daily average on the hottest summer day. For the living room of the three-storey building, it was assumed that the stack effect was only done with the windows on the corridor on the second floor. A higher flow rate could be achieved by opening the windows on the third floor. For cross-ventilation, a normal shielding class was assumed and the wind profile for Trondheim was used. The higher the window, the higher the rate achieved because of the wind velocity dependent on the height. Overall, the stack ventilation seems to provide a higher flow rate.

TABLE 4. ANNUAL OVERHEATING HOURS PER ROOM

Location	Without screen/ ventilation h/y	Single-sided ventilation h/y	Single-sided ventilation & screen h/y
Living room 1st floor	4,580	992	0
Bedroom 1st floor	1,046	21	0
Bedroom 2nd floor (2-storey unit)	2,876	584	0
Bedroom 2nd floor (3-storey unit)	3,625	933	0
Bedroom 3rd floor (3-storey unit)	2,876	584	0

TABLE 3. AIRFLOW RATE THROUGH STACK AND CROSS VENTILATION

Location	Airflow stack ventilation m^3/h	Airflow cross-ventilation m/h^3
Living room 1st floor	7,813	2,507
Bedroom 2nd floor (2-storey unit)	5,125	3,197
Bedroom 3rd floor (3-storey unit)	5,125	4,156

PASSIVE STRATEGIES

DAYLIGHTING

The design of the windows was done to provide good daylighting conditions in living areas. As much as possible, the windows were placed between the wall joists to limit the number of additional studs. A daylight factor analysis was performed with the use of Rhino and Grasshopper to ensure that living areas reach a daylight factor of at least 2.0 as required. The results are shown in Figure 32. Since the buildings have different obstructions, i.e. the surrounding buildings are at different distances, the analysis was done for all of them. The results are illustrated in Figure X and the numbers are in Table 5. The results show that the buildings achieve similar daylight factors. The critical rooms are those of building C and E, because of the proximity with the buildings in the front. The windows were then sized to provide enough daylight in those critical rooms.

In the living room, a large area of the south facade is glazed to provide a good daylight quality throughout the room. The average daylight factor varies between 2.2 and 3.2. The areas where the daylight factor is the lowest are those where the kitchen furniture stands. There are two same-size windows and a glazed door to access the exterior patio area. An additional long and narrow window was placed in line with the kitchen cabinets to provide more daylight at the back of the room. People can therefore look through that window while preparing their meal. The window header of all windows on the first floor is at a height of 2.1 meters, which corresponds to the height of the entrance door.

The windows in the corridor were placed at a height which corresponds to the viewing level of a standing person. The glazed entrance door and the windows up in the corridor provide daylight in the entrance area. The average daylight factor in the corridors is about 2.0, while it is of about 1.5 in the entrance. Areas that are not permanently occupied, such as corridors and bathrooms, are exempt from the 2.0-minimum requirement. Windows are still added in those areas to reduce the electricity consumption from artificial lighting and improve the quality of the space. The windows in the corridor are facing the fjords, which provides a nice view for the students living there. However, since windows on the north facade increases the energy consumption of the building, windows were limited in size and only placed at the viewing level of a standing person.

On the second floor of the three-storey building, the square windows are 1.4 by 1.4 meters of dimensions. They are positioned at a height of 0.7 meters from the floor, which corresponds to the height of the desk that is placed on that same facade. The windows provide therefore the person inside the room with views to the outside in both sitting and standing positions. The average daylighting factor is about 2.3.

On the first floor, it was decided to reduce the size of the square window from 1.4 to 1.1 meters on the south side and add a window on the other facade for cross-ventilation. Having a smaller window on the south facade also provides more privacy in the room. The windows have their header at a height of 2.1 meters. The window on the side facade is an horizontal window placed above the bed. The average daylight factor is about 2.2.

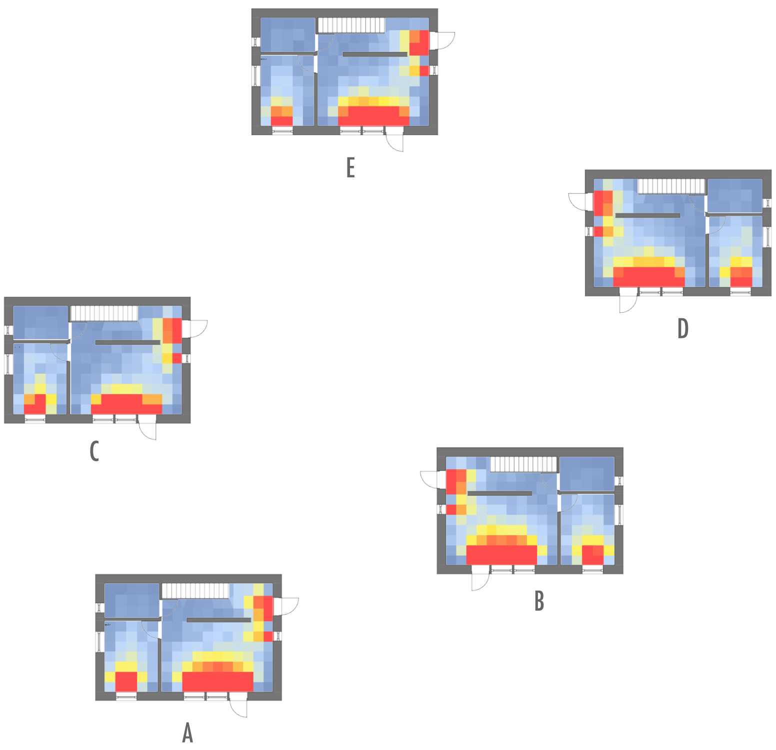
In the mezzanine rooms, there is a window on the south facade and a skylight on the north roof. The window on the lower level is designed in a similar manner to that of the windows on the second storey of the three-storey building, but its height was reduced from 1.4 to 1.3 meters because of the floor to ceiling height of 2.0 meters on that facade. The window sill is at the same height as the desk. The lower part of the bedroom has an average daylight factor ranging between 2.0 and 3.0. The skylight at the mezzanine provides daylight to both the mezzanine and the lower part of the room. The skylight was placed as low as possible in the roof so that a standing person can look outside. The skylight is 1 meter high and 0.8 meter wide. In plan view, the skylights are placed on the side of the stairs to allow the person to look through it while going upstairs to the mezzanine. Having the skylight on one side of the mezzanine also leaves the freedom to place the bed in order to either look through the window or not. Skylights were aligned with the roof joists. The skylights provide to mezzanine space with an average daylight factor of 4.5.

A small square 0.5 by 0.5 meter window is placed at height of 1.5 meters from the floor in each bathroom. The windows are aligned with the door, so that a person entering the bathroom can look directly through the window. The average daylight factor in the bathrooms is about 0.16. The windows will therefore provide some light and views, but artificial lighting will be needed to reach an acceptable lighting level.

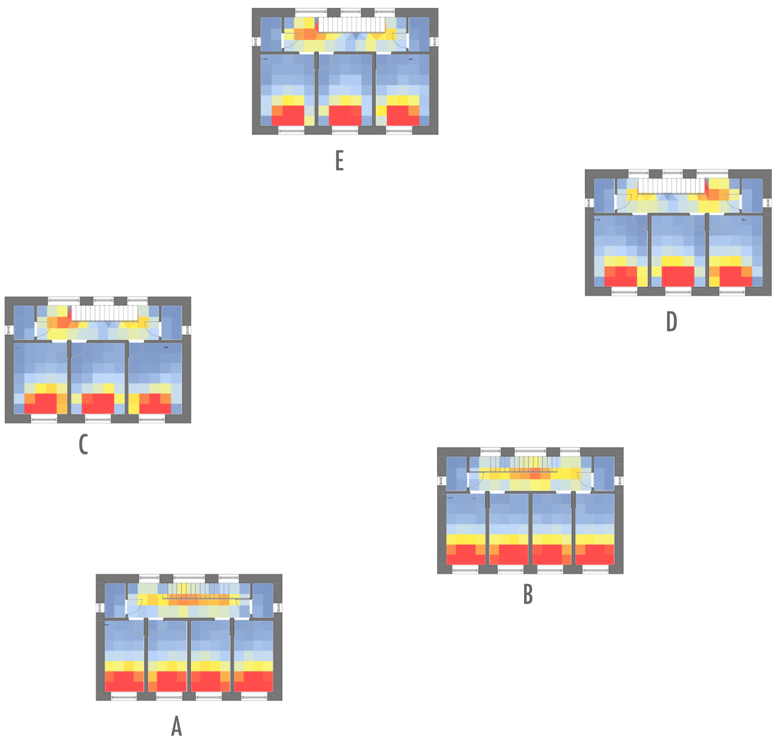
TABLE 5. AVERAGE DAYLIGHT FACTOR PER ROOM

Location	A	B	C	D	E
FIRST FLOOR					
Living room	3.1	3.2	2.2	2.6	2.5
Bedroom	2.3	2.3	2.1	2.2	2.0
Entrance	1.5	1.5	1.4	1.5	1.4
Bathroom	0.16	0.13	0.14	0.16	0.16
SECOND FLOOR					
Bedrooms	3.0	3.0	2.2	2.4	2.2
Corridor	2.0	2.0	2.1	2.1	2.0
Bathrooms	0.18	0.18	0.16	0.18	0.20
THIRD FLOOR					
Bedrooms	-	-	2.9	3.0	2.8
Mezzanine	4.5	4.6	-	-	-
Corridor	-	-	2.3	2.3	2.2
Bathrooms	-	-	0.14	0.17	0.17
FOURTH FLOOR					
Mezzanine	-	-	4.5	4.6	4.6

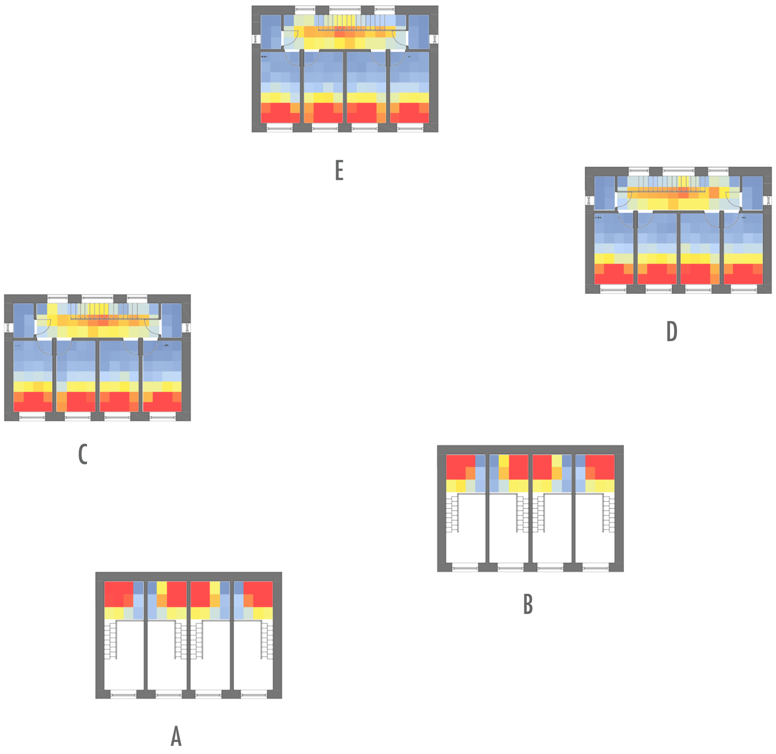
PASSIVE STRATEGIES



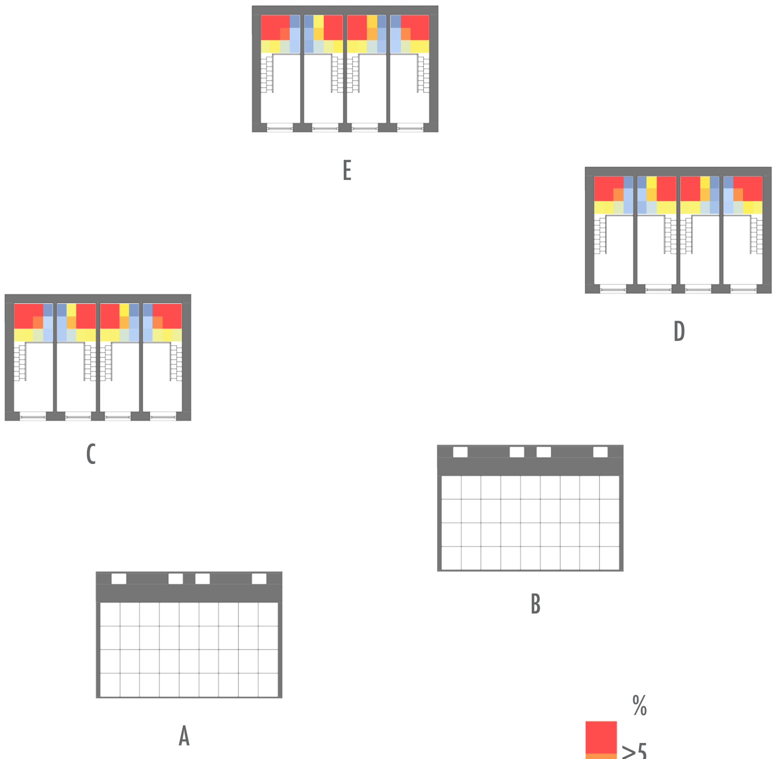
FIRST FLOOR



SECOND FLOOR

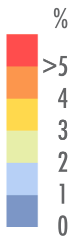


THIRD FLOOR



FOURTH FLOOR

FIGURE 32. DAYLIGHT FACTOR ANALYSIS, SCALE 1:400



ACTIVE STRATEGIES
1:50
SECTION E-E'

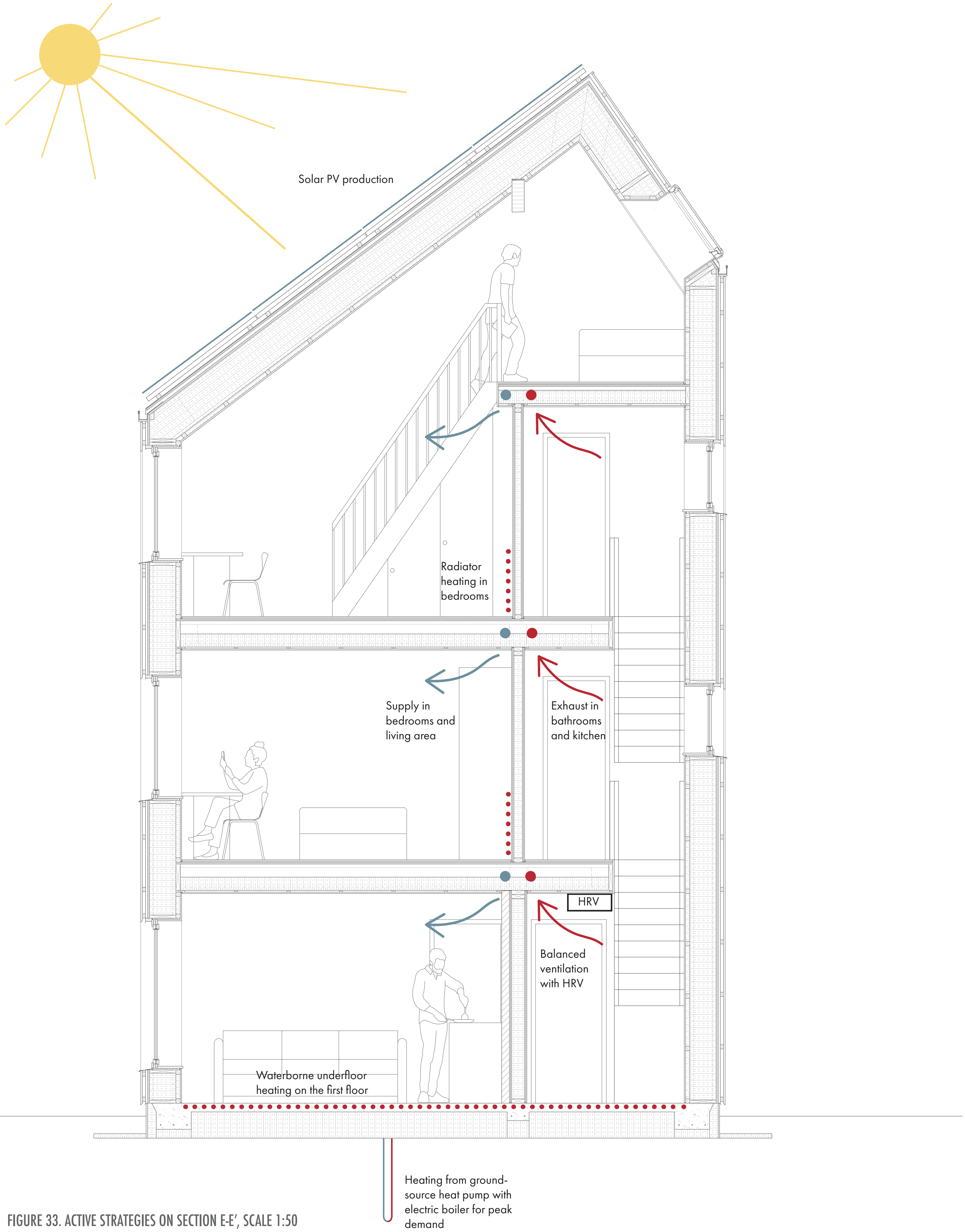


FIGURE 33. ACTIVE STRATEGIES ON SECTION E-E', SCALE 1:50

ACTIVE STRATEGIES

BALANCED VENTILATION & HEAT RECOVERY

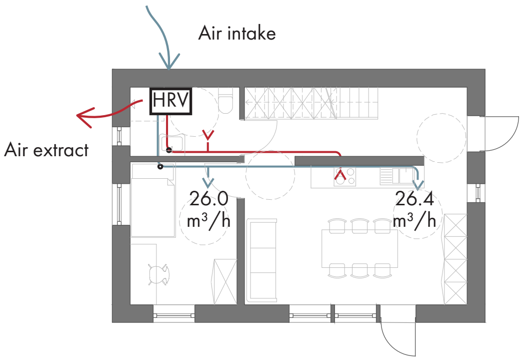
The ventilation requirements in residential buildings are provided by §13-2 of TEK17. To ensure good indoor air quality, residential units shall have an average fresh air supply of at 1.2 m^3 per hour per square meter of floor space during occupation. Mechanical ventilation is the easiest way to meet the airflow requirements. Natural ventilation can of course be used all year round by opening the windows. However, in cold climate, natural ventilation can cause cold draft problems during the cold season. Heating the fresh air before supplying it in the rooms leads to better comfort. Balanced ventilation with heat recovery is a suitable solution to satisfy the Passive House energy requirements (Standard Norge, 2012) and the TEK17 ventilation requirements. An hybrid ventilation system, where balanced ventilation with heat recovery is used in the cold season, and natural ventilation is used in the mild season, is also an option that optimizes both ventilation types. Indeed, balanced ventilation with heat recovery works best in the winter since it recovers the heat, but is less beneficial in the summer when the heating demand is lower. Relying on natural ventilation in the summer reduces the energy consumption of fans. One drawback of hybrid ventilation is the switching between the two ventilation modes that requires a more advanced control strategy.

The buildings in this project were designed to meet the airflow requirements with a constant-air-volume (CAV) balanced ventilation system with a heat recovery (HRV) unit of 86 percent efficiency. Ventilation heating is done with the ground-source system. Natural ventilation is used in the summer as additional ventilation to reach comfortable indoor temperatures. Fresh air is supplied through diffusers in the bedrooms and in the living room at the same rate at which it is extracted through extractors in the bathrooms and in the kitchen. The air ducts run in the floor, through the I-joists, on each side of the load-bearing wall which divides the services area from the living area. In the bedrooms, airflow requirements are higher, being of 26 m^3 per hour per bedroom. An air speed of 3 meter per second was assumed to determine the duct diameter. The dimensions are shown in Table 6.

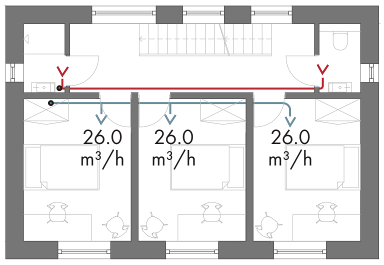
TABLE 6. AIR DUCTS DIMENSIONS

Location	Airflow m^3/h	Diameter mm
2-STOREY BUILDING		
Horizontal duct from CAV to vertical shaft on 1st floor	156.4	150
Horizontal duct from vertical shaft on 1st floor	52.4	100
Vertical duct from 1st to 2nd floor	104.0	125
Horizontal duct from vertical shaft on 2nd floor	104.0	125
3-STOREY BUILDING		
Horizontal duct from CAV to vertical shaft on 1st floor	234.4	175
Horizontal duct from vertical shaft on 1st floor	52.4	100
Vertical duct from 1st to 2nd floor	182.0	150
Horizontal duct from vertical shaft on 2nd floor	78.0	100
Vertical duct from 2nd to 3rd floor	104.0	125
Horizontal duct from vertical shaft on 1st floor	104.0	125

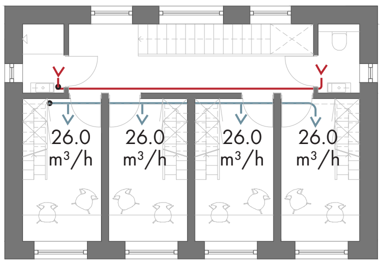
The CAV unit with heat recovery is placed in the ceiling of the bathroom on the first floor. The floor to ceiling height in the bathroom is therefore reduced to accommodate the ventilation unit. The air intake and exhaust are located on different facades to prevent contamination of fresh air as much as possible. The duct configuration is shown in Figure 34.



FIRST FLOOR



SECOND FLOOR



THIRD FLOOR

FIGURE 34. PLAN VIEW OF THE MECHANICAL VENTILATION SYSTEM, SCALE 1:200

ACTIVE STRATEGIES

GROUND-SOURCE ENERGY

A centralized ground-source heat pump system provides heating and cooling for the Moholt 50|50 buildings. It consists of three heat pump units of 84 kW at 4/50 degrees Celsius, for a total of 252 kW. The system is connected to a set of 23 vertical boreholes drilled at 250 meters deep in bedrock, which is used for thermal energy storage (Stene, 2019). The boreholes are located between the kindergarten and the project site as shown in Figure 1. The boreholes are charged with the energy from solar collectors installed on the kindergarten, as well as from the heat recovered from both grey water and exhaust ventilation air. The ground-source heating system is used for ventilation, domestic hot water and snow melting. The borehole thermal storage system also provides cooling of ventilation air. The heating system produces hot water at 50 degrees Celsius. Field measurements of the heating system have revealed that it has a seasonal coefficient of performance (SCOP) of 3.2 (Granås, 2020). An electric boiler of 300 kW is installed for peak load. For the scope of this thesis, it was assumed that the existing ground-source system has spare capacity to provide energy for space heating, domestic hot water and ventilation heating. Further work would need to be done to assess whether that is the case or if extra capacity should be added.

SPACE HEATING

Space heating on the first floor is distributed through an underfloor waterborne system embedded in the concrete slab. Such distribution system is efficient and well suited for an exposed concrete slab, which could become cold and create discomfort otherwise. Underfloor heating is however more expensive than installing a radiator for instance. On the upper floors, underfloor waterborne heating was therefore only installed in the shower rooms. Each bedroom is equipped with a radiator. It would have been less expensive to install electric baseboard heaters in the bedrooms, as it was done in the towers of Moholt 50|50, but considering the small scale of the project and the fact that utilizing the ground-source heating system leads to less GHG emissions from operation, it was decided to have a hydronic heating system throughout the buildings. Indeed, the SCOP of the ground-source system is 3.2, whereas a fully-electric system has a coefficient of performance (COP) closer to 1.0. There is no heating in the toilet rooms and the corridors on the upper floors since those are not for permanent residence and the heat from the first floor will travel upstairs with buoyancy. The configuration of the hydronic heating system in shown in Figure 35.

DOMESTIC HOT WATER HEATING

In highly-insulated residential buildings, domestic hot water accounts for a higher share of the total energy demand. In Moholt 50|50, a grey water heat recovery system was installed to reduce the amount of energy needed to heat domestic hot water. Such system could also be installed in the new buildings. The domestic hot water tank is centrally located under the stairs on the first floor. It is halfway between the kitchen and the bathroom, reducing pipe length. Having the hot water tank close to the shower also reduces the time for water to reach its desired temperature. On the upper floors, the shower room is located on the same side of the building as the hot water tank.

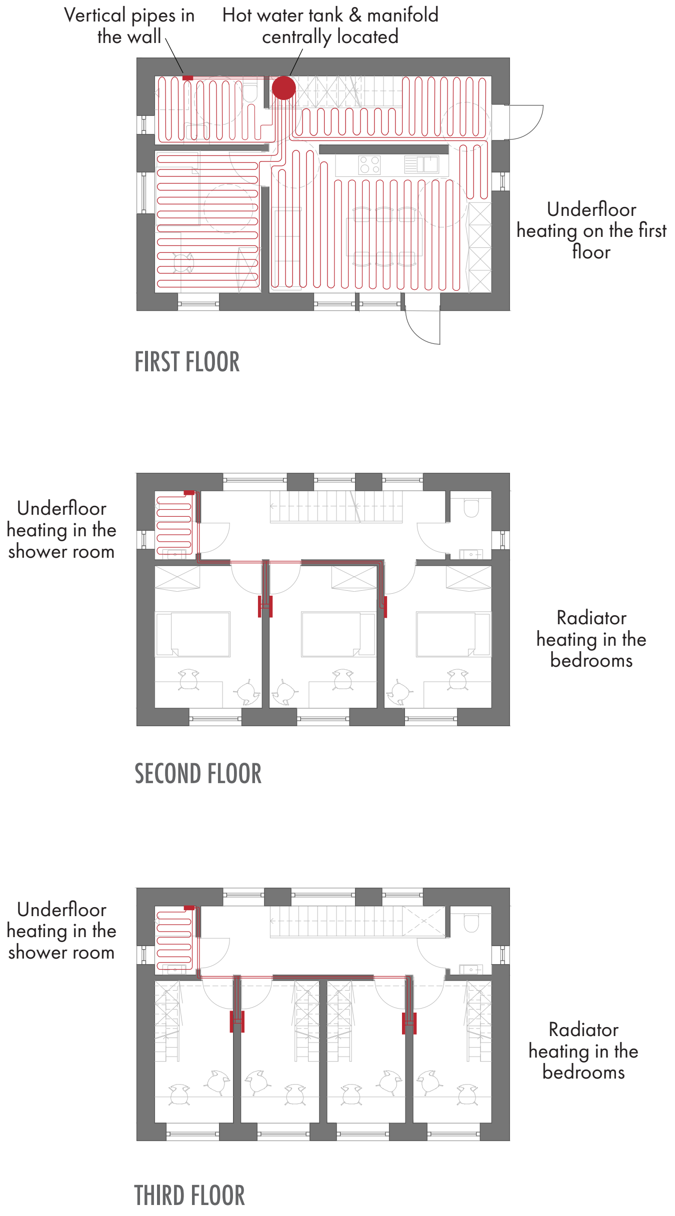


FIGURE 35. PLAN VIEW OF THE HYDRONIC SPACE HEATING SYSTEM, SCALE 1:200

ACTIVE STRATEGIES

RENEWABLE ELECTRICITY

The building roof was shaped to have integrated PV panels to produce renewable electricity on-site to offset the GHG emissions from both operation and materials. As discussed in Chapter III, the long axis of the building is oriented in the east-west direction and the roof is tilted at an angle of 37 degrees to achieve a high irradiation level (kWh/m²) on the south-facing roof. The sloping roof not only provided a large PV collection surface, but also space to have an extra bedroom on the upper floor.

Both the two- and three-storey buildings have the same PV collection surface. The roof was designed to fit an even number of modules. The surface is large enough to have four rows of nine modules mounted in portrait layout. Each module is 1.558 meter long and 1.046 meter wide. The modules chosen are manufactured in France by SunPower and are distributed by GETEK in Trondheim. They have a uniform black finish and reach an efficiency up to 22 percent, which is one of the most efficient solutions available on the market for residential applications. There is currently no EPD for the SunPower modules, but their X-Series are Cradle to Cradle Certified Bronze, meaning that materials are sourcing in a safe way for both humans and the environment and that they are recycled at the end of their life.

The modules are semi-integrated in the roof, where the racks are mounted on asphalt sheathing. The rack creates an air space between the module and the asphalt sheathing to ventilate the module.

The five buildings were modelled in Rhino and their PV panel electricity production was obtained through Grasshopper simulations. The buildings generate a total of 50,340 kWh per year. Shading from surrounding buildings was taken into account, reducing the total production by 595 kWh per year. The results for each building is presented in Table 7, corresponding building location on Figure 36.

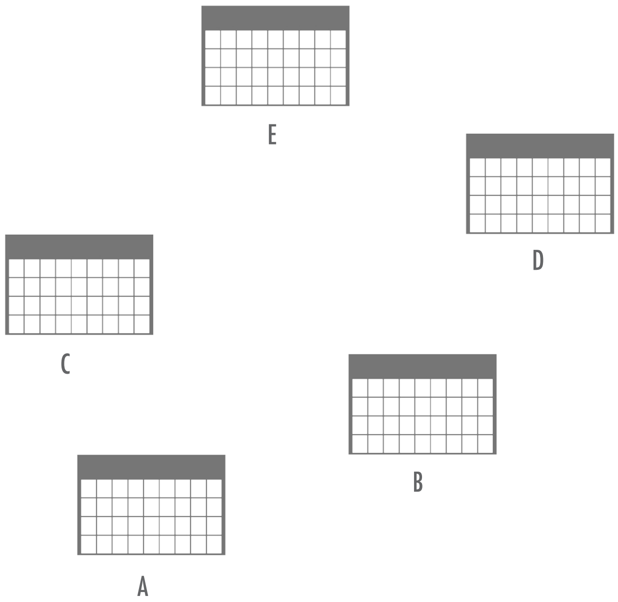
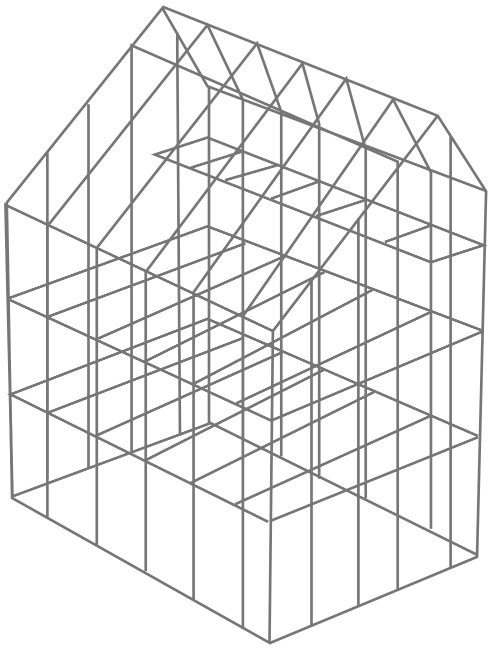


FIGURE 36. PLAN VIEW OF THE PV PANELS CONFIGURATION, SCALE 1:500

TABLE 7. ANNUAL PV PRODUCTION PER BUILDING

Building	Without shading kWh/year	With shading kWh/year
A	10,187	10,061
B	10,187	10,120
C	10,187	10,144
D	10,187	10,167
E	10,187	9,848
Total	50,935	50,340



VI:
MATERIALS & DETAILS

MATERIALS

In the quest of reaching ZEB-OM, there is a need to document in detail the type of materials chosen as well as their quantity. Throughout that process, the manufacture location, the environmental impact as well as the performance of materials were accounted for.

STRUCTURE

The building is an I-joist construction where I-joists are placed vertically in external walls, horizontally in internal floors and diagonally in the sloped roof. The exterior wall joists are 30 centimetres high, while those in the roof are 40 centimetres for a snow load of 3.5 kilo Newton per square meter, which corresponds to Trondheim's snow load. Their dimension was decided based on the required insulation thickness to reach the Passive House standard. The joists in the floors are placed in the south-north direction to limit their span. The floor joist height is 30 centimetres, except the floor in the mezzanine with is 20 centimetres due to its smaller span. The I-joists are placed at 60-centimeter distance from center to center. All I-joists have a width of 4.5 centimetres. The dimensioning tables from Hunton were used to determine the I-joists dimensions. A summary of joist dimension is presented in Table 8.

An interior load-bearing wall was needed to support the floor joists. Otherwise, high joist section would have been required and that would have taken more space, increasing the building height. That interior load-bearing wall is that separating the services area from the living area. It runs from west to east. The timber stud dimension of the interior load-bearing walls was determined from the Byggforsk recommendations for residential buildings. The studs in the non-load bearing partitions were set to 73 millimetres as recommended by Byggforsk. Studs are placed at 60 centimetres from center to center.

To have a cathedral ceiling in the mezzanine bedrooms, the roof joists are supported by a glue-laminated ridge beam that is itself supported by columns at its ends and at mid-length. The ridge beam is aligned with the load-bearing internal wall, and is therefore aligned with the stairs landing to the mezzanine. To keep a free height of 2 meters at the stairs landing, the ridge beam had to have a support at its mid-length to get an acceptable cross-section dimension. The possibility of having the ridge beam at the junction between roof I-joists was also investigated. Having the beam at the highest point in the room would have would have enabled a larger cross-section beam dimension, therefore remove the need for a column supporting it midway. However, the columns would have then been placed where the windows in the bathrooms are and where the entrance door is. It was therefore decided to keep the roof ridge beam aligned with the interior load-bearing wall. Details of the roof and external walls are shown in Figure 37.

ACOUSTICS

According to TEK17 § 13-6 (2), air sound insulation between rooms in a student housing unit shall have a weighted field-measured noise reduction number of at least 45 decibels. The acoustics requirements for student housing is not as stringent as those for other residential buildings where a noise reduction of 54 decibels is required between accommodation units. That level corresponds to the sound class C in Norwegian Standard NS 8175:2019 (Standard Norge, 2019). The design of internal walls was done to provide a noise reduction of at least 45 decibels throughout the building. Additional air insulation was done to reach a noise reduction level of 54 decibels for the walls separating the bedroom and the common area on the first floor, and for the walls between the bedrooms on the upper floors. To reach 45 decibels noise reduction, partition walls must be filled with insulation. Gypsum is usually used on both sides of the studs to improve the air insulation. In that case, Fermacell Fibergips was chosen because of its sound insulation properties and its low emission rating. Since it is heavier than regular gypsum board, it achieves a higher sound insulation value for the same board thickness. It is made mostly of plaster (80 percent) and wood fibre (20 percent). It is classified as M1 in terms of total volatile chemical pollutants, which is the best class. Hunton's handbook was used as a reference to determine the number of board layers needed to achieve the required noise reduction (Hunton, 2016). Two 12.5-milimeter boards on each side of the 73-milimeter studs provide a noise reduction value of 48 decibels together with the cavity insulation. Where a higher noise reduction is needed, a double wall construction was chosen where a 20-milimeter cavity separates the 73-milimeter studs. Having insulation between studs and one Fermacell 12.5-milimeter board on each side results in a noise reduction value of 56 decibels. A summary of the stud dimensions and noise reduction values is presented in Table 9. Details of internal walls is shown in the floor plans. For internal floor construction, 15 centimetres of insulation should be placed between the I-joists for acoustics purposes. There is also a 12-centimeter porous wood fibre board under the parquet flooring to further reduce noise levels. Details of floor construction is shown in Figure 17.

TABLE 8. I-JOISTS DIMENSIONS AND LOCATION

Type	I-joist size mm	Location
SW45H300	45x300	Exterior walls
SJ45H200	45x200	2- & 3-storey building: mezzanine floor
SJ45H200	45x300	2-storey building: 2nd floor 3-storey building: 2nd and 3rd floor
SJ45H400	45x400	Roof

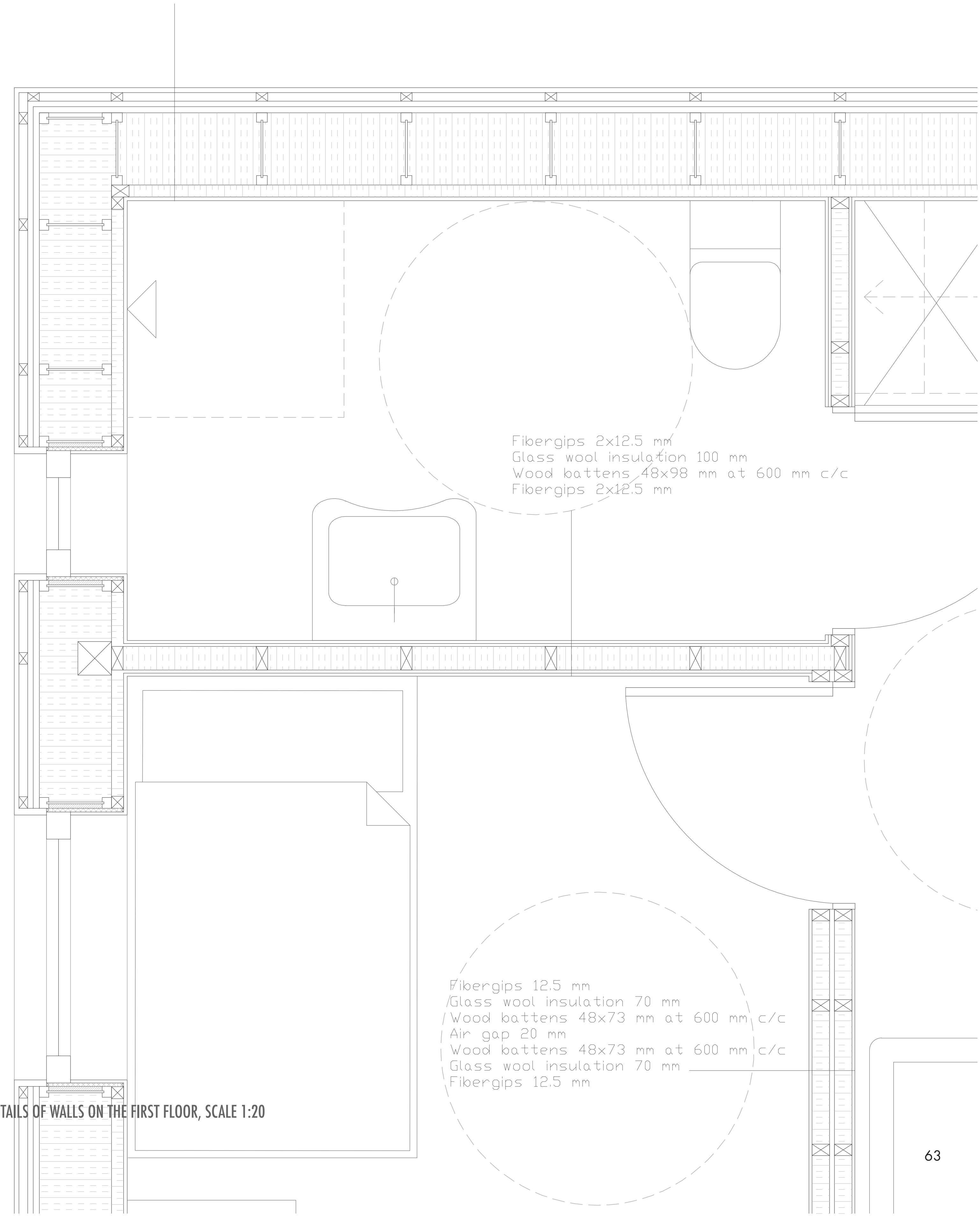
TABLE 9. STUDS DIMENSIONS, NOISE REDUCTION AND LOCATION

Type	Stud size mm	Noise reduction dB	Location
Partition wall	48x73	48	Between bathrooms and corridor
Double partition wall	2x 48x73	56	Between bedrooms Between bedroom and common area
Load-bearing wall to support one floor	48x73	48	2-storey building: 2nd floor 3-storey building: 3rd floor
Load-bearing wall to support two floors	48x98	49	2-storey building: 1st floor 3-storey building: 2nd floor
Load-bearing wall to support three floors	48x148	50	3-storey building: 1st floor

DETAILS EXTERNAL & INTERNAL WALLS
1:20
FLOOR PLAN - FIRST FLOOR - 2-STOREY BUILDING

Exterior cladding 19 mm
Horizontal battens 36x48 mm
Vertical battens 23x36 mm
Wind barrier 25 mm
I-joist 300 mm at 600 mm c/c
Wood fiber blown insulation 300 mm
Vapour barrier 0.15 mm
Horizontal battens 48x48 mm
Wood fiber board insulation 50 mm
Interior lining 15 mm

U-value 0.12 W/m2K



Fibergips 2x12.5 mm
Glass wool insulation 100 mm
Wood battens 48x98 mm at 600 mm c/c
Fibergips 2x12.5 mm

Fibergips 12.5 mm
Glass wool insulation 70 mm
Wood battens 48x73 mm at 600 mm c/c
Air gap 20 mm
Wood battens 48x73 mm at 600 mm c/c
Glass wool insulation 70 mm
Fibergips 12.5 mm

FIGURE 37. DETAILS OF WALLS ON THE FIRST FLOOR, SCALE 1:20

DETAILS WALL, FLOOR & FOUNDATIONS
1:20
SECTION D-D'

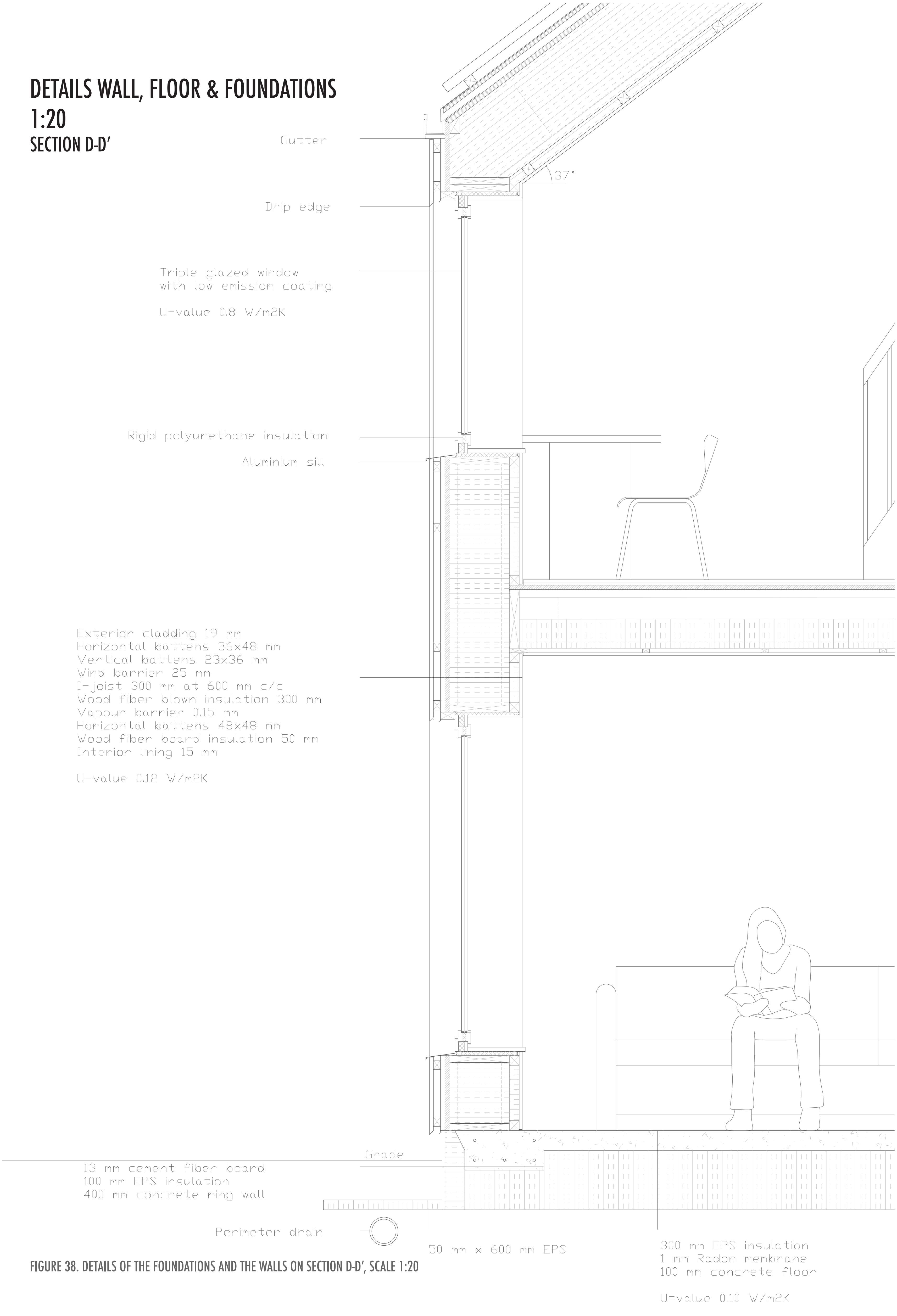


FIGURE 38. DETAILS OF THE FOUNDATIONS AND THE WALLS ON SECTION D-D', SCALE 1:20

MATERIALS

FOUNDATIONS

Foundations and groundwork usually account for a large part of a building's embodied emissions due to the high emissions from concrete. Most ZEB pilot projects have a strip concrete foundation with raised timber floor as a strategy to limit the use of concrete. Such foundation was therefore looked at more in detail. Strip foundations is categorized as an open foundation by Byggforsk. In open foundations, the bottom of the raised timber floor is exposed to outdoor climate and is therefore at risk of draft problems. Although strip foundation seems to be beneficial in terms of reduced embodied emissions, it is not recommended for residential buildings according to Byggforsk. Further work would need to be done to assess whether strip foundations with raised timber floor is a suitable solution for that project. In the scope of this thesis, the recommendations from Byggforsk were followed and a slab on grade was used instead.

It should be noted that further information on the ground conditions on site should be gathered before finalizing the design of the foundations. For the scope of this thesis, a preliminary foundation design was done based on the size of the building as well as the guidelines from Byggforsk in order to have an idea of the amount of materials needed for the ZEB-OM analysis.

The slab on grade can be either monolithic, i.e. foundation wall and slab cast in one, or cast in two where the concrete slab is separated from the concrete wall by insulation. Both options require about the same amount of concrete, but it was decided to go for the monolithic slab since it requires only one pouring of concrete, saving on the operation costs and time.

A concrete slab intended to support loads from non-load bearing walls and interior furniture is usually cast in thicknesses between 50 to 100 mm according to Byggforsk. It was assumed that 100 mm would be sufficient for the current project. The non-load-bearing walls are installed directly on the concrete floor. The slab should be thickened and reinforced under load-bearing walls.

The width of the foundation wall was set to 400 mm as recommended by Benders, which produces SINTEF certified insulation elements to be placed on the ground before the concrete is poured (Benders, 2015). Again from Benders, a foundation wall depth of 200 mm should provide enough stability for a house of two storeys in lightweight timber construction, while a wall depth of 400 mm is suggested for industrial buildings. It was therefore decided to use a foundation wall depth of 200 mm for the two-storey buildings and of 300 mm for the three-storey building. The top of the slab is located 150 mm above the grade as suggested by Byggforsk.

In cold climate, a slab on grade must be frost protected since the depth of the foundation wall is above the frost line. The insulation needed depends on the frost conditions of the site. The frost line in Trondheim is 1.5 meters below grade and the frost amount (F_{100}) is 20,000 h˚C. Insulation should be placed in four places: along the foundation wall (wall insulation), under the slab (floor insulation), under the foundation wall and perpendicular to the foundation wall at least 300 mm below grade (ground insulation). Based on Trondheim's frost amount, there should a minimum thickness of 100 mm placed vertically along the foundation wall, as well as 50-mm thick ground insulation laid horizontally over 400 mm from the foundation wall and over 600 mm in the corners. The insulation thickness under the foundation wall should be at least 100 mm and its compressive strength should be high enough to support the load above it. The insulation under the concrete floor must be thick enough to reach the Passive House standard. To do so, an insulation thickness of about 300 mm is needed to reach a U-value of 0.10 W/m²K. EPS from EPS-Gruppen manufactured in Frederikstad was chosen because of its recycling program and lower GHG emissions. The summary of the insulation thickness required for Trondheim's climate and to reach the Passive House standard is shown in Table 10.

Slab on grades are reinforced with steel bars. In the foundation wall, five reinforcement bars of 12 mm diameter were placed: three at the bottom and two at the top. The concrete floor is reinforced with a steel wire mesh of 6-mm bars at 150 mm spacing on both directions. Again, ground conditions affect the reinforcement needed and further work should be done to finalize the foundations design. Exterior insulation along the foundation wall must be mechanically protected with a fibre cement panel of 13-mm thickness. A radon membrane should be placed under the concrete slab to prevent radon-contaminated air from entering the building. The foundation details are shown in Figure 38.

TABLE 10. FOUNDATION INSULATION DIMENSIONS FOR TRONDHEIM

Location	Thickness mm	Width mm
Along wall insulation	100	-
Floor insulation	300	-
Under wall insulation	100	-
Ground insulation perimeter	50	400
Ground insulation corner	50	600

MATERIALS

WINDOWS & DOORS

Triple-glazed windows and doors were chosen to reach the maximum thermal transmittance (U-value)of 0.8 W/m²K as required to reach the Passive House standard.

Windows are located 30 millimetres away from the wind barrier, further in the wall. Having the window inserted further into wall, rather than in line with the wind barrier, reduces thermal bridging. However, that leaves the part of the wall under the window at risk of rain exposure. A waterproof membrane must therefore be installed under the window sill.

As recommended by Byggforsk, the internal linings of skylights should be positioned so that the room air can easily circulate along the interior surface of the window. That limits the risk of condensation along the window. The lining above the window should be horizontal, while the lining below should be vertical. Doing so, the daylight quality is improved in the bedroom as well. Also, having a horizontal lining above the window reduces the risk of someone to hit their head on the lining if it were kept perpendicular to the window pane. One drawback of positioning the interior lining this way is that the insulation thickness around the window is reduced. The horizontal lining above the window was therefore positioned to have at least 10 centimetres of insulation. Since the bottom of the skylight is almost at the junction with the external wall, the interior lining was kept perpendicular to the window pane, and only the last section of it is aligned with the vertical wall.

INSULATION

The insulation thickness of exterior walls and roof was based on Passive House levels. Mineral wool is commonly used and products with recycled content is also available on the market, like Glava products for instance. Hunton manufactures wood fibre insulation that is an interesting alternative to mineral wool. Both products are produced in Norway, wood fibre in Gjovik (about 400 km from Trondheim), and mineral wool in Askim (about 550 km from Trondheim). Mineral wool has a heat conductivity of 0.034 W/mK, while wood fibre has a value of 0.038 W/mK. A higher insulation thickness is therefore required with wood fibre to achieve the same insulation value. On the other hand, wood fibre insulation has a lower environmental impact than mineral wool. Although Hunton wood fibre insulation does not have an EPD yet, documentation available on their website reveals that the environmental footprint of blown insulation is 0.4 kilograms of CO_2 per square meters, which is lower than the value of 0.43 kg/CO_2/m² of mineral wool (Hunton, 2018). Both values are for an insulation material of thermal resistance of 1.0 m²K/W. Both insulation types are therefore good options, but for the scope of this thesis, wood fibre was chosen because of it is manufactured closer to Trondheim and has a lower environmental impact.

Hunton recommends using a layer of plate insulation between the interior lining and the vapour barrier. Doing so, the vapour barrier is 50 millimetres further into the wall, protected from the perforation for electricity or other services. Byggforsk also recommends this retracted vapour barrier practice in their Passive House in wood chapter. For exterior walls, the insulation thickness is then 350 millimetres of which 300 is blown and 50 is plate, reaching a total U-value of 0.12 W/m²K. For the roof, the insulation thickness is 450 millimetres of which 400 is blown and 50 is plate, reaching a total U-value of 0.09 W/m²K.

OTHER MATERIALS

Exterior wall cladding is made out of untreated wood to create a similar look to the surrounding Moholt 50|50 buildings. Natural wood has low greenhouse gas emissions since no treatment is applied to it. The buildings on site have different natural wood cladding configurations to break the uniformity between them: one three-storey unit has horizontal cladding; one two-storey and one three-storey unit have vertical cladding and; one two-storey and one-three storey have horizontal wood chips. The wood chips cladding is produced locally by Norsk Spon in Melhus, Sor-Trondelag. The horizontal and vertical cladding is made out of untreated natural wool.

The exterior material is different on the north and south sides of the roof. On the south side, the roof is mostly covered with semi-integrated PV panels, where the racks are mounted on plywood and asphalt sheathing. On the north side, the roof is covered with black metal roofing. Metal roofing was chosen over asphalt shingles for its durability and its look which creates a similar finish to that of PV panels. PV panels are therefore more visually integrated in the design of the building.

On the first floor, the concrete slab is exposed in all rooms, removing the need for additional flooring materials. An exposed concrete floor is durable, easy to clean and waterproof. It can be stained, polished, painted or top-coated to customize it. The upper floors are covered with parquet in bedrooms and corridors, and ceramic tiles in the bathrooms.

The interior lining on the ceiling and walls is plywood. The walls in the shower areas are covered with ceramic to protect the wall structure from moisture. The rest of the walls in bathrooms were protected from moisture by applying a paint.

DETAILING

Integrated gutters are a common practice in achieving a minimalistic and frame-less architectural style, especially in Scandinavia. Having a fully integrated gutter at the bottom of the roof would in this case is not ideal since the PV panels and the skylights are placed close to the intersection with the wall. A semi-integrated gutter was therefore designed, where it does not interrupt the insulation and wind barrier.

DETAILS ROOF, SKYLIGHT & WINDOW
1:20
SECTION D-D’

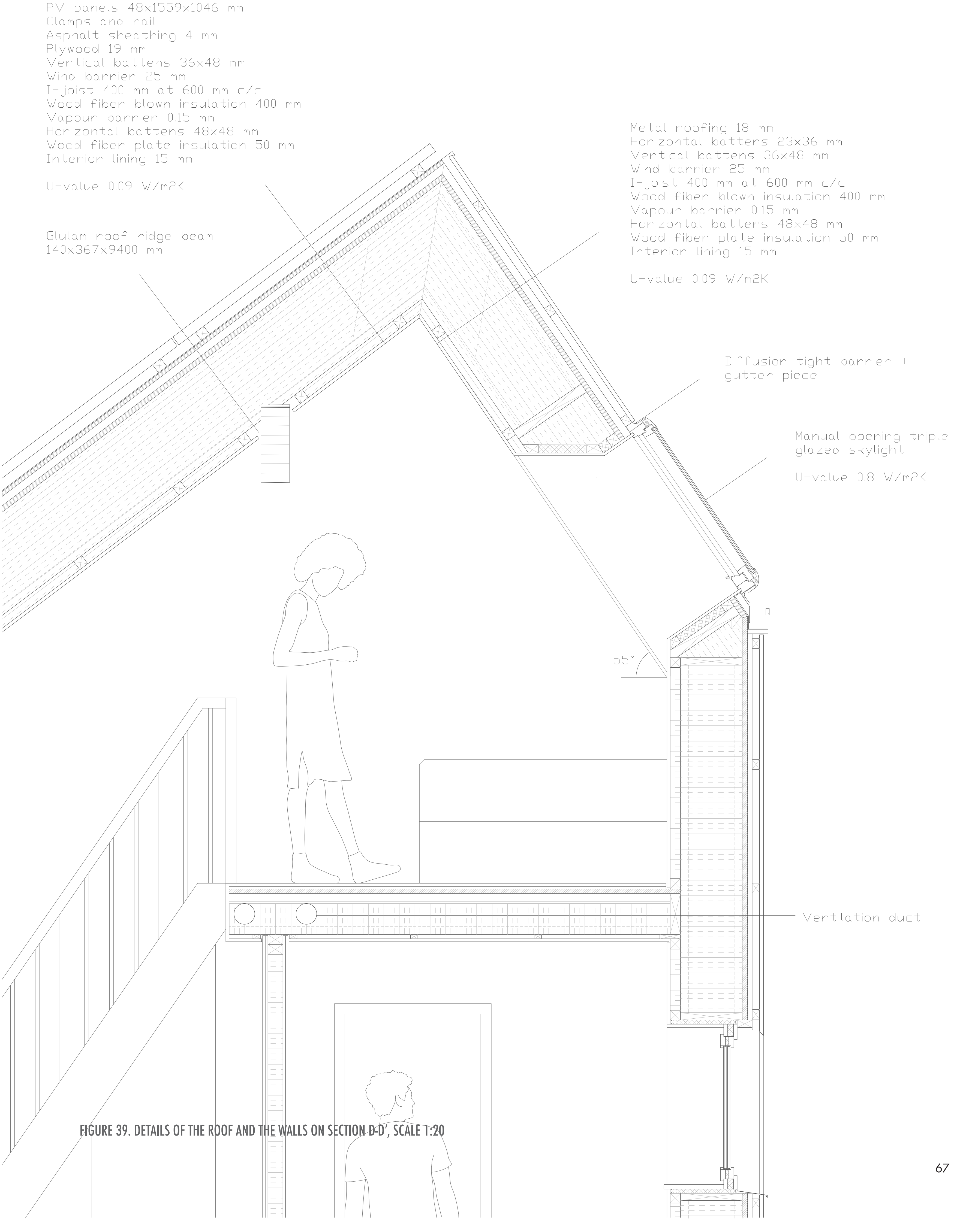
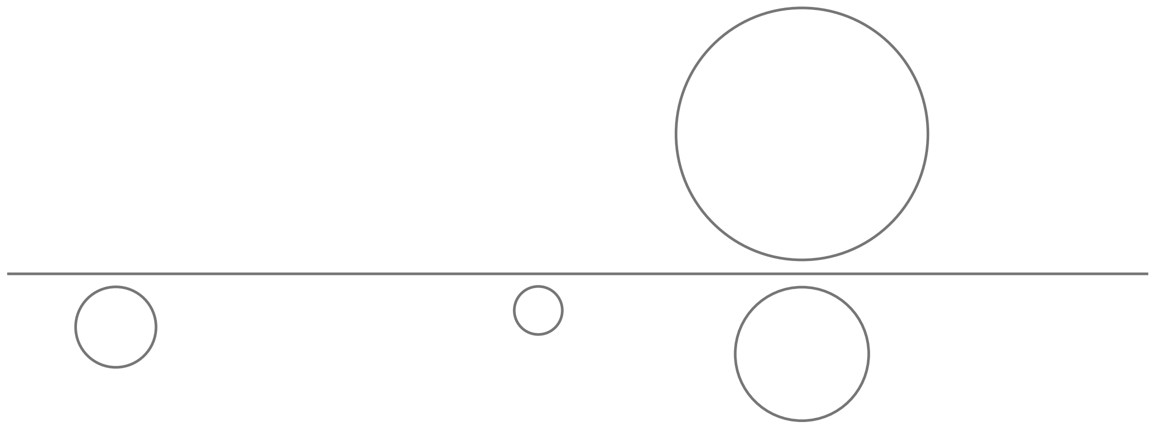


FIGURE 39. DETAILS OF THE ROOF AND THE WALLS ON SECTION D-D’, SCALE 1:20



VII:
ZEB
BALANCE

ZEB BALANCE

EMISSIONS FROM OPERATION

An energy simulation with the use of SIMIEN was performed to determine the annual energy need and energy delivered of the buildings. A whole-building simulation was done, meaning that the building was simulated as one zone. This is a simplification method commonly used for energy simulation of residential single-detached buildings. Two building simulations were performed, one for each building type: two-storey and three-storey. The SIMIEN reports are in Appendix B.

The energy need of the building is covered by an electric boiler and a ground-source heat pump. The production energy efficiency of the heat pump was set to 3.2, based on field measurements done on the existing energy system on site.

The buildings were designed to reach the Passive House standard and therefore the buildings were simulated to reach the minimum requirements set by NS 3700 in addition to those set by TEK17 and NS 3031 (Standard Norge, 2016). Simulation parameters are summarized in Table 11.

The total energy need is of 10,037 kWh per year (83.4 kWh/m^2) for the two-storey building, and of 13,977 kWh per year (81,4 kWh/m^2) for the three-storey building. It was assumed that the energy need is the same for all buildings of the same height, i.e. the position of the buildings with respect to each other and the shading it creates was not accounted for in the simulations. In reality, the energy demand will slightly be different between buildings of the same height. The energy need per building use results are shown in Figure 40.

TABLE 11. BUILDING PARAMETERS

Parameter	Value	Reference
Heated floor area (BRA)	2-storey: 120.4 m^2 3-storey: 171.7 m^2	-
Heated volume	2-storey: 299.5 m^3 3-storey: 414.5 m^3	-
Exterior surface (measured from inside)	2-storey: 298.4 m^2 3-storey: 379.4 m^2	-
U-value	Exterior wall: 0.12 W/m^{2}K Roof: 0.09 W/m^{2}k Slab on grade: 0.10 W/m^{2}K Windows & doors: 0.8 W/m^{2}K	TEK17 NS 3700
Infiltration rate	0.6 h^{-1}	NS 3700
Normalized thermal bridge	0.03 W/mK	NS 3700
Glazing to BRA ratio	2-storey: 20.4% 3-storey: 19.7%	TEK17
Operational hours	Ventilation: 24 h/d Lighting: 16 h/d Technical equipment: 16 h/d Occupancy: 24 h/d	NS 3031
Internal gains	Lighting: 1.95 W/m^2 Technical equipment: 3.00 W/m^2 Domestic hot water: 3.40 W/m^2 People: 1.50 W/m^2	NS 3031
Ventilation rate	1.2 m^3/h/m^2	TEK17
Other	Specific pump power: 1.5kW/m^3/s Heat recovery efficiency: 0.86	TEK17

As expected for residential Passive House buildings, domestic hot water heating takes the highest share, accounting for 37 percent of the annual energy demand. As previously mentioned, a grey water heat recovery system could be installed in the buildings to reduce the energy need for domestic water heating. The domestic hot water need in residential buildings is set to 3.4 W per square meter. It is therefore based on the floor area of the building rather than the building occupancy. Based from data and experiences from other Sit student villages, the average annual domestic hot water energy consumption per year is 1,000 kWh per student. That is also the case for Moholt 50|50, where the estimated consumption is 1,050 kWh per student. Using that same logic, the domestic hot water energy consumption would become 5,000 kWh per year for the two-storey building and 8,000 kWh per year for the three-storey building. It was therefore decided not to include the grey water heat recovery savings in the energy simulation to yield conservative results. The next highest energy demand is technical equipment with 21-22 percent of the total demand. Space heating comes in close third place with 20 -21 percent of the total demand. Lighting accounts for about 14 percent of the total demand. The lighting load could be reduced with the use of motion detectors in the corridors and in the common room.

The heat losses are mainly through the windows and doors, due to their lower heat resistance than other parts of the building envelope, as shown in Figure 41. The window-to-floor area ratio was kept to 20 percent to limit the heat losses, but still provide a good daylighting quality. The maximum window-to-floor area ratio is set to 25 percent by TEK17. Exterior walls also contribute to a large part of the heat losses with their significant share of the total exterior surface of the building.

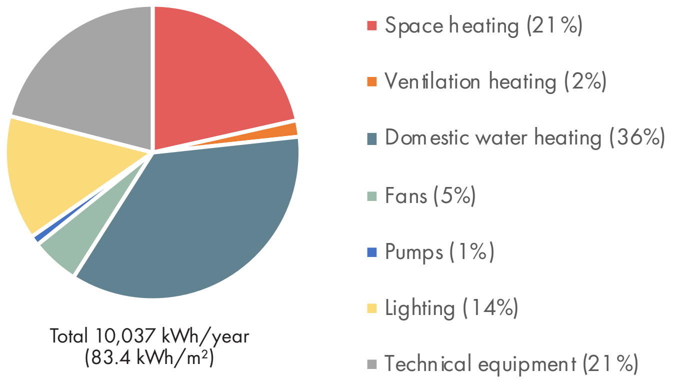
The total electricity delivered to the building is 6,739 kWh per year (56.0 kWh/m^2) for the two-storey building, and 9,447 kWh per year (55.1 kWh/m^2) for the three-storey building. The energy delivered to the building is lower than the energy need because of the ground-source heating system having a SCOP of 3.2 and the electricity provided by the PV panels.

A GHG emission factor of 132 gCO$_2$eq per kWh was used for electricity. That factor corresponds to the emission factor used in ZEB projects and it is based on the assumption that the electricity supply in Europe will be carbon neutral in 2050. The total CO2 equivalent emissions for energy operation are of 889 kg for the two-storey building and of 1,247 kg for the three-storey building. The results are summarized in Table 12.

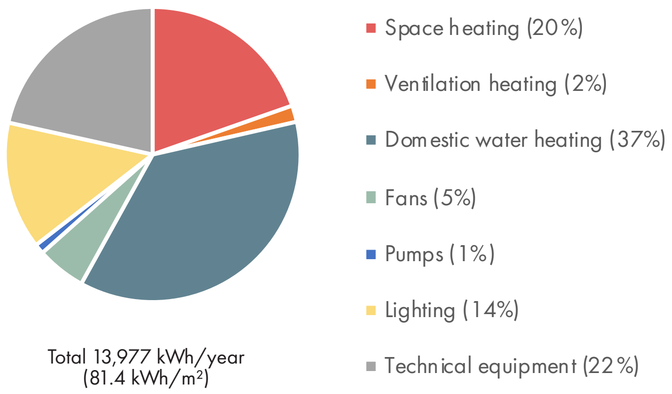
TABLE 12. ANNUAL ENERGY NEED AND ENERGY DELIVERED

	Two-storey building	Three-storey building
Annual energy need (kWh/y)	10,037	13,997
Annual specific energy need (kWh/m^2/y)	83.4	81.4
Annual energy delivered (kWh/y)	6,739	9,447
Annual specific energy delivered (kWh/m^2/y)	56.0	55.1
Operation emissions (kgCO$_{2eq}$/y)	889	1,247
Specific annual emissions (kCO$_{2eq}$/m^2/y)	7.38	7.26

ZEB BALANCE

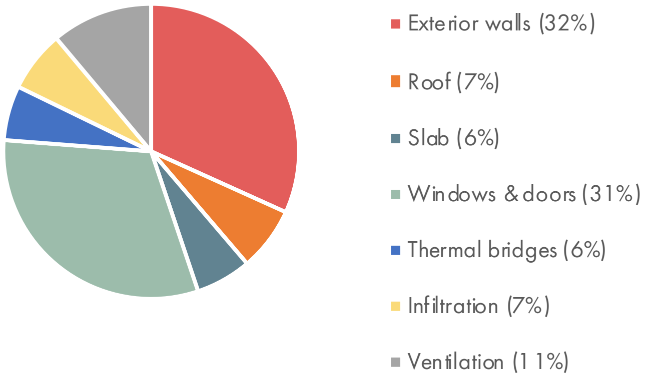


TWO-STOREY BUILDING

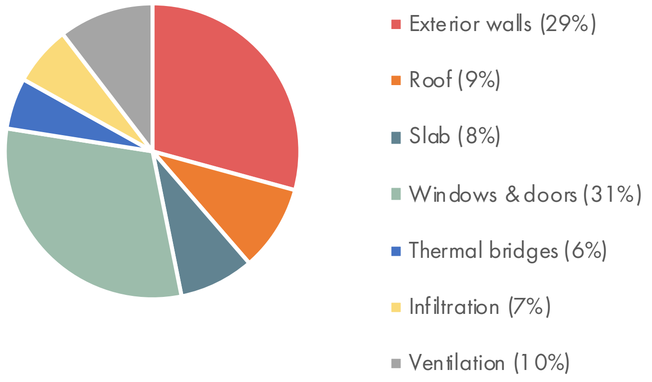


THREE-STOREY BUILDING

FIGURE 40. ENERGY DEMAND PER END-USE



TWO-STOREY BUILDING



THREE-STOREY BUILDING

FIGURE 41. HEAT LOSS PER COMPONENT

AVOIDED EMISSIONS FROM PV PRODUCTION

The PV panels mounted on the south roof produce renewable electricity in an aim to offset the emissions from operation and materials. The PV panels produce on average 10,091 kWh per year on the two-storey building, and 10,053 kWh on the three-storey building. The corresponding avoided emissions obtained with the electricity factor of 132 g/kWh are shown in Table 13. Although the PV panels theoretically produce enough electricity to cover the electricity need of the building over a year, the electricity output of the PV panels does not always match that of the building need. Unfortunately, the highest PV electricity production occurs in the summer, when the energy need of the building is at its lowest. About 27 percent of the electricity generated on site is delivered to the building, the rest being exported to the grid contributing to low carbon electricity. Since Sit is the owner of the surrounding buildings at Moholt, the excess electricity could possibly be used by the other buildings in the village.

EMISSIONS FROM MATERIALS

The CO_2-equivalent emissions from the materials production (A1-A3) and replacement (B4) over a building lifetime of 60 years were calculated for the two types of buildings. The Excel ZEB tool developed by NTNU and Sintef was used as the spreadsheet to compile results (Houlihan Wilberg, 2017). The Norwegian EPD library available from EPD-norge.no was used as much as possible to document to emission factors and lifetime values of the materials. Although the emissions from the materials transportation from the manufacturer to the site (A4)was not included in the calculations, materials produced locally were prioritized in the selection.

The building itself is used as the system boundary. However, only the general building components were accounted for in the calculations, namely: groundwork and foundations; superstructure; outer walls; inner walls; floor structure; outer roof and stairs. The ventilation duct and PV panels were also included. Further work would need to be done to assess the emissions contribution of the fixed furniture, appliances, piping, radiators, lighting and other components. It should also be noted that the results presented in this section are based on the drawings produced in the design stage of the project and are just an overview of the actual emissions from materials. The material quantities and the emission factors used in the calculations are presented in Table 14-15 for the two-storey building, and in Table 16-17 for the three-storey building.

TABLE 13. AVOIDED EMISSIONS FROM PV PRODUCTION

	Two-storey building	Three-storey building
Annual delivered PV electricity (kWh/y)	2,786	2,776
Annual exported PV electricity (kWh/y)	7,304	7,277
Total PV annual PV production (kWh/y)	10,091	10,053
Total avoided emissions (kgCO_{2eq}/y)	1,332	1,327
Specific annual emissions (kCO_{2eq}/m²/y)	11.06	7.29

TABLE 14. EMBODIED EMISSIONS FOR THE TWO-STOREY BUILDING

Building element	Product	Amount	Unit	A1-A3 Emission factor	A1-A3 Production emissions	A1-A3 Contribution	B4 Lifetime factor	B4 Replacement emissions	Reference
2 Building									
21 Groundwork and foundations	Low-carbon concrete	11.52	m^3	188.2	2,168.0	64%	0	0	NEPD 283N (2014)
	Steel reinforcement bars (0.91 kg/m for Ø12mm)	108.11	kg	0.3	35.1	1%	0	0	NEPD 347-238-EN (2015)
	Steel mesh reinforcement (30.2 kg/stk for Ø6mm K189)	181.20	kg	0.3	60.0	2%	0	0	NEPD 348-237-EN (2015)
	EPS 80 kN/m^2, 50 mm	14.72	m^2	2.9	42.1	1%	0	0	NEPD 322-185-NO (2015)
	EPS 80 kN/m^2, 100 mm	172.59	m^2	5.7	987.2	29%	0	0	NEPD 322-185-NO (2015)
	Radon membrane (polyethylene and polyester)	66.33	m^2	1.3	82.9	3%	0	0	NEPD 209N (2013)
					3,375.3			0	
22 Superstructure	Ridge glulam beam	0.48	m^3	92.0	44.1	49%	0	0	NEPD 336-222-NO (2015)
	Glulam columns	0.50	m^3	92.0	45.9	51%	0	0	NEPD 336-222-NO (2015)
					90.0			0	
23 Outer walls	Untreated wood external cladding, 19 mm	200.70	m^2	1.4	273.0	7%	0	0	NEPD 378-264-NO (2015)
	Windbarrier, 12 mm (area adjusted for 25mm)	401.40	m^2	0.4	239.2	13%	0	0	NEPD 1247-400-NO (2012)
	Timber I-beams	312.30	m	1.8	565.3	15%	0	0	NEPD 311-186-NO (2015)
	Wood fibre blown insul, 38mm (area adjusted for 300mm)	1,218.71	m^2	0.4	487.5	13%	0	0	Hunton 2018
	Wood fibre plate insul, 38mm (area adjusted for 50mm)	188.47	m^2	0.78	147.0	4%	0	0	Hunton 2018
	Vapour barrier (polyethylene)	200.70	m^2	0.3	63.0	2%	0	0	NEPD 341-230-NO (2015)
	Timber battens (structural pine or spruce)	2.78	m^3	53.0	145.4	4%	0	0	NEPD 308-179-NO (2015)
	Wood interior cladding, 14 mm	110.30	m^2	0.8	86.0	2%	0	0	NEPD 309-180-NO (2015)
	Ceramics	16.78	m^2	9.7	162.8	4%	0.2	34.2	IBU EPD IKF 2011111-EN
	Glass exterior doors (1 pc of 1,230x2,180 mm)	1.63	pc	221.1	360.2	10%	0.5	180.1	NEPD 330-212-NO (2015)
	Windows (1 pc of 1,230x1,480 mm)	10.00	pc	117.3	1,172.7	32%	0.5	586.4	NEPD 329-212-NO (2015)
					3,704.0			800.7	
24 Inner walls	Timber battens (structural pine or spruce)	1.13	m^3	53.0	60.1	7%	0	0	NEPD 308-179-NO (2015)
	Glass wool insulation, 70 mm	52.63	m^2	1.1	58.4	7%	0	0	NEPD 221N (2013)
	Glass wool insulation, 100 mm	13.46	m^2	1.6	21.9	2%	0	0	NEPD 221N (2013)
	Acoustic fibreboard, 12.5 mm	251.88	m^2	1.1	287.1	32%	0	0	NEPD 1332-430-EN (2016)
	Inner wood door	8.00	pc	59.7	477.8	53%	1	477.8	NEPD 157N (2012)
					905.4			477.8	
25 Floor structure	Timber I-beams, 300mm	142.18	m	1.8	257.3	22%	0	0	NEPD 311-186-NO (2015)
	Glass wool insulation, 150 mm	64.33	m^2	2.4	157.1	13%	0	0	NEPD 211N (2013)
	Particle board	1.46	m^3	223.0	324.6	28%	0	0	NEPD 1324-428-NO (2017)
	Acoustic fibreboard	0.73	m^3	196.0	143.7	12%	0	0	NEPD 274N (2014)
	Solid wood flooring	58.7	m^2	0.8	45.8	14%	0	0	NEPD 309-180-NO (2015)
	Ceramics	7.30	m^2	9.7	70.8	6%	0.2	14.9	IBU EPD IKF 2011111-EN
					1,178.1			14.9	
26 Outer roof	Bitumen felt	66.04	m^2	0.3	20.7	1%	1	188.1	NEPD 186N (2013)
	Steel roofing sheets	23.04	m^2	19.1	440.0	22%	0	0	EPD IFBS 2013211-EN
	Particle board	1.19	m^3	223.0	265.5	13%	0	0	NEPD 1324-428-NO (2017)
	Wind barrier, 18 mm	85.70	m^2	1.3	107.1	5%	0	0	NEPD 1248-401-NO (2015)
	Timber I-beams (length adjusted for 400mm)	153.68	m	1.8	278.2	14%	0	0	NEPD 311-186-NO (2015)
	Wood fibre blown insul, 38mm (area adjusted for 300mm)	800.27	m^2	0.4	320.1	16%	0	0	Hunton 2018
	Wood fibre plate insul, 38mm (area adjusted for 50mm)	84.67	m^2	0.78	66.0	3%	0	0	Hunton 2018
	Vapour barrier (polyethylene)	66.04	m^2	0.3	20.7	1%	0	0	NEPD 341-230-NO (2015)
	Timber battens (structural pine or spruce)	0.90	m^3	53.0	47.6	2%	0	0	NEPD 308-179-NO (2015)
	Skylight (1 pc of 1,140x1,400 mm)	2.01	pc	103.0	206.5	10%	0	0	
					1,980.6			188.1	
28 Stairs	Main stairs: structural timber	0.34	m^3	53.0	18.0		0	0	NEPD 308-179-NO (2015)
	Stairs to mezzanine: structural timber	0.66	m^3	53.0	35.1		0	0	NEPD 308-179-NO (2015)
					53.0			0	

TABLE 15. EMBODIED EMISSIONS FOR THE TWO-STOREY BUILDING (CONTINUED)

Building element	Product	Amount	Unit	A1-A3 Emission factor	A1-A3 Production emissions	A1-A3 Contribution	B4 Lifetime factor	B4 Replacement emissions	Reference
3 Heating, ventilation and sanitary									
36 Ventilation and air conditioning	Air outlet and inlet	1.00	pc	27.5	27.1	36%	0	0	Ecoinvent v.3.1 (2014)
	Flexible duct	34.10	m	1.4	47.7	64%	0	0	Ecoinvent v.3.1 (2014)
					53.0			0	
4 Electric power									
49 Other	Photovoltaic panel	58.67	m^2	210.0	12,320.3	100%	1	12,320.3	Ecoinvent v.3.1 (2014)
					12,320.3			12,320.3	
Total = 37,484 kgCO$_{2eq}$					A1-A3: 23,682 kgCO$_{2eq}$			B4:13,802 kgCO$_{2eq}$	

The total embodied emissions from material production and replacement over 60 years is 37,484 kgCO2eq for the two-storey building. This is equivalent to 5.19 kgCO$_2$eq/m^2/year. The production part accounts for 63 percent, while the remaining 37 percent is for replacement. Most materials have a lifetime of at least 60 years, and therefore it was assumed that they do not require a replacement.

In terms of building component, PV panels account for 66 percent of total emissions, followed by outer walls with 12 percent, and groundwork and foundations with 9 percent. Results are illustrated in Figure 42. The main materials contributing to each component are PV panels, concrete and windows.

The building material with the highest share of the embodied emissions is the PV panels, as expected. The generic value from Ecoinvent was used since no EPD was found for SunPower. PV panels have a lifetime of about 30 years. It was assumed that their replacement factor is 1. This is a conservative assumption since the emission factor for PV panels could be lowered in 30 years from now with the advancement in technology and the decarbonization of the grid.

The next material with highest emissions is concrete, although low-carbon concrete was used. It should be noted that an adjustment factor of 1.5 was applied to the concrete amount since the foundation design was done without knowing the ground conditions, and therefore the amount of concrete could be higher in reality.

Windows come in third place. The window-to-floor area ratio was limited to 20 percent, which is high enough to provide good daylight, but lower than the maximum limit of 25 percent. Wooden frame windows have a lifetime of 40 years. Although they could possibly last for 60 years, a conservative factor of 0.5 was used as recommended by the ZEB Tool.

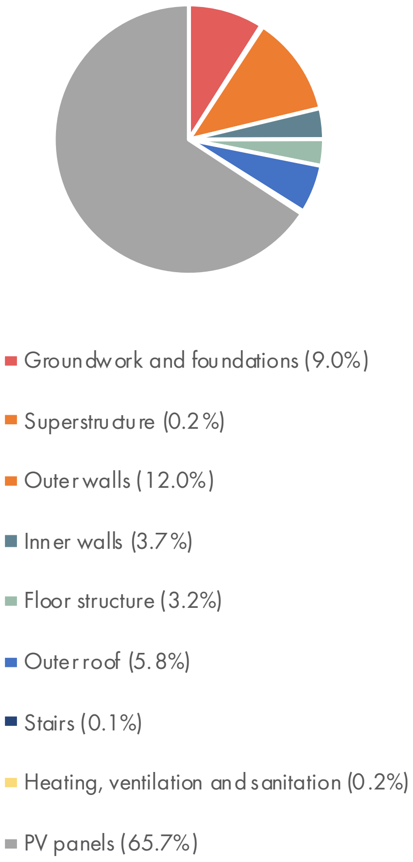


FIGURE 42. EMBODIED EMISSIONS PER BUILDING COMPONENT - TWO-STOREY BUILDING

TABLE 16. EMBODIED EMISSIONS FOR THE THREE-STOREY BUILDING

Building element	Product	Amount	Unit	A1-A3 Emission factor	A1-A3 Production emissions	A1-A3 Contri-bution	B4 Life-time factor	B4 Re-placement emissions	Reference
2 Building									
21 Groundwork and foundations	Low-carbon concrete	14.01	m^3	188.2	2,637.4	70%	0	0	NEPD 283N (2014)
	Steel reinforcement bars (0.91 kg/m for Ø12mm)	108.11	kg	0.3	35.1	1%	0	0	NEPD 347-238-EN (2015)
	Steel mesh reinforcement (30.2 kg/stk for Ø6mm K189)	181.20	kg	0.3	60.0	2%	0	0	NEPD 348-237-EN (2015)
	EPS 80 kN/m^2, 50 mm	14.72	m^2	2.9	42.1	1%	0	0	NEPD 322-185-NO (2015)
	EPS 80 kN/m^2, 100 mm	163.26	m^2	5.7	933.9	25%	0	0	NEPD 322-185-NO (2015)
	Radon membrane (polyethylene and polyester)	66.33	m^2	1.3	82.9	2%	0	0	NEPD 209N (2013)
					3,791.4			0	
22 Superstructure	Ridge glulam beam	0.48	m^3	92.0	44.1	41%	0	0	NEPD 336-222-NO (2015)
	Glulam columns	0.69	m^3	92.0	63.1	59%	0	0	NEPD 336-222-NO (2015)
					107.2			0	
23 Outer walls	Untreated wood external cladding, 19 mm	281.34	m^2	1.4	382.6	8%	0	0	NEPD 378-264-NO (2015)
	Windbarrier, 12 mm (area adjusted for 25mm)	562.68	m^2	0.4	335.4	11%	0	0	NEPD 1247-400-NO (2012)
	Timber I-beams	471.20	m	1.8	852.9	17%	0	0	NEPD 311-186-NO (2015)
	Wood fibre blown insul, 38mm (area adjusted for 300mm)	1,454.48	m^2	0.4	581.79	11%	0	0	Hunton 2018
	Wood fibre plate insul, 38mm (area adjusted for 50mm)	274.53	m^2	0.78	214.13	4%	0	0	Hunton 2018
	Vapour barrier (polyethylene)	281.3	m^2	0.3	88.3	2%	0	0	NEPD 341-230-NO (2015)
	Timber battens (structural pine or spruce)	3.28	m^3	53.0	173.9	3%	0	0	NEPD 308-179-NO (2015)
	Wood interior cladding, 14 mm	168.85	m^2	0.8	131.7	3%	0	0	NEPD 309-180-NO (2015)
	Ceramics	21.28	m^2	9.7	206.4	4%	0.2	43.4	IBU EPD IKF 2011111-EN
	Glass exterior doors (1 pc of 1,230x2,180 mm)	1.63	pc	221.1	360.2	7%	0.5	180.1	NEPD 330-212-NO (2015)
	Windows (1 pc of 1,230x1,480 mm)	15.08	pc	117.3	1,769.4	35%	0.5	884.7	NEPD 329-212-NO (2015)
					5,096.7			1,108.2	
24 Inner walls	Timber battens (structural pine or spruce)	2.15	m3	53.0	114.0	8%	0	0	NEPD 308-179-NO (2015)
	Glass wool insulation, 70 mm	52.63	m2	1.1	99.02	7%	0	0	NEPD 221N (2013)
	Glass wool insulation, 100 mm	14.52	m2	1.6	23.6	2%	0	0	NEPD 221N (2013)
	Glass wool insulation, 150 mm	13.46	m2	2.4	32.9	2%	0	0	NEPD 221N (2013)
	Acoustic fibreboard, 12.5 mm	363.72	m2	1.1	414.64	28%	0	0	NEPD 1332-430-EN (2016)
	Inner wood door	13.00	pc	59.7	776.5	53%	1	776.5	NEPD 157N (2012)
					1,460.7			776.5	
25 Floor structure	Timber I-beams, 300mm	251.18	m	1.8	454.6	24%	0	0	NEPD 311-186-NO (2015)
	Glass wool insulation, 150 mm	111.37	m^2	2.4	272.0	14%	0	0	NEPD 211N (2013)
	Particle board	2.52	m^3	223.0	561.9	30%	0	0	NEPD 1324-428-NO (2017)
	Acoustic fibreboard	0.91	m^3	196.0	178.6	9%	0	0	NEPD 274N (2014)
	Solid wood flooring	137.70	m^2	0.8	260.3	14%	0	0	NEPD 309-180-NO (2015)
	Ceramics	9.30	m^2	9.7	90.2	5%	0.2	18.9	IBU EPD IKF 2011111-EN
					1,897.0			18.9	
26 Outer roof	Bitumen felt	66.04	m^2	0.3	20.7	1%	1	188.1	NEPD 186N (2013)
	Steel roofing sheets	23.04	m^2	19.1	440.0	22%	0	0	EPD IFBS 2013211-EN
	Particle board	1.19	m^3	223.0	265.5	13%	0	0	NEPD 1324-428-NO (2017)
	Wind barrier, 18 mm	85.70	m^2	1.3	107.1	5%	0	0	NEPD 1248-401-NO (2015)
	Timber I-beams (length adjusted for 400mm)	153.68	m	1.8	278.2	14%	0	0	NEPD 311-186-NO (2015)
	Wood fibre blown insul, 38mm (area adjusted for 300mm)	800.27	m^2	0.4	320.1	16%	0	0	Hunton 2018
	Wood fibre plate insul, 38mm (area adjusted for 50mm)	84.67	m^2	0.78	66.0	3%	0	0	Hunton 2018
	Vapour barrier (polyethylene)	66.04	m^2	0.3	20.7	1%	0	0	NEPD 341-230-NO (2015)
	Timber battens (structural pine or spruce)	0.90	m^3	53.0	47.6	2%	0	0	NEPD 308-179-NO (2015)
	Skylight (1 pc of 1,140x1,400 mm)	2.01	pc	103.0	206.5	10%	0	0	EPD library Norge
					1,980.6			188.1	
28 Stairs	Main stairs: structural timber	0.66	m^3	53.0	35.1	50%	0	0	NEPD 308-179-NO (2015)
	Stairs to mezzanine: structural timber	0.66	m^3	53.0	35.1	50%	0	0	NEPD 308-179-NO (2015)
					70.2			0	

TABLE 17. EMBODIED EMISSIONS FOR THE THREE-STOREY BUILDING (CONTINUED)

Building element	Product	Amount	Unit	A1-A3 Emission factor	A1-A3 Production emissions	A1-A3 Contribution	B4 Lifetime factor	B4 Replacement emissions	Reference
3 Heating, ventilation and sanitary									
36 Ventilation and air conditioning	Air outlet and inlet	1.00	pc	27.5	27.1	27%	0	0	Ecoinvent v.3.1 (2014)
	Flexible duct	52.10	m	1.4	72.9	73%	0	0	Ecoinvent v.3.1 (2014)
					100.4			0	
4 Electric power									
49 Other	Photovoltaic panel	58.67	m^2	210.0	12,320.3	100%	1	12,320.3	Ecoinvent v.3.1 (2014)
					12,320.3			12,320.3	
Total = 41,236 $kgCO_{2eq}$				A1-A3: 26,824 $kgCO_{2eq}$			B4: 14,412 $kgCO_{2eq}$		

The total emissions for the three-storey building is of 41,236 kgCO2eq over a lifetime of 60 years. Having an extra floor results in an increase in emissions of 10 percent. The increase is not significant since the quantity of the material with most emissions, PV panels, is the same in both cases. Both buildings also have a similar amount of emissions from outer walls and foundations. The increase is mostly due to the increase in outer walls area. Emissions from production (A1-A3) accounts for 65 percent of the total emissions, while replacement accounts for 35 percent.

The embodied emissions distribution per building component is shown in Figure 43. The distribution is similar to that of the two-storey building and similar conclusions can be drawn.

A summary of the embodied emissions for both building types is presented in Table 18.

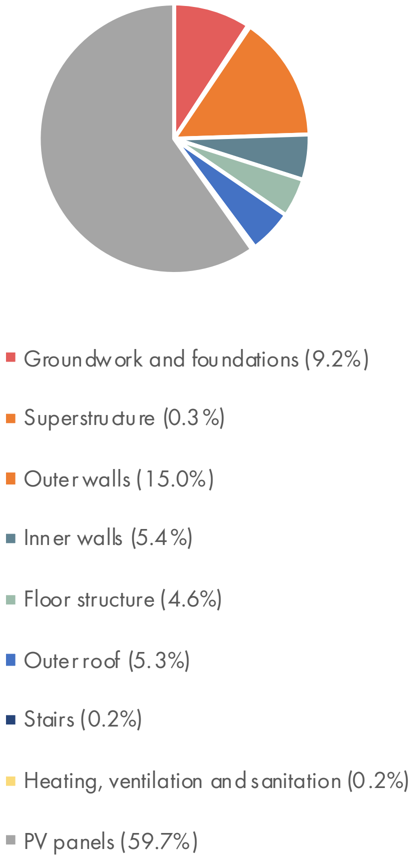


FIGURE 43. EMBODIED EMISSIONS PER BUILDING COMPONENT - THREE-STOREY BUILDING

TABLE 18. TOTAL EMBODIED EMISSIONS

	Two-storey building	Three-storey building
A1-A3		
Total emissions over 60 years ($kgCO_{2eq}$)	23,682	26,824
Annualized specific emissions ($kgCO_{2eq}/m^2/y$)	3.28	2.60
B4		
Total emissions over 60 years ($kgCO_{2eq}$)	13,802	14,412
Annualized specific emissions ($kgCO_{2eq}/m^2/y$)	1.91	1.40
TOTAL		
Total emissions over 60 years ($kgCO_{2eq}$)	37,484	41,236
Annualized specific emissions ($kgCO_{2eq}/m^2/y$)	5.19	4.00

ZEB BALANCE

The ZEB balance calculations were done with the ZEB Tool. The results are shown in Figure 44 for the two-storey building, and in Figure 45 for the three-storey building. The ZEB balance was done with the annualized emissions per square meter.

The results from calculations show that the installed PV panels do not produce enough electricity to balance the emissions from operation and materials. The two-storey building is closer to the target with only 1.39 kg in positive balance. It produces enough electricity to balance the emissions from material production (A1-A3) and operational energy (B6).

The results show that it is more challenging to reach ZEB-OM for the three-storey building. This is mostly due to the fact that the same amount of PV panels are installed on both building types. Since the larger building have a higher emissions in operational energy and materials, then necessarily a higher surface of PV is needed. This is an interesting finding since overall, the three-storey unit can house three more students and therefore has a lower heated volume and floor area per person. Nonetheless, the three-storey building produces enough renewable electricity to offset the emissions from operation.

Both buildings therefore seem to be in a good way to reach the ZEB-O target based on the assumptions made. More investigation on low-carbon alternatives would be required to reach the ZEB-OM target.

Going back to the roof shape analysis, an asymmetrical roof shape was chosen over a monoslope roof because of its better quality of space and its compactness. The chosen design appeared to be a good choice overall, reaching ZEB-O and even more for the two-storey building. Going an extra step to reach ZEB-OM could possibly done by changing the roof to a monoslope shape. Doing so, there would be room for an extra row of PV panels. The PV production would be increased to about 12,613 kWh per year per building. The emissions from PV panels on the other hand would increase by 6,160 kgCO2eq. Further study is needed to assess the potential of the monoslope roof in reaching ZEB-OM.

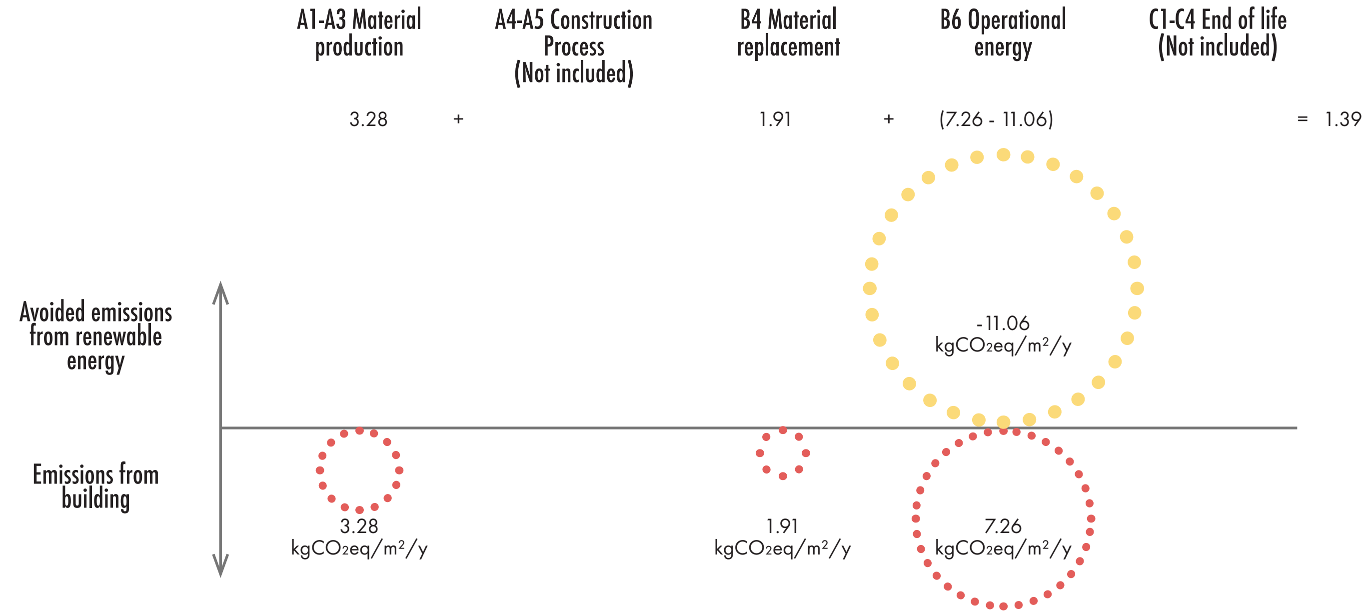


FIGURE 44. ZEB BALANCE - TWO-STOREY BUILDING

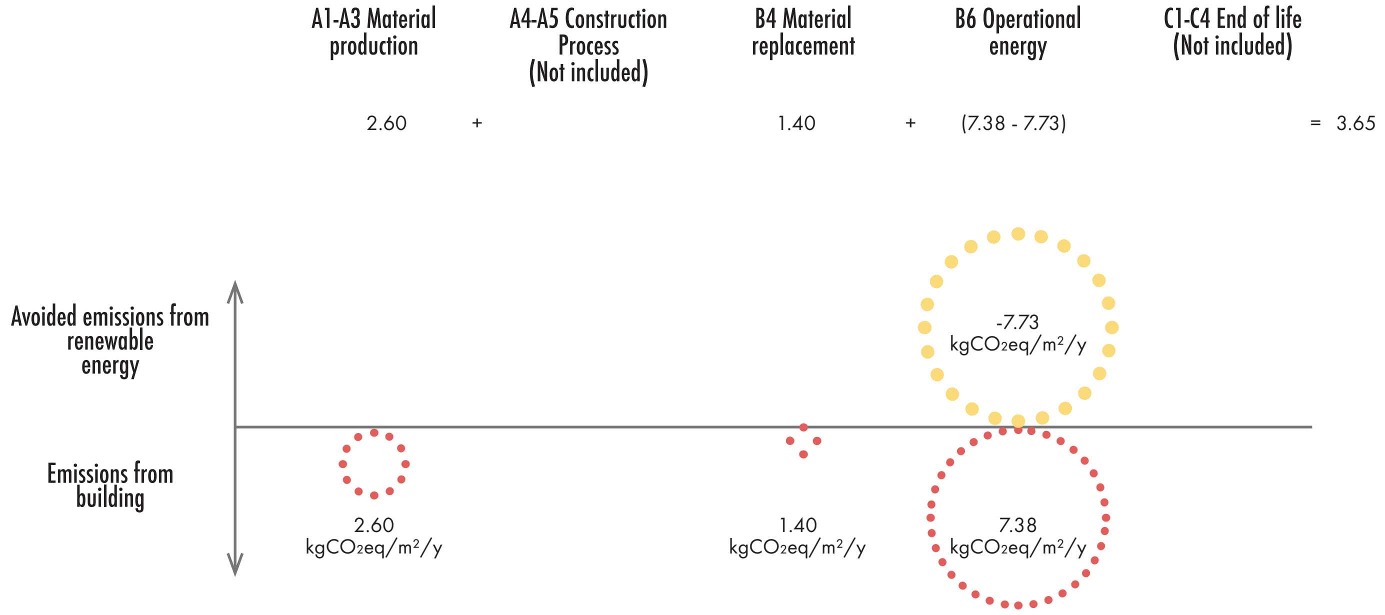


FIGURE 45. ZEB BALANCE - THREE-STOREY BUILDING

VIII:
CONCLUSION

CONCLUSION

With the current need for student housing in Trondheim, new buildings will be built and rehabilitated in the upcoming years to respond to the demand. On the other hand, it is crucial to limit the GHG emissions from the construction of new buildings. To address that challenge, Sit and other student housing developers must find low-carbon alternatives to reduce the climate footprint of their building stock. In that context, this thesis investigated ways to reduce both embodied and operational emissions through the design of low-rise student housing units at Haugenhuset, in Moholt Studentby. The ZEB concept was used as the main guideline to assess the carbon footprint of the building.

The potential to reducing the carbon footprint of new student housing units through the choice of the building shape, building materials and passive and active strategies was demonstrated in this thesis. In the case of low-rise units in cold climate, the building shape plays a big role in the performance of the building. The shape was kept simple and compact, but also with a sloped roof to increase the output from renewable energy from PV panels. The sloped roof shape created space for an additional bedroom, using the extra volume from the sloped roof in an useful way. The bedrooms and living areas are facing south to benefit from solar heating and the summer breeze. The buildings are arranged around a common outdoor space at the heart of the site. That configuration is inspired from that of the surrounding brick buildings. The distance between the buildings is large enough to provide a good daylight quality inside the rooms and prevent excess of shading on the south roofs. The integration of reused bricks and windows in the building design shows how building materials can be prevented from going to waste. Reused bricks are a low-carbon thermal mass alternative and reused windows contribute to creating a pleasing outside environment by being assembling in a greenhouse structure.

Overall, the design choices and assumptions led to a set of buildings which generate enough electricity to offset the emissions from their operational energy. Further work would need to be done to assess the ZEB level of the buildings.

One of the main limitations was the calculations of embodied emissions. It requires a detailed compilation of all material quantities and availability of documentation on the emission factor (EPD) of the materials. More information on the site conditions would also be needed to come up with more representative results. The exercise of calculating the embodied emissions was nonetheless useful in having an overview of the contribution of each building component. More work would need to be done to assess the emissions from the heating, lighting and ventilation systems, as well as other components that were omitted in the calculations. Although the manufacturer location was taken into account in the selection of materials, the emissions from transport to the site were not included in the calculations. That could also be part of future work to get a full overview of the carbon footprint of the buildings designed.

To further investigate whether the buildings could reach ZEB-OM, the monoslope shape could be studied more in detail. The preliminary calculations show that there is a greater potential for that shape to balance the emissions from both materials and operation.

REFERENCES

Benders (2015) *Sokkelelement*. Available at: https://www.benders.se/globalassets/c4-assets/document/no-broschyr-sockel-2015-.pdf (Accessed: June 1, 2020).

Brønmo, M.S. (1998) *Tøfler og trøfler : Studentsamskipnaden i Trondheim 1948-1998*. Trondheim: Studentsamskipnaden.

Direktoratet for Byggkvalitet (2017) *Byggteknisk forskrift (TEK17) med veiledning*. Available at: https://dibk.no/byggereglene/byggteknisk-forskrift-tek17/ (Accessed: June 1, 2020).

Fufa, S.M., Schlanbusch, R.D., Sørnes, K., Inman, M. and Andresen, I. (2016) *A Norwegian ZEB Definition Guideline*, (ZEB Project report 29-2016). Trondheim: SINTEF Academic Press and NTNU. Available at: https://www.sintefbok.no/book/index/1092 (Accessed June 1, 2020).

Granås, S. (2020) Terningkast 4 til varmepumpeanlegget på Moholt 50|50 i Trondheim. *Tekniske Nyheter*, April 2. Available at: https://www.tekniskenyheter.no/forside/varmepumper/terningkast-4-til-varmepumpeanlegget-pa-moholt-50-50-i-trondheim (Accessed: June 1, 2020).

Houlihan Wilberg, A. (2017) ZEB-COM Tool v.1.

Hunton (2016) *Konstruksjonsoversikt Fermacell Fibergips*. Available at: https://www.hunton.no/wp-content/uploads/2018/09/fermacell-konstruksjonsoversikt0219_web.pdf (Accessed: June 1, 2020).

Hunton (2018) *Isolere fornybart og lagre CO2*. Available at: https://www.hunton.no/wp-content/uploads/2018/08/isolereoglagreco2_web.pdf (Accessed: June 1, 2020).

Kristjansdottir, T.F., Houlihan Wiberg, A., Andresen, I. , Georges, L., Heeren, N., Good, C.S. and Brattebø, H. (2018) Is a net life cycle balance for energy and materials achievable for a zero emission single-family building in Norway?, *Energy & Buildings*. Vol. 168, pp. 457-469. doi: 10.1016/j.enbuild.2018.02.046

Norsk Telegrambyrå, NTB (2019) Over 17.000 studenter står uten bolig, *Aftenposten*. August 2. Available at: https://www.aftenposten.no/norge/i/WbxAVd/over-17000-studenter-staar-uten-bolig (Accessed: June 1, 2020).

Nøysom Arkitekter (2017) *Experimental housing at Svartlamon*. Available at: http://www.eksperimentboliger.no/ (Accessed: June 1, 2020).

Ramm, B. (2019) Professor måtte slutte å invitere studentene til borettslaget: – Det var så mange som flyttet hit. *Dagens Næringsliv*, November 27. Available at: https://www.dn.no/d2/arkitektur/steffen-wellinger/ntnu/rosenborg/professor-matte-slutte-a-invitere-studentene-til-borettslaget-det-var-sa-mange-som-flyttet-hit/2-1-708792
(Accessed: June 1, 2020)

SINTEF (2020) *Byggforskserien*. Available at: https://www.byggforsk.no/byggforskserien (Accessed: June 1, 2020).

Standard Norge (2012) *NS 3701:2012 Kriterier for passivhus og lavenergibygninger, Yrkesbygninger*. Available at: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=587802 (Accessed: June 1, 2020)

Standard Norge (2016) *SN/TS 3031:2016 Bygningers energiytelse: Beregning av energibehov og energiforsyning*. Available at: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=587802 (Accessed: June 1, 2020).

Standard Norge (2019) *NS 8175:2019 Lydforhold i bygninger - Lydklasser for ulike bygningstyper*. Available at: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=1045700 (Accessed: June 1, 2020).

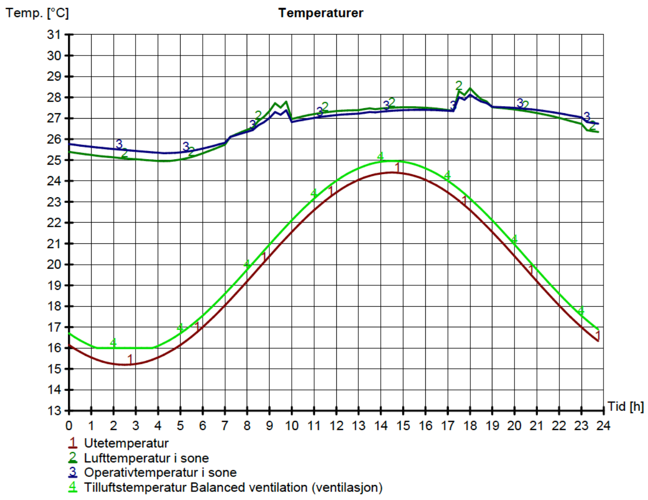
Stene, J. 2019. Monitoring of Passive House and Near Zero Energy Buildings with Advanced Thermal Energy Systems Exchanging Excess Heat with Adjacent Buildings, *1st Nordic Conference on Zero Emission and Plus Energy Buildings*. Available at: https://www.ntnu.edu/documents/1281770977/1290532244/Session+16_J%C3%B8rn+Stene.pdf/13e8d956-e803-b6d1-a480-4560b527ccd8?t=1574077997113 (Accessed: June 1, 2020).

World Green Building Council (2019) *New report: the building and construction sector can reach net zero carbon emissions by 2050*. Available at: https://www.worldgbc.org/news-media/WorldGBC-embodied-carbon-report-published#_ftn1 (Accessed: June 1, 2020).

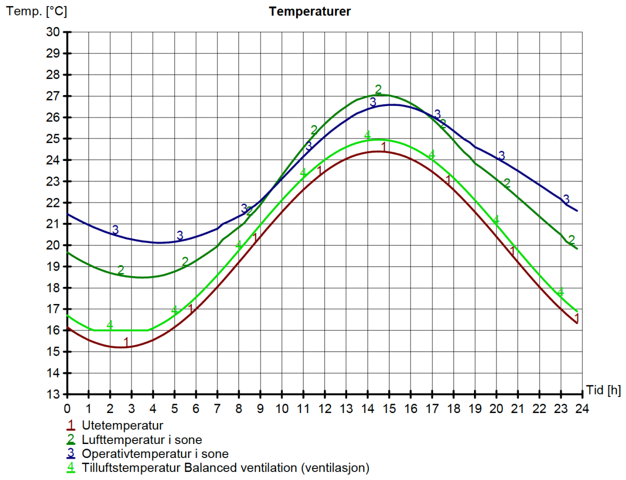
APPENDICES

APPENDIX A: OVERHEATING ANALYSIS

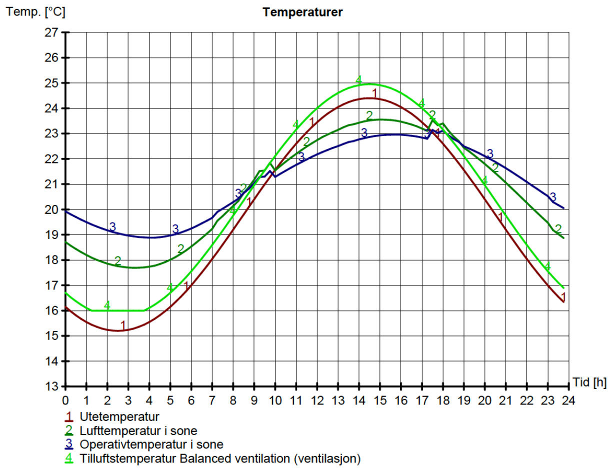
COMMON LIVING ROOM



WITHOUT SHADING AND WINDOW VENTILATION

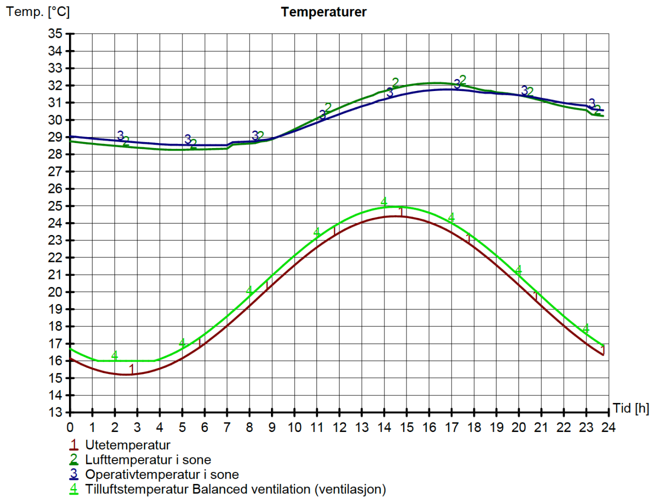


WITH SINGLE-SIDED VENTILATION

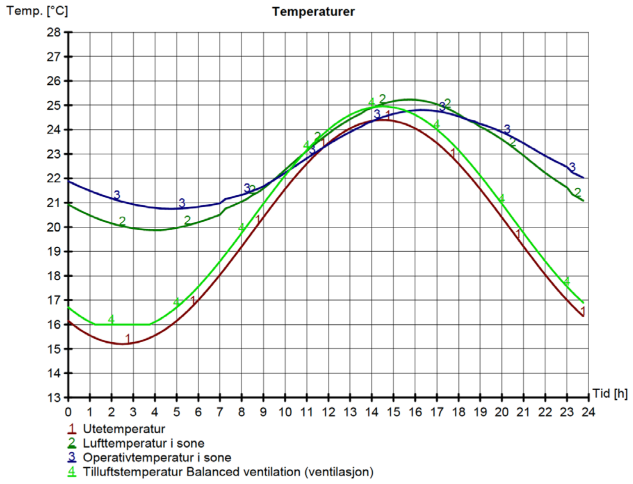


WITH SINGLE-SIDED VENTILATION & EXTERNAL SCREEN
MANUALLY CONTROLLED

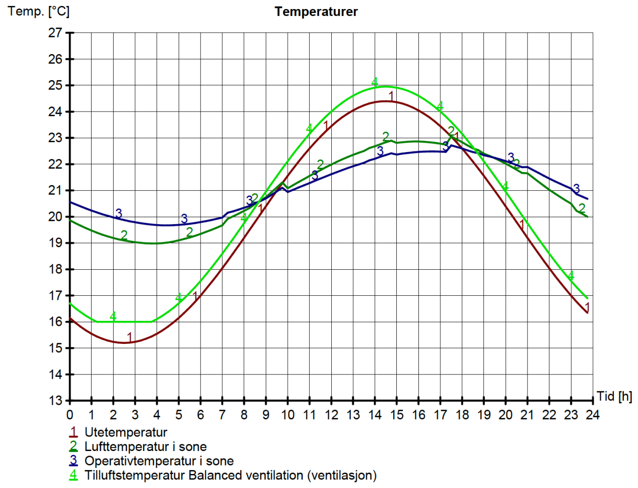
BEDROOM FIRST FLOOR



WITHOUT SHADING AND WINDOW VENTILATION

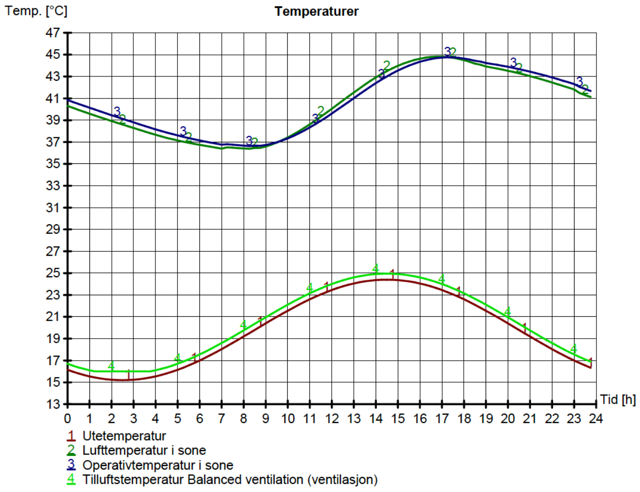


WITH SINGLE-SIDED VENTILATION

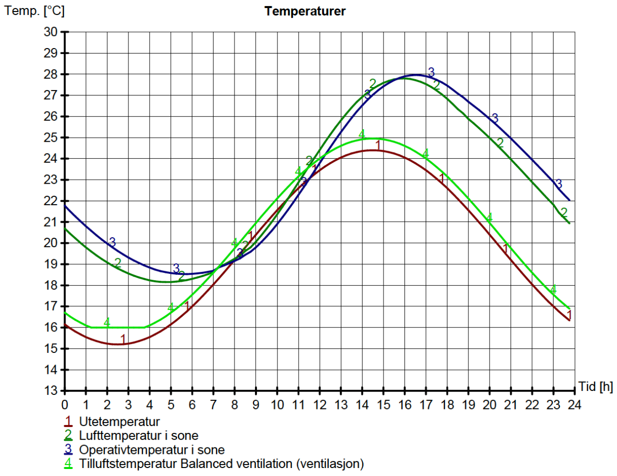


WITH SINGLE-SIDED VENTILATION & EXTERNAL SCREEN
MANUALLY CONTROLLED

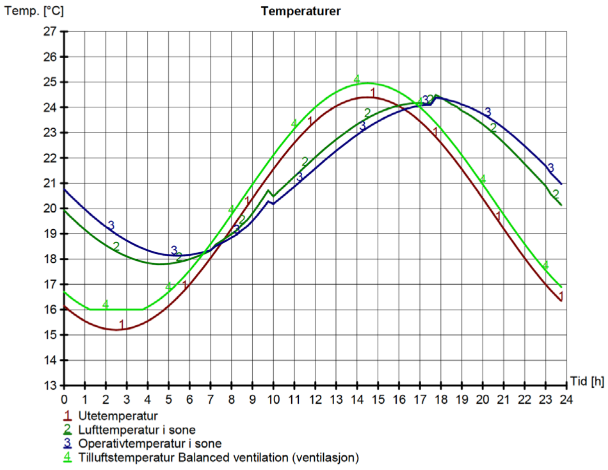
BEDROOM SECOND FLOOR (THREE-STOREY BUILDING)



WITHOUT SHADING AND WINDOW VENTILATION

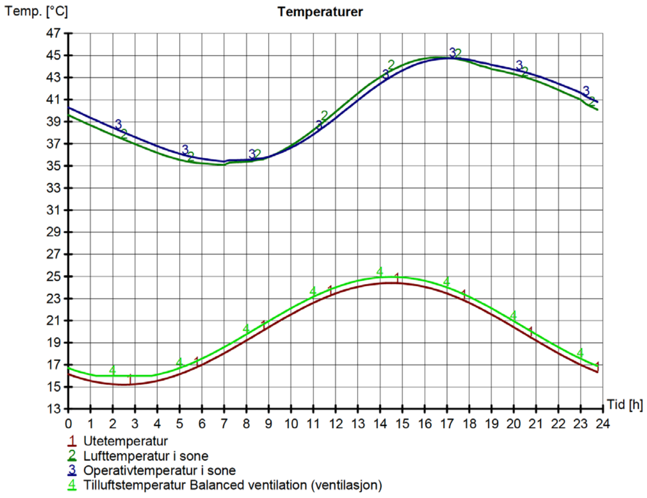


WITH SINGLE-SIDED VENTILATION

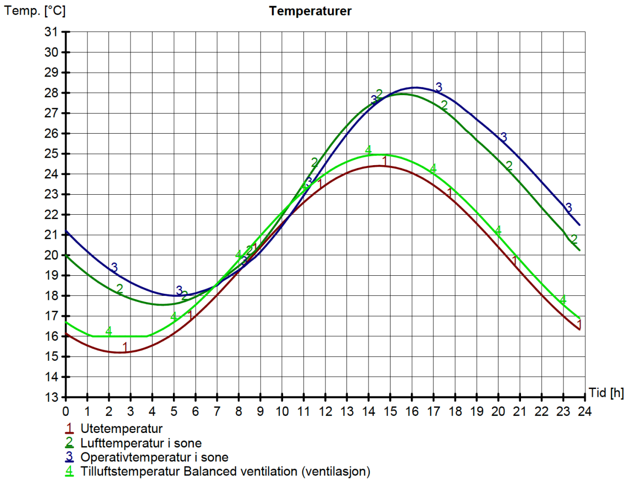


WITH SINGLE-SIDED VENTILATION & EXTERNAL SCREEN
MANUALLY CONTROLLED

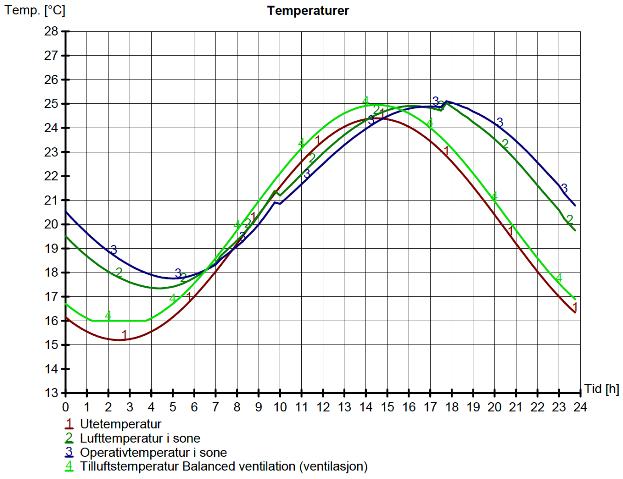
BEDROOM MEZZANINE



WITHOUT SHADING AND WINDOW VENTILATION



WITH SINGLE-SIDED VENTILATION



WITH SINGLE-SIDED VENTILATION & EXTERNAL SCREEN
MANUALLY CONTROLLED

APPENDIX B: SIMIEN REPORT

TWO-STOREY BUILDING

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building

Energibudsjett

Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	2157 kWh	17,9 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	180 kWh	1,5 kWh/m²
2 Varmtvann (tappevann)	3585 kWh	29,8 kWh/m²
3a Vifter	528 kWh	4,4 kWh/m²
3b Pumper	107 kWh	0,9 kWh/m²
4 Belysning	1371 kWh	11,4 kWh/m²
5 Teknisk utstyr	2109 kWh	17,5 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	0 kWh	0,0 kWh/m²
Totalt netto energibehov, sum 1-6	10037 kWh	83,4 kWh/m²

Levert energi til bygningen (beregnet)

Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	5071 kWh	42,1 kWh/m²
1b El. til varmepumpesystem	1668 kWh	13,9 kWh/m²
1c El. til solfangersystem	0 kWh	0,0 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-2675 kWh	-22,2 kWh/m²
Totalt levert energi, sum 1-7	4064 kWh	33,8 kWh/m²
Solstrøm til eksport	-7013 kWh	-58,2 kWh/m²
Netto levert energi	-2949 kWh	-24,5 kWh/m²

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building

Dekning av energibudsjett fordelt på energikilder

Energikilder	Romoppv.	Varmebatterier	Varmtvann	Kjølebatterier	Romkjøling	El. spesifikt
El.	2,7 kWh/m²	0,2 kWh/m²	4,5 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	34,2 kWh/m²
Olje	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Gass	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Fjernvarme	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Biobrensel	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Varmepumpe	15,2 kWh/m²	1,3 kWh/m²	25,3 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Sol	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Annen	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Sum	17,9 kWh/m²	1,5 kWh/m²	29,8 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	34,2 kWh/m²

Årlige utslipp av CO2

Energivare	Utslipp	Spesifikt utslipp
1a Direkte el.	669 kg	5,6 kg/m²
1b El. til varmepumpesystem	220 kg	1,8 kg/m²
1c El. til solfangersystem	0 kg	0,0 kg/m²
2 Olje	0 kg	0,0 kg/m²
3 Gass	0 kg	0,0 kg/m²
4 Fjernvarme	0 kg	0,0 kg/m²
5 Biobrensel	0 kg	0,0 kg/m²
6. Annen energikilde	0 kg	0,0 kg/m²
7. Solstrøm til egenbruk	-353 kg	-2,9 kg/m²
Totalt utslipp, sum 1-7	536 kg	4,5 kg/m²
Solstrøm til eksport	-926 kg	-7,7 kg/m²
Netto CO2-utslipp	-389 kg	-3,2 kg/m²

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building

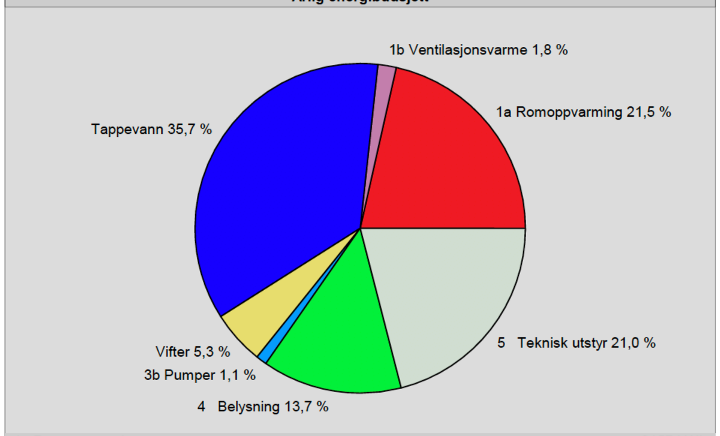
Kostnad kjøpt energi

Energivare	Energikostnad	Spesifikk energikostnad
1a Direkte el.	4057 kr	33,7 kr/m²
1b El. til varmepumpesystem	1335 kr	11,1 kr/m²
1c El. til solfangersystem	0 kr	0,0 kr/m²
2 Olje	0 kr	0,0 kr/m²
3 Gass	0 kr	0,0 kr/m²
4 Fjernvarme	0 kr	0,0 kr/m²
5 Biobrensel	0 kr	0,0 kr/m²
6. Annen energikilde	0 kr	0,0 kr/m²
7. Solstrøm til egenbruk	-2140 kr	-17,8 kr/m²
Årlige energikostnader, sum 1-7	3251 kr	27,0 kr/m²
Solstrøm til eksport	-3156 kr	-26,2 kr/m²
Netto energikostnad	95 kr	0,8 kr/m²

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building

Årlig energibudsjett

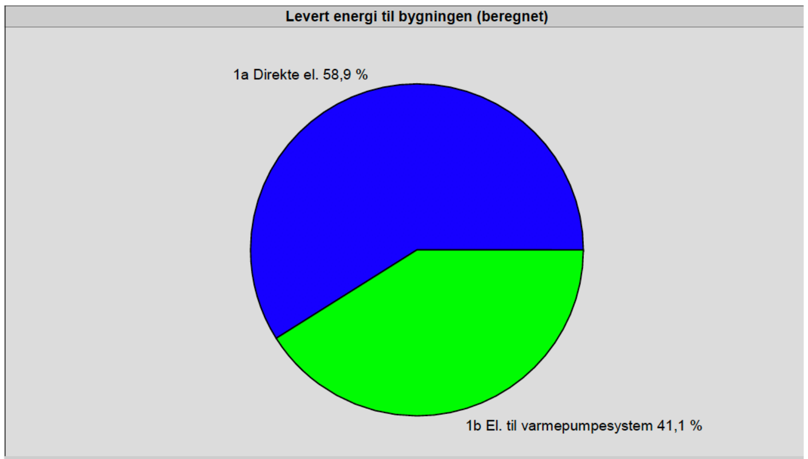


1a Romoppvarming	2157 kWh
1b Ventilasjonsvarme (varmebatterier)	180 kWh
2 Varmtvann (tappevann)	3585 kWh
3a Vifter	528 kWh
3b Pumper	107 kWh
4 Belysning	1371 kWh
5 Teknisk utstyr	2109 kWh
6a Romkjøling	0 kWh
6b Ventilasjonskjøling (kjølebatterier)	0 kWh
Totalt netto energibehov, sum 1-6	10037 kWh

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building

Levert energi til bygningen (beregnet)

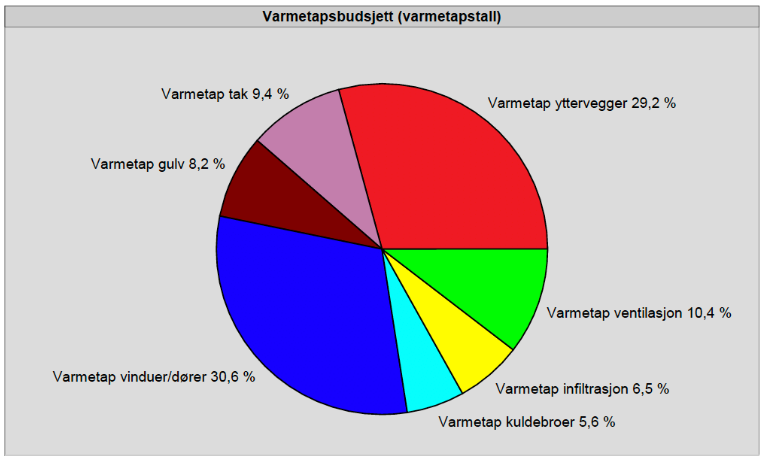


1a Direkte el.	2395 k
1b El. til varmepumpesystem	1668 k
1c El. til solfangersystem	0 k
2 Olje	0 k
3 Gass	0 k
4 Fjernvarme	0 k
5 Biobrensel	0 k
6. Annen energikilde	0 k
Totalt levert energi, sum 1-7	4064 k

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building

Varmetapsbudsjett (varmetapstall)

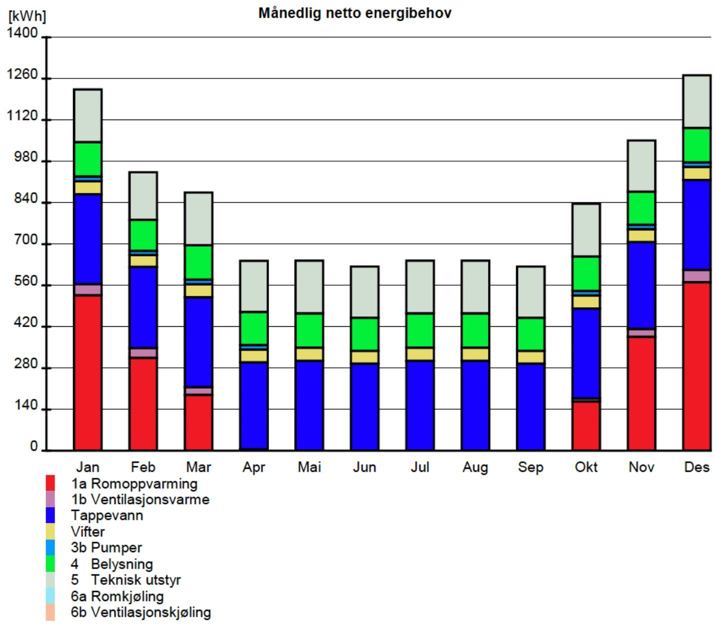


Varmetapstall yttervegger	0,16 W/m²K
Varmetapstall tak	0,05 W/m²K
Varmetapstall gulv på grunn/mot det fri	0,04 W/m²K
Varmetapstall glass/vinduer/dører	0,16 W/m²K
Varmetapstall kuldebroer	0,03 W/m²K
Varmetapstall infiltrasjon	0,03 W/m²K
Varmetapstall ventilasjon	0,06 W/m²K
Totalt varmetapstall	0,53 W/m²K

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building

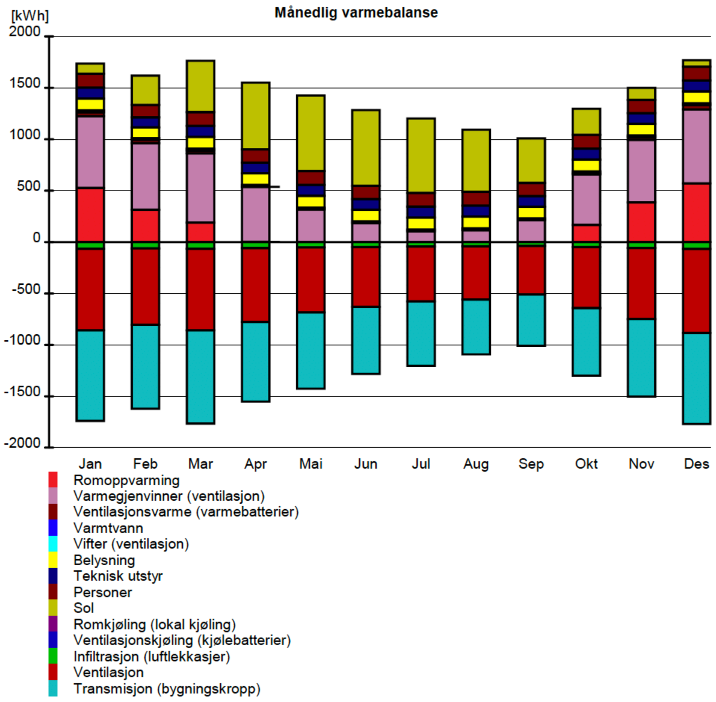
Månedlig netto energibehov



SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building

Månedlig varmebalanse



Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building

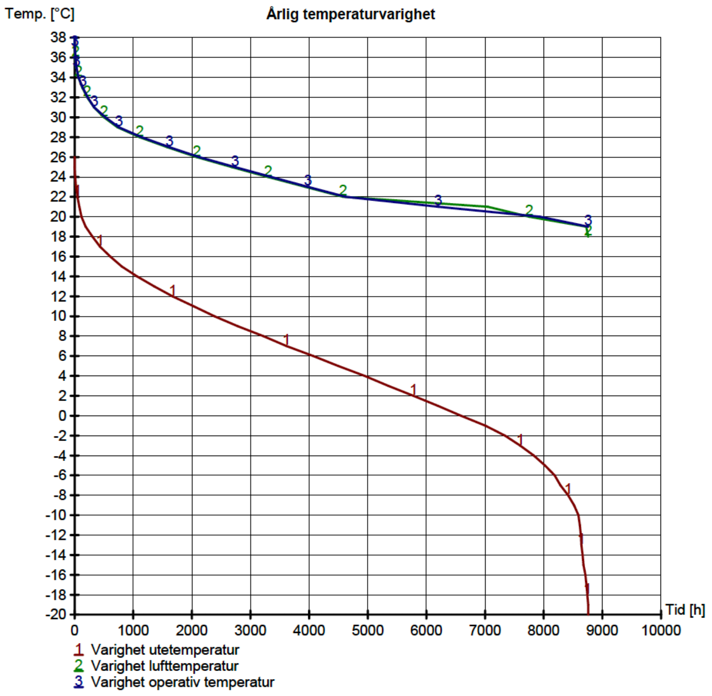
Månedlige temperaturdata (lufttemperatur)

Måned	Midlere ute	Maks. ute	Min. ute	Midlere sone	Maks. sone	Min. sone
Januar	-1,2 °C	8,5 °C	-19,5 °C	20,5 °C	23,1 °C	19,0 °C
Februar	-1,7 °C	9,0 °C	-16,7 °C	20,9 °C	24,9 °C	19,0 °C
Mars	-0,2 °C	10,7 °C	-12,0 °C	21,5 °C	28,5 °C	19,0 °C
April	3,8 °C	14,2 °C	-5,6 °C	24,2 °C	29,4 °C	19,2 °C
Mai	7,4 °C	20,1 °C	-2,4 °C	24,7 °C	31,1 °C	20,1 °C
Juni	11,1 °C	22,7 °C	1,2 °C	27,6 °C	35,0 °C	21,6 °C
Juli	13,8 °C	23,6 °C	4,8 °C	28,5 °C	34,4 °C	24,3 °C
August	13,7 °C	25,0 °C	3,5 °C	27,9 °C	37,7 °C	21,5 °C
September	10,1 °C	20,8 °C	0,6 °C	23,5 °C	29,1 °C	19,0 °C
Oktober	5,2 °C	15,5 °C	-3,3 °C	21,5 °C	28,0 °C	19,0 °C
November	1,0 °C	10,7 °C	-11,1 °C	20,6 °C	22,9 °C	19,0 °C
Desember	-1,9 °C	9,6 °C	-17,6 °C	20,5 °C	22,3 °C	19,0 °C

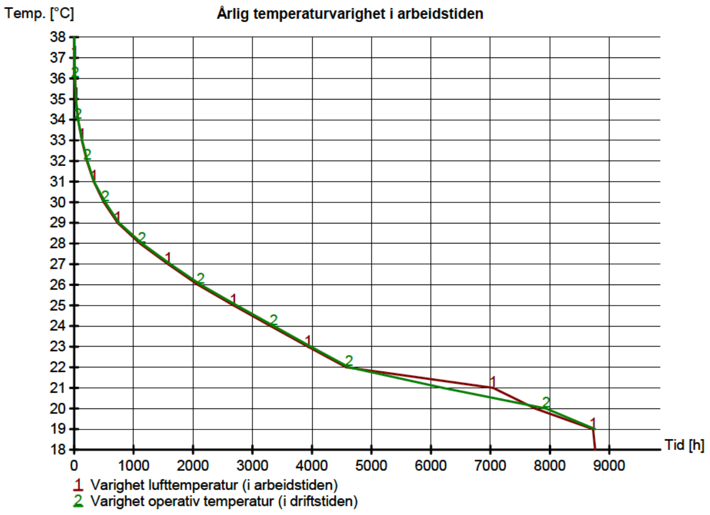
Månedlige temperaturdata (operativ temperatur)

Måned	Midlere ute	Maks. ute	Min. ute	Midlere sone	Maks. sone	Min. sone
Januar	-1,2 °C	8,5 °C	-19,5 °C	20,6 °C	22,7 °C	19,4 °C
Februar	-1,7 °C	9,0 °C	-16,7 °C	20,9 °C	24,4 °C	19,2 °C
Mars	-0,2 °C	10,7 °C	-12,0 °C	21,6 °C	28,2 °C	19,2 °C
April	3,8 °C	14,2 °C	-5,6 °C	24,2 °C	29,0 °C	19,6 °C
Mai	7,4 °C	20,1 °C	-2,4 °C	24,8 °C	30,9 °C	20,7 °C
Juni	11,1 °C	22,7 °C	1,2 °C	27,7 °C	34,7 °C	22,3 °C
Juli	13,8 °C	23,6 °C	4,8 °C	28,6 °C	34,1 °C	24,6 °C
August	13,7 °C	25,0 °C	3,5 °C	28,0 °C	37,4 °C	22,0 °C
September	10,1 °C	20,8 °C	0,6 °C	23,6 °C	28,7 °C	19,3 °C
Oktober	5,2 °C	15,5 °C	-3,3 °C	21,5 °C	27,5 °C	19,2 °C
November	1,0 °C	10,7 °C	-11,1 °C	20,6 °C	22,6 °C	19,1 °C
Desember	-1,9 °C	9,6 °C	-17,6 °C	20,5 °C	21,9 °C	19,2 °C

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building



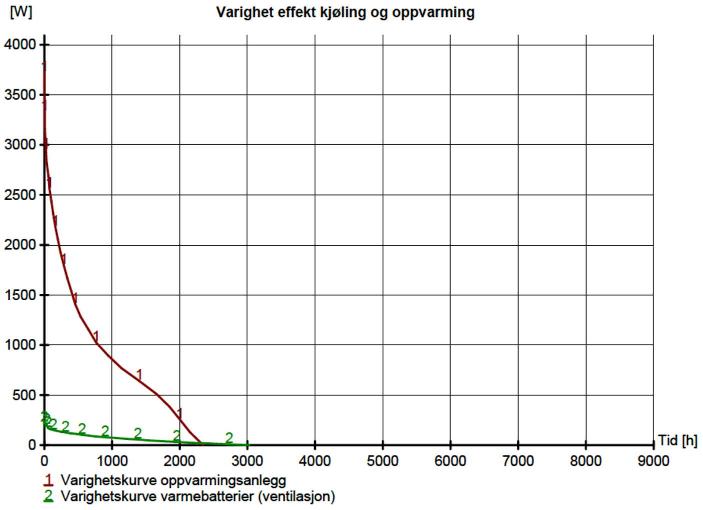
Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building



Årlig varighet operativ temperatur i arbeidstiden

Beskrivelse	Operativ temperatur
Antall timer over 26°C	2130

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building



SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building

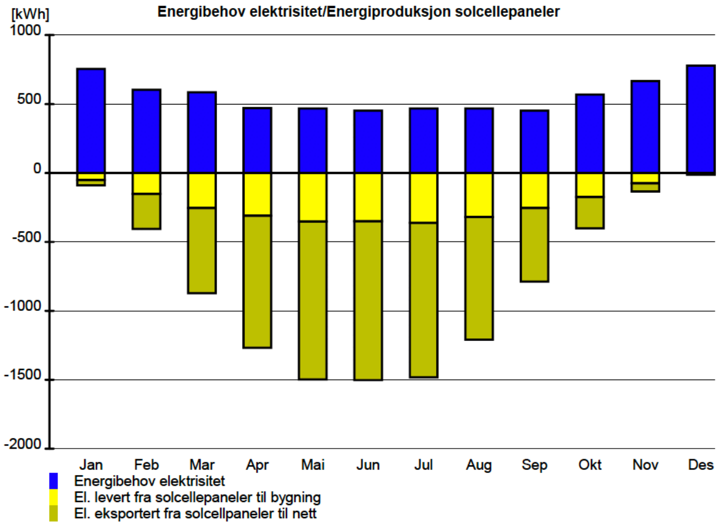
Dekningsgrad effekt/energi oppvarming

Effekt (dekning)	Dekningsgrad energibruk
3,4 kW (90 %)	100 %
3,0 kW (80 %)	100 %
2,6 kW (70 %)	99 %
2,2 kW (60 %)	97 %
1,9 kW (50 %)	94 %
1,5 kW (40 %)	88 %
1,1 kW (30 %)	79 %
0,7 kW (20 %)	63 %
0,4 kW (10 %)	38 %
Nødvendig effekt til oppvarming av tappevann er ikke inkludert	-

---

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building



Energiproduksjon solceller [kWh]

Panel	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des	Totalt
Produsert Solar panels	92	408	873	1271	1500	1505	1485	1211	790	403	136	14	9688
Levert til bygning	51	152	254	311	353	352	363	319	255	175	75	14	2675
Eksportert til nett	41	256	618	960	1147	1154	1121	892	535	228	61	0	7013

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building

Dokumentasjon av sentrale inndata (1)

Beskrivelse	Verdi	Dokumentasjon
Areal yttervegger [m²]:	156	
Areal tak [m²]:	67	
Areal gulv [m²]:	51	
Areal vinduer og ytterdører [m²]:	25	
Oppvarmet bruksareal (BRA) [m²]:	120	
Oppvarmet luftvolum [m³]:	300	
U-verdi yttervegger [W/m²K]	0,12	
U-verdi tak [W/m²K]	0,09	
U-verdi gulv [W/m²K]	0,10	
U-verdi vinduer og ytterdører [W/m²K]	0,80	
Areal vinduer og dører delt på bruksareal [%]	20,4	
Normalisert kuldebroverdi [W/m²K]:	0,03	
Normalisert varmekapasitet [Wh/m²K]	47	
Lekkasjetall (n50) [1/h]:	0,60	
Temperaturvirkningsgr. varmegjenvinner [%]:	86	

Dokumentasjon av sentrale inndata (2)

Beskrivelse	Verdi	Dokumentasjon
Estimert virkningsgrad gjenvinner justert for frostsikring [%]:	86,0	
Spesifikk vifteeffekt (SFP) [kW/m³/s]:	1,50	
Luftmengde i driftstiden [m³/hm²]	1,20	
Luftmengde utenfor driftstiden [m³/hm²]	0,00	
Systemvirkningsgrad oppvarmingsanlegg:	2,26	
Installert effekt romoppv. og varmebatt. [W/m²]:	90	
Settpunkttemperatur for romoppvarming [°C]	20,3	
Systemeffektfaktor kjøling:	2,50	
Settpunkttemperatur for romkjøling [°C]	0,0	
Installert effekt romkjøling og kjølebatt. [W/m²]:	0	
Spesifikk pumpeeffekt romoppvarming [kW/(l/s)]:	0,50	
Spesifikk pumpeeffekt romkjøling [kW/(l/s)]:	0,00	
Spesifikk pumpeeffekt varmebatteri [kW/(l/s)]:	0,50	
Spesifikk pumpeeffekt kjølebatteri [kW/(l/s)]:	0,00	
Driftstid oppvarming (timer)	16,0	

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:29 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 5 students.smi
Prosjekt: 5 students - model h
Sone: Whole building

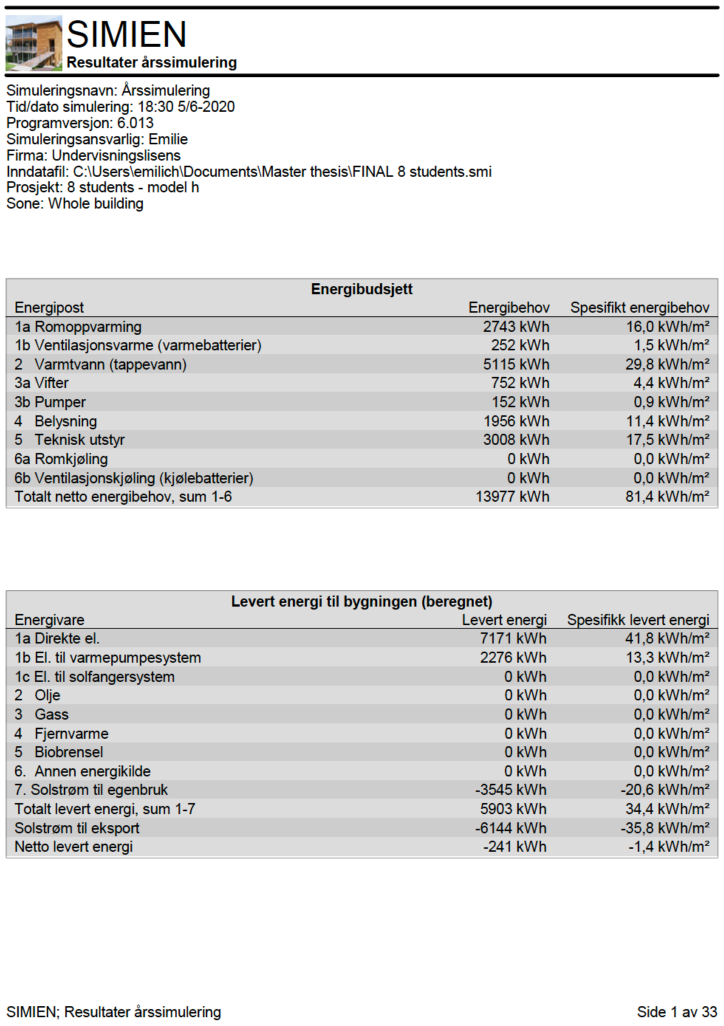
Dokumentasjon av sentrale inndata (3)

Beskrivelse	Verdi	Dokumentasjon
Driftstid kjøling (timer)	0,0	
Driftstid ventilasjon (timer)	24,0	
Driftstid belysning (timer)	16,0	
Driftstid utstyr (timer)	16,0	
Oppholdstid personer (timer)	24,0	
Effektbehov belysning i driftstiden [W/m²]	1,95	
Varmetilskudd belysning i driftstiden [W/m²]	1,95	
Effektbehov utstyr i driftstiden [W/m²]	3,00	
Varmetilskudd utstyr i driftstiden [W/m²]	1,80	
Effektbehov varmtvann på driftsdager [W/m²]	3,40	
Varmetilskudd varmtvann i driftstiden [W/m²]	0,00	
Varmetilskudd personer i oppholdstiden [W/m²]	1,50	
Total solfaktor for vindu og solskjerming:	0,45	
Gjennomsnittlig karmfaktor vinduer:	0,28	
Solskjermingsfaktor horisont/utspring (N/Ø/S/V):	0,77/0,91/0,88/0,72	

Inndata bygning

Beskrivelse	Verdi
Bygningskategori	Småhus
Simuleringsansvarlig	Emilie
Kommentar	

THREE-STOREY BUILDING



SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

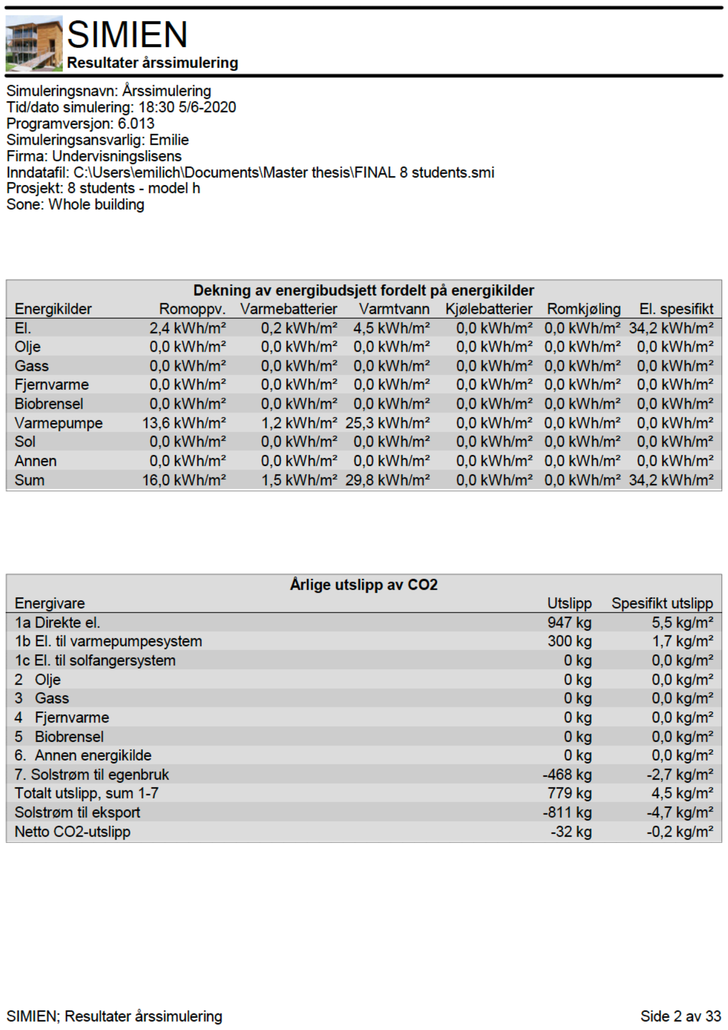
Energibudsjett

Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	2743 kWh	16,0 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	252 kWh	1,5 kWh/m²
2 Varmtvann (tappevann)	5115 kWh	29,8 kWh/m²
3a Vifter	752 kWh	4,4 kWh/m²
3b Pumper	152 kWh	0,9 kWh/m²
4 Belysning	1956 kWh	11,4 kWh/m²
5 Teknisk utstyr	3008 kWh	17,5 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	0 kWh	0,0 kWh/m²
Totalt netto energibehov, sum 1-6	13977 kWh	81,4 kWh/m²

Levert energi til bygningen (beregnet)

Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	7171 kWh	41,8 kWh/m²
1b El. til varmepumpesystem	2276 kWh	13,3 kWh/m²
1c El. til solfangersystem	0 kWh	0,0 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	0 kWh	0,0 kWh/m²
6. Annen energikilde	0 kWh	0,0 kWh/m²
7. Solstrøm til egenbruk	-3545 kWh	-20,6 kWh/m²
Totalt levert energi, sum 1-7	5903 kWh	34,4 kWh/m²
Solstrøm til eksport	-6144 kWh	-35,8 kWh/m²
Netto levert energi	-241 kWh	-1,4 kWh/m²

SIMIEN; Resultater årssimulering Side 1 av 33



SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

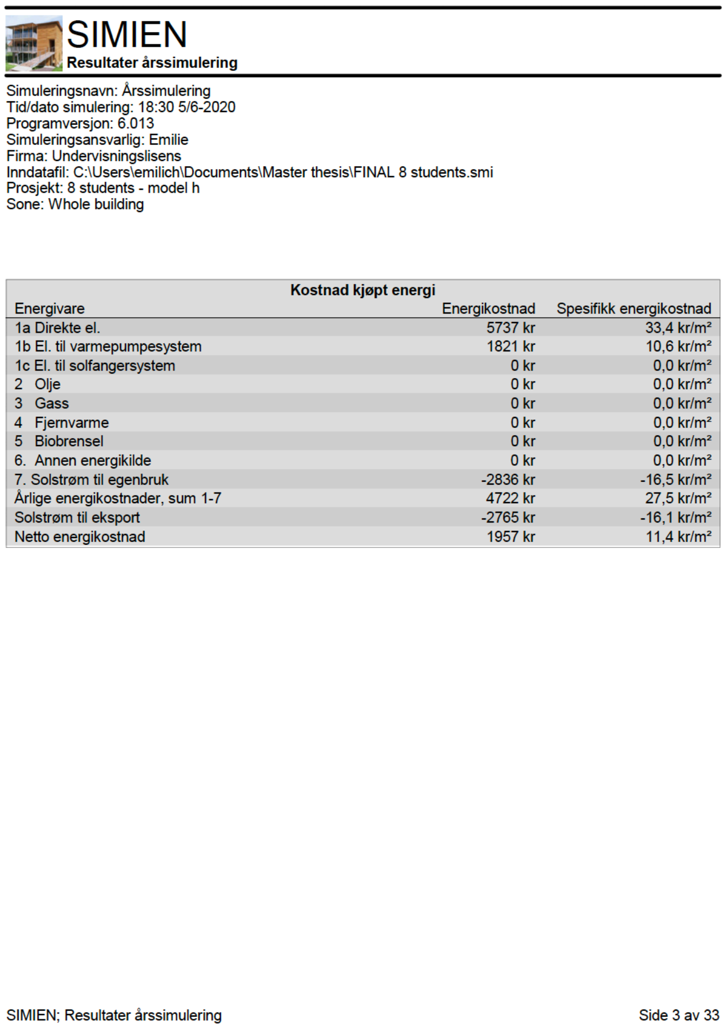
Dekning av energibudsjett fordelt på energikilder

Energikilder	Romoppv.	Varmebatterier	Varmtvann	Kjølebatterier	Romkjøling	El. spesifikt
El.	2,4 kWh/m²	0,2 kWh/m²	4,5 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	34,2 kWh/m²
Olje	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Gass	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Fjernvarme	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Biobrensel	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Varmepumpe	13,6 kWh/m²	1,2 kWh/m²	25,3 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Sol	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Annen	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	0,0 kWh/m²
Sum	16,0 kWh/m²	1,5 kWh/m²	29,8 kWh/m²	0,0 kWh/m²	0,0 kWh/m²	34,2 kWh/m²

Årlige utslipp av CO2

Energivare	Utslipp	Spesifikt utslipp
1a Direkte el.	947 kg	5,5 kg/m²
1b El. til varmepumpesystem	300 kg	1,7 kg/m²
1c El. til solfangersystem	0 kg	0,0 kg/m²
2 Olje	0 kg	0,0 kg/m²
3 Gass	0 kg	0,0 kg/m²
4 Fjernvarme	0 kg	0,0 kg/m²
5 Biobrensel	0 kg	0,0 kg/m²
6. Annen energikilde	0 kg	0,0 kg/m²
7. Solstrøm til egenbruk	-468 kg	-2,7 kg/m²
Totalt utslipp, sum 1-7	779 kg	4,5 kg/m²
Solstrøm til eksport	-811 kg	-4,7 kg/m²
Netto CO2-utslipp	-32 kg	-0,2 kg/m²

SIMIEN; Resultater årssimulering Side 2 av 33



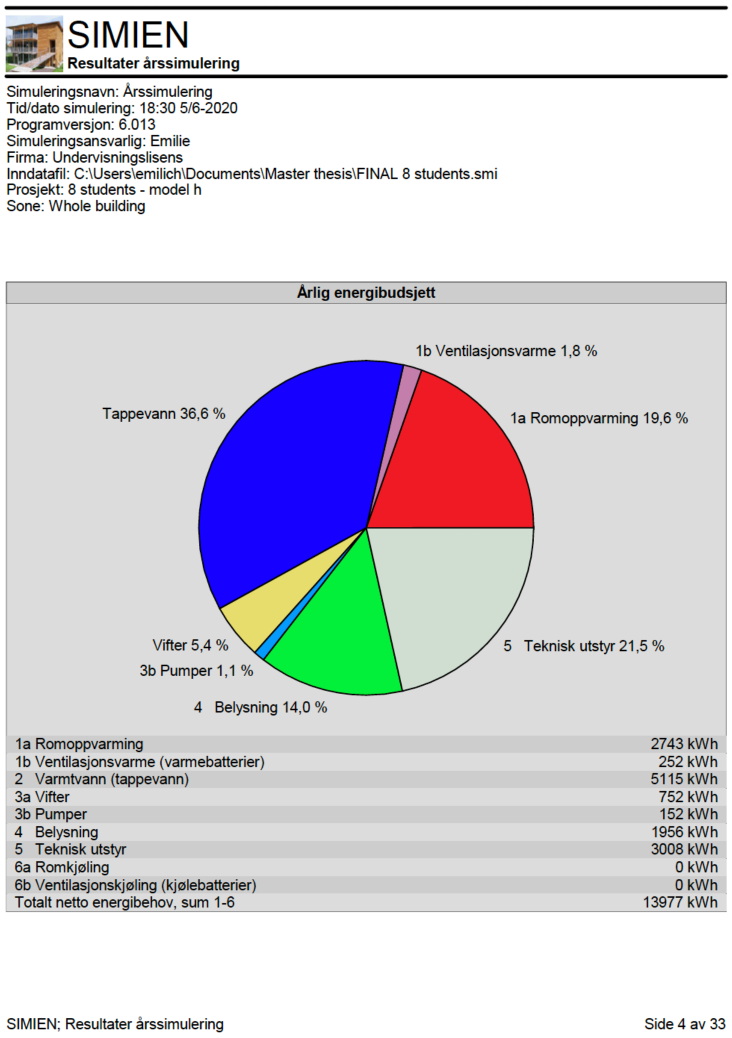
SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

Kostnad kjøpt energi

Energivare	Energikostnad	Spesifikk energikostnad
1a Direkte el.	5737 kr	33,4 kr/m²
1b El. til varmepumpesystem	1821 kr	10,6 kr/m²
1c El. til solfangersystem	0 kr	0,0 kr/m²
2 Olje	0 kr	0,0 kr/m²
3 Gass	0 kr	0,0 kr/m²
4 Fjernvarme	0 kr	0,0 kr/m²
5 Biobrensel	0 kr	0,0 kr/m²
6. Annen energikilde	0 kr	0,0 kr/m²
7. Solstrøm til egenbruk	-2836 kr	-16,5 kr/m²
Årlige energikostnader, sum 1-7	4722 kr	27,5 kr/m²
Solstrøm til eksport	-2765 kr	-16,1 kr/m²
Netto energikostnad	1957 kr	11,4 kr/m²

SIMIEN; Resultater årssimulering Side 3 av 33



SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

Årlig energibudsjett

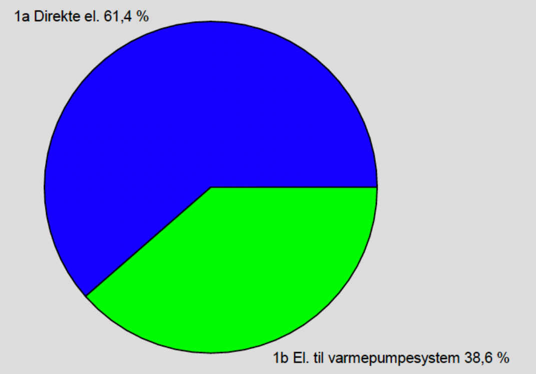
1a Romoppvarming	2743 kWh
1b Ventilasjonsvarme (varmebatterier)	252 kWh
2 Varmtvann (tappevann)	5115 kWh
3a Vifter	752 kWh
3b Pumper	152 kWh
4 Belysning	1956 kWh
5 Teknisk utstyr	3008 kWh
6a Romkjøling	0 kWh
6b Ventilasjonskjøling (kjølebatterier)	0 kWh
Totalt netto energibehov, sum 1-6	13977 kWh

SIMIEN; Resultater årssimulering Side 4 av 33

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

Levert energi til bygningen (beregnet)



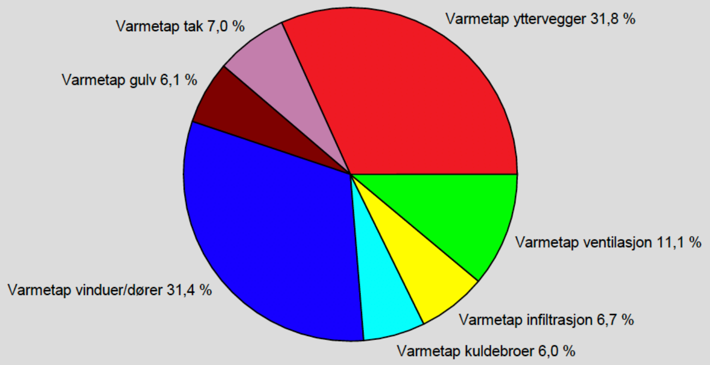
1a Direkte el.	3626 k
1b El. til varmepumpesystem	2276 k
1c El. til solfangersystem	0 k
2 Olje	0 k
3 Gass	0 k
4 Fjernvarme	0 k
5 Biobrensel	0 k
6. Annen energikilde	0 k
Totalt levert energi, sum 1-7	5903 k

SIMIEN; Resultater årssimulering Side 5 av 33

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

Varmetapsbudsjett (varmetapstall)



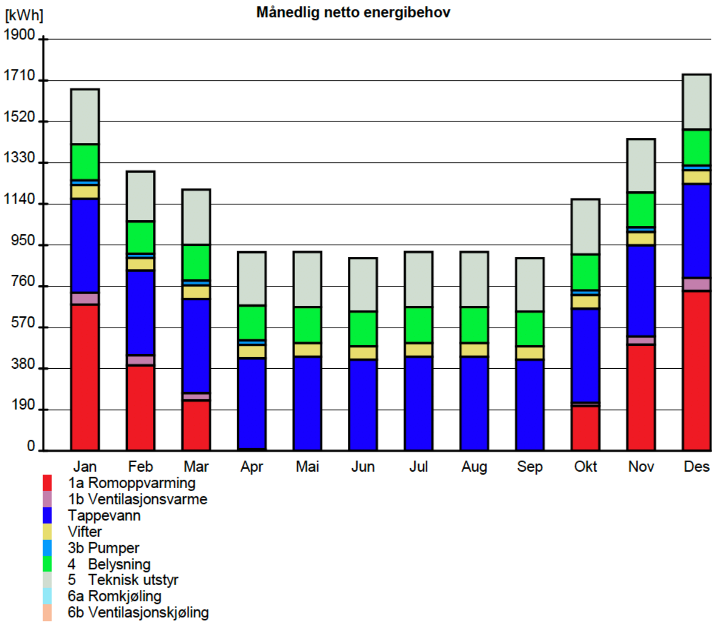
Varmetapstall yttervegger	0,16 W/m²K
Varmetapstall tak	0,03 W/m²K
Varmetapstall gulv på grunn/mot det fri	0,03 W/m²K
Varmetapstall glass/vinduer/dører	0,16 W/m²K
Varmetapstall kuldebroer	0,03 W/m²K
Varmetapstall infiltrasjon	0,03 W/m²K
Varmetapstall ventilasjon	0,06 W/m²K
Totalt varmetapstall	0,50 W/m²K

SIMIEN; Resultater årssimulering Side 6 av 33

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

Månedlig netto energibehov

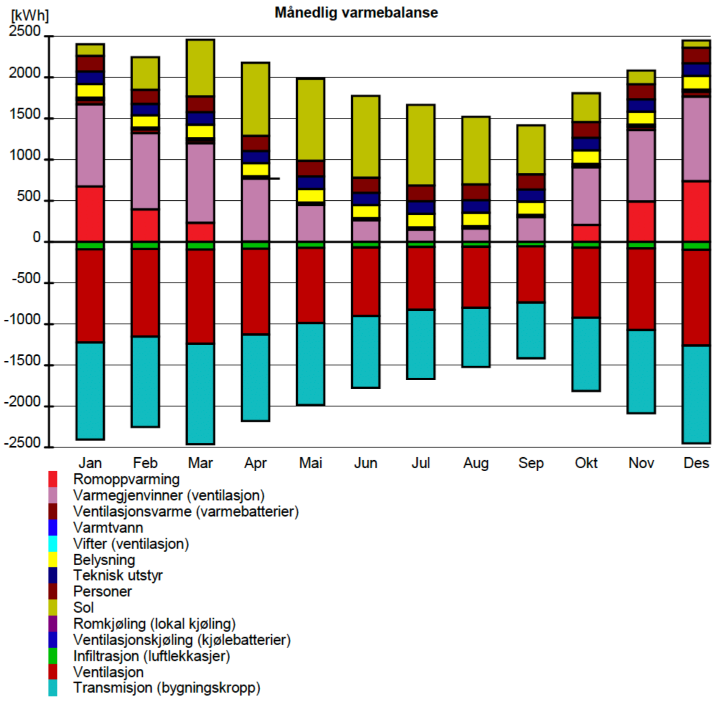


SIMIEN; Resultater årssimulering Side 7 av 33

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

Månedlig varmebalanse



SIMIEN; Resultater årssimulering Side 8 av 33

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

Månedlige temperaturdata (lufttemperatur)

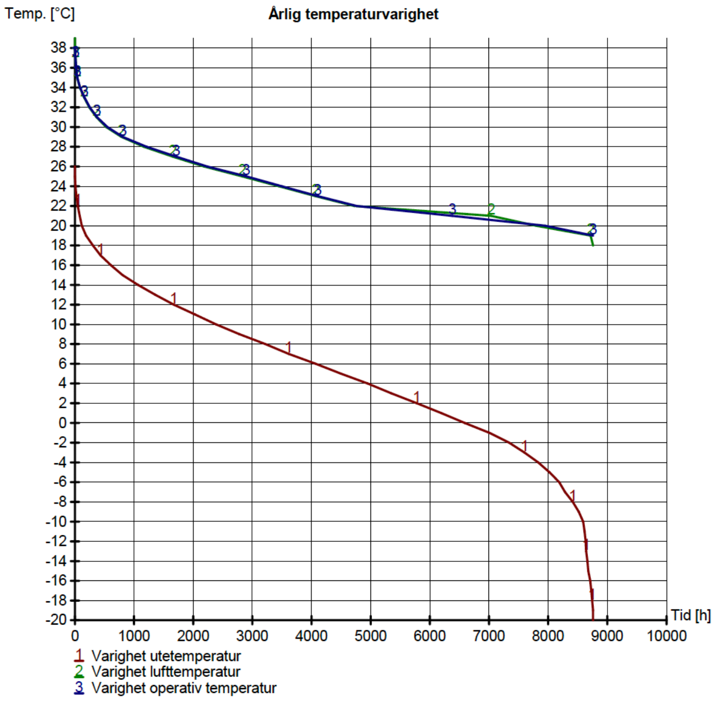
Måned	Midlere ute	Maks. ute	Min. ute	Midlere sone	Maks. sone	Min. sone
Januar	-1,2 °C	8,5 °C	-19,5 °C	20,6 °C	23,3 °C	19,0 °C
Februar	-1,7 °C	9,0 °C	-16,7 °C	21,0 °C	25,4 °C	19,0 °C
Mars	-0,2 °C	10,7 °C	-12,0 °C	21,8 °C	29,4 °C	19,0 °C
April	3,8 °C	14,2 °C	-5,6 °C	24,5 °C	30,0 °C	19,1 °C
Mai	7,4 °C	20,1 °C	-2,4 °C	25,0 °C	31,5 °C	20,2 °C
Juni	11,1 °C	22,7 °C	1,2 °C	27,7 °C	35,3 °C	21,5 °C
Juli	13,8 °C	23,6 °C	4,8 °C	28,6 °C	34,8 °C	24,1 °C
August	13,7 °C	25,0 °C	3,5 °C	27,9 °C	38,2 °C	21,4 °C
September	10,1 °C	20,8 °C	0,6 °C	23,7 °C	29,6 °C	18,9 °C
Oktober	5,2 °C	15,5 °C	-3,3 °C	21,6 °C	28,8 °C	19,0 °C
November	1,0 °C	10,7 °C	-11,1 °C	20,6 °C	23,2 °C	19,0 °C
Desember	-1,9 °C	9,6 °C	-17,6 °C	20,5 °C	22,5 °C	19,0 °C

Månedlige temperaturdata (operativ temperatur)

Måned	Midlere ute	Maks. ute	Min. ute	Midlere sone	Maks. sone	Min. sone
Januar	-1,2 °C	8,5 °C	-19,5 °C	20,6 °C	23,0 °C	19,1 °C
Februar	-1,7 °C	9,0 °C	-16,7 °C	21,0 °C	25,0 °C	19,1 °C
Mars	-0,2 °C	10,7 °C	-12,0 °C	21,8 °C	29,1 °C	19,1 °C
April	3,8 °C	14,2 °C	-5,6 °C	24,6 °C	29,7 °C	19,4 °C
Mai	7,4 °C	20,1 °C	-2,4 °C	25,1 °C	31,3 °C	20,6 °C
Juni	11,1 °C	22,7 °C	1,2 °C	27,8 °C	35,1 °C	22,2 °C
Juli	13,8 °C	23,6 °C	4,8 °C	28,7 °C	34,5 °C	24,4 °C
August	13,7 °C	25,0 °C	3,5 °C	28,0 °C	37,9 °C	22,0 °C
September	10,1 °C	20,8 °C	0,6 °C	23,8 °C	29,2 °C	19,1 °C
Oktober	5,2 °C	15,5 °C	-3,3 °C	21,7 °C	28,4 °C	19,1 °C
November	1,0 °C	10,7 °C	-11,1 °C	20,7 °C	22,9 °C	19,1 °C
Desember	-1,9 °C	9,6 °C	-17,6 °C	20,5 °C	22,1 °C	19,1 °C

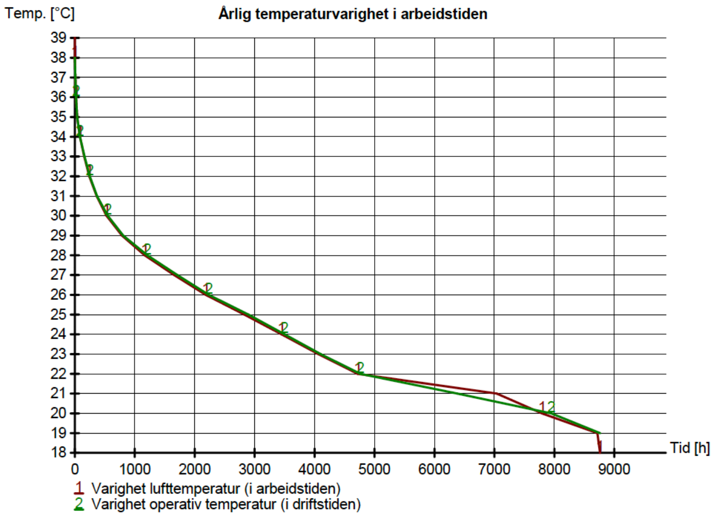
SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building



SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

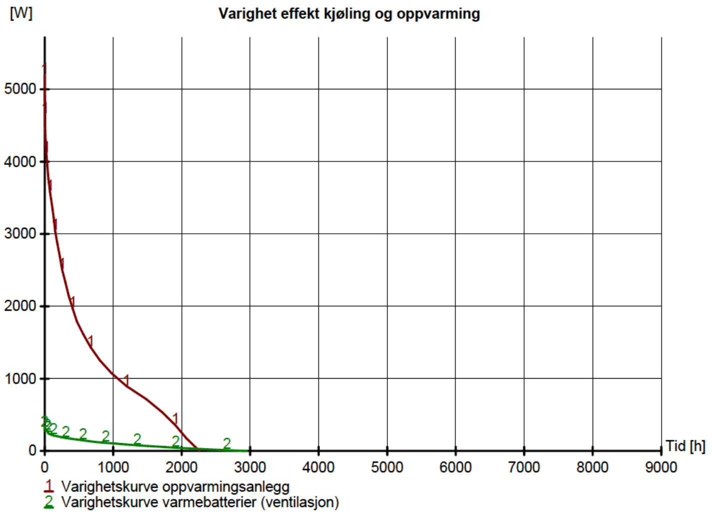


Årlig varighet operativ temperatur i arbeidstiden

Beskrivelse	Operativ temperatur
Antall timer over 26°C	2237

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building



SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

Dekningsgrad effekt/energi oppvarming

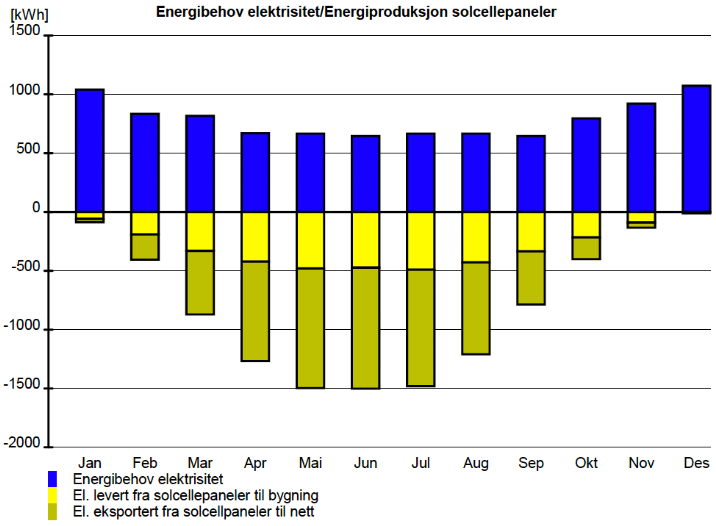
Effekt (dekning)	Dekningsgrad energibruk
4,7 kW (90 %)	100 %
4,2 kW (80 %)	100 %
3,7 kW (70 %)	99 %
3,1 kW (60 %)	97 %
2,6 kW (50 %)	93 %
2,1 kW (40 %)	88 %
1,6 kW (30 %)	79 %
1,0 kW (20 %)	64 %
0,5 kW (10 %)	39 %
Nødvendig effekt til oppvarming av tappevann er ikke inkludert	-

SIMIEN; Resultater årssimulering Side 13 av 33

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

Energibehov elektrisitet/Energiproduksjon solcellepaneler



Energiproduksjon solceller [kWh]

Panel	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des	Totalt
Produsert Solar panels	92	408	873	1271	1500	1505	1485	1211	790	403	136	14	9688
Levert til bygning	61	193	331	424	482	475	492	429	337	217	91	14	3545
Eksportert til nett	31	215	542	847	1018	1031	992	782	453	187	45	0	6144

SIMIEN; Resultater årssimulering Side 14 av 33

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

Dokumentasjon av sentrale inndata (1)

Beskrivelse	Verdi	Dokumentasjon
Areal yttervegger [m^2]:	228	
Areal tak [m^2]:	67	
Areal gulv [m^2]:	51	
Areal vinduer og ytterdører [m^2]:	34	
Oppvarmet bruksareal (BRA) [m^2]:	172	
Oppvarmet luftvolum [m^3]:	415	
U-verdi yttervegger [W/m^2K]	0,12	
U-verdi tak [W/m^2K]	0,09	
U-verdi gulv [W/m^2K]	0,10	
U-verdi vinduer og ytterdører [W/m^2K]	0,80	
Areal vinduer og dører delt på bruksareal [%]	19,7	
Normalisert kuldebroverdi [W/m^2K]:	0,03	
Normalisert varmekapasitet [Wh/m^2K]	40	
Lekkasjetall (n50) [1/h]:	0,60	
Temperaturvirkningsgr. varmegjenvinner [%]:	86	

Dokumentasjon av sentrale inndata (2)

Beskrivelse	Verdi	Dokumentasjon
Estimert virkningsgrad gjenvinner justert for frostsikring [%]:	86,0	
Spesifikk vifteeffekt (SFP) [$kW/m^3/s$]:	1,50	
Luftmengde i driftstiden [m^3/hm^2]	1,20	
Luftmengde utenfor driftstiden [m^3/hm^2]	0,00	
Systemvirkningsgrad oppvarmingsanlegg:	2,27	
Installert effekt romoppv. og varmebatt. [W/m^2]:	90	
Settpunkttemperatur for romoppvarming [°C]	20,3	
Systemeffektfaktor kjøling:	2,50	
Settpunkttemperatur for romkjøling [°C]	0,0	
Installert effekt romkjøling og kjølebatt. [W/m^2]:	0	
Spesifikk pumpeeffekt romoppvarming [kW/(l/s)]:	0,50	
Spesifikk pumpeeffekt romkjøling [kW/(l/s)]:	0,00	
Spesifikk pumpeeffekt varmebatteri [kW/(l/s)]:	0,50	
Spesifikk pumpeeffekt kjølebatteri [kW/(l/s)]:	0,00	
Driftstid oppvarming (timer)	16,0	

SIMIEN; Resultater årssimulering Side 15 av 33

SIMIEN
Resultater årssimulering

Simuleringsnavn: Årssimulering
Tid/dato simulering: 18:30 5/6-2020
Programversjon: 6.013
Simuleringsansvarlig: Emilie
Firma: Undervisningslisens
Inndatafil: C:\Users\emilich\Documents\Master thesis\FINAL 8 students.smi
Prosjekt: 8 students - model h
Sone: Whole building

Dokumentasjon av sentrale inndata (3)

Beskrivelse	Verdi	Dokumentasjon
Driftstid kjøling (timer)	0,0	
Driftstid ventilasjon (timer)	24,0	
Driftstid belysning (timer)	16,0	
Driftstid utstyr (timer)	16,0	
Oppholdstid personer (timer)	24,0	
Effektbehov belysning i driftstiden [W/m^2]	1,95	
Varmetilskudd belysning i driftstiden [W/m^2]	1,95	
Effektbehov utstyr i driftstiden [W/m^2]	3,00	
Varmetilskudd utstyr i driftstiden [W/m^2]	1,80	
Effektbehov varmtvann på driftsdager [W/m^2]	3,40	
Varmetilskudd varmtvann i driftstiden [W/m^2]	0,00	
Varmetilskudd personer i oppholdstiden [W/m^2]	1,50	
Total solfaktor for vindu og solskjerming:	0,45	
Gjennomsnittlig karmfaktor vinduer:	0,27	
Solskjermingsfaktor horisont/utspring (N/Ø/S/V):	0,77/0,89/0,88/0,71	

Inndata bygning

Beskrivelse	Verdi
Bygningskategori	Småhus
Simuleringsansvarlig	Emilie
Kommentar	

SIMIEN; Resultater årssimulering Side 16 av 33

NTNU

Norwegian University of
Science and Technology