Passive House 11°50°

TEAM 7

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Abstract

The architectural form concept of this passive row-house project comes as a result of a parametric form study, strongly influenced by the impact of local climate conditions of the project site, located in Gunnesbo, Sweden.

Added to the form concept of the buildings, are both innovative solutions of moisture safety design and a parametric study comprising passive strategies for improved energy performance. Results and suggested solutions of these studies conclude that the buildings' envelope structure obviates any risk of moisture damage and that the buildings perform within limits set by Swedish passive house regulations for space heating demand.

High interior thermal and visual comfort are aspired in this project, whereby adequate operative temperatures and daylight factors are examined. The interior comfort is further regarded in the functional distribution of rooms and construction methods and materials chosen to reduce thermal bridges.

Suggestions in terms of accessibility and functionality of the site in terms of urban planning, garbage and storage facilities as well as drainage and fresh water systems are proposed.

Key words: Passive house, row house, moisture safety design, energy performance, daylight factor, thermal bridge

Table of content

Abbreviation / Notation

Cooling demand	Annual needed energy to keep the inside temperature under a certain threshold
DHW	Domestic hot water
EPBD	Energy Performance of Buildings Directive
EU	European Union
FEBY	Forum för Energieffektiva Byggnader
Heating demand	Annual needed energy to keep the inside temperature over a certain threshold
HVAC	Heating, ventilation and air conditioning
low-e	Low emission
q_{50}	Airtightness of an envelope at standardized pressure difference of 50 Pascal
N	North
NE	North-East
NNE	North-North-East
NNW	North-North-West
NW	North-West
NZEB	Net-Zero Energy Building
PH	Passive house
PV	Photovoltaic
RH	Relative humidity
S	South
SE	South-East
SSE	South-South-East
SSW	South-South-West
SW	South-West
T_{inside}	Inside temperature (degrees Celsius)
$T_{outside}$	Outside temperature (degrees Celsius)
U-value	Heat transmission coefficient of a certain component (W/m^2K)
W	West

Contributions

Since each group member has been keen on learning as much as possible of the process of informed, energy-efficient and moisture safe design, the finished project comes as a result of equal participation of each member. The initial climate analysis and form concept of the design was a combined effort, where all decisions were taken collectively. Once the project procedure was established with general goals, further architectural design results was developed mostly by Magda Lena. Final results comprising moisture analysis and construction detailing was comprised mostly by Amanda and finally results surrounding the energy parametric study were comprised mostly by Roman. All other aspects of the project process such as room distribution, water supply, sewage, thermal bridging, active potential and daylighting were established more or less as a team. Due to the efficient collaboration, all team members can justify results and concepts presented throughout the report.

Team 7 would like to thank Jiangtao Du for consultation with DesignBuilder, Kaisa Svennberg and Akram Abdul Hamid for consultation with moisture safety issues and to Jouri Kanters for guidance in active potential analysis.

1 Introduction

Today, when existing buildings represent approximately 40 percent of the world's energy demand, it is essential to focus on low-energy design and construction, in order to comply with prevailing Swedish building regulations and those set by the Energy Performance of Buildings Directive or EPBD (Concerted Action EPBD, 2005). The EPBD is a document by the EU-government, first published in 2002 and amended in 2010 in order to improve the energetic qualities of buildings in Europe. Furthermore, moisture damage of buildings is a prevailing risk in Swedish climate conditions. When not handled in the early design phase, moisture risks of a construction may lead to unpredictable restoration costs and health issues for inhabitants. (ByggaF, 2013)

The aim of this project is hereby to design a passive row-house, consisting of eight residential units, focusing on the technical demands of energy performance and moisture safety design, whilst maintaining an architectural vision. Additionally, aspects of thermal comfort, active solar potential and daylighting are considered.

2 Method

2.1 Swedish passive house regulations (FEBY 2012)

The requirements for passive house standard aim to minimize the peak load for space heating in a residential building and hereafter, to allow for the required thermal comfort in the building to be obtained through heat distribution with an efficient heat recovery ventilation system. (Lunds Tekniska Högskola, 2008)

Swedish passive house criteria originates from standards originally set by the German Passivhaus Institute, with adjustments made according to Swedish climatic conditions and national building code. The current criteria is assembled by the organization FEBY- Forum för Energieffektiva Byggnader. (Sveriges Centrum för nollenergiehus, 2012)

Peak load regulations for space heating in the Swedish passive house criteria are climatically dependent. Sweden is hereby divided into three climate zones according to the Swedish building code. For the purpose of this project, zone III is considered.

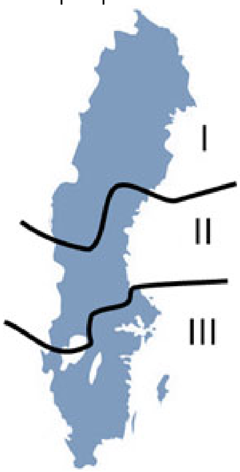


Figure 1, Climate zones according to FEBY

This project takes the following passive house criteria into consideration:

Table 1, Passive house requirements according to FEBY

Parameter	Regulative value (climatic zone III)
Space heating demand (area < 200m^2)	≤ 15 kWh/m^2,yr
Primary energy use (weighting factor of 2 for electrically heated buildings)	≤ 68 kWh/m^2,yr
Infiltration (q_{50})	≤ 0,30 l/s, m^2
U-value for exterior doors and windows	≤ 0,80 W/m^{2}K
Mechanical heat recovery efficacy	≥ 70%
Indoor temperature set point	21°C
Maximum supply air temperature	52°C

(Sveriges Centrum för nollenergiehus, 2012)

Other regarded aspects

- Ventilation air flow (mechanical) ≥ 0.35l/s,m2 (Boverket, 2012)
- Internal gains ≤ 4 W/m2 (Lunds Tekniska Högskola, 2008)

2.2 Site layout and spatial requirements

The project site is located on Fågelhundsvägen in the suburban district of Gunnesbo, Sweden. The site is surrounded by a large number of trees and several two-story buildings predominantly from the so called "miljonprogrammet". The centre of the site is open, with a small hill located towards the south.

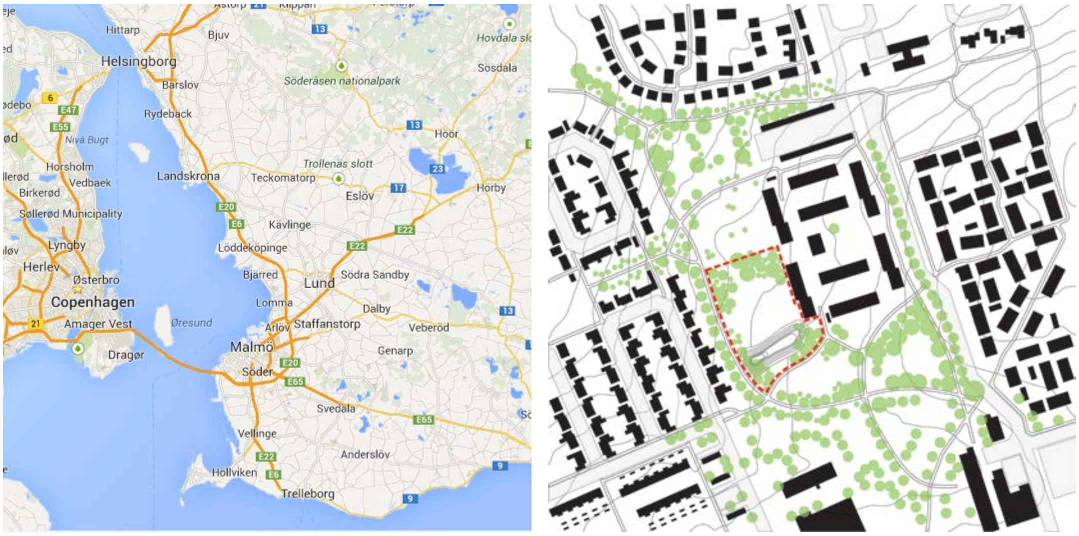


Figure 2, Left figure: Localisation of Lund in Skåne; Right figure: 2D-Model of the site with surrounding area

The passive row-house is to consist of eight residential units adhering to the following special and functional requirements (amounting to a total floor area of 117 m² per unit):

- Hall, 7 m²
- Kitchen, 8 m²
- Living room and dining room, 30 m²
- Office, 12 m²
- Bathroom with toilet + shower, 2.5 m²
- Bathroom with toilet, bath and washing facilities for clothes, 8 m²
- Staircase, 2.5 m²
- 3 Bedrooms, each 12 m²
- Storage space, 4 m²
- Circulation, 7 m²

2.3 Climate Analysis

To establish the micro climatic conditions of the site, an initial climate analysis is performed, with respect to temperature, precipitation, solar and wind conditions on the site. The simulation tools used for this analysis are Autodesk Ecotect and Autodesk Vasari. In both programs, weather data files for the neighbouring city of Lund is applied.

The average temperature in Lund is 7.8°C. The annual precipitation of 653 mm is which an increasing intensity during autumn and a subsequent decline in spring. The predominant wind direction is SW, according to Figure xx.

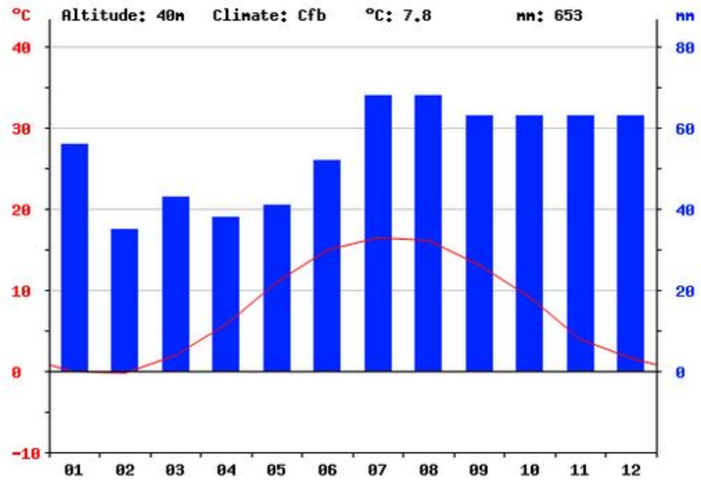


Figure 3, Climate diagram of Lund, Sweden (Climate-Data.org, u.d.)

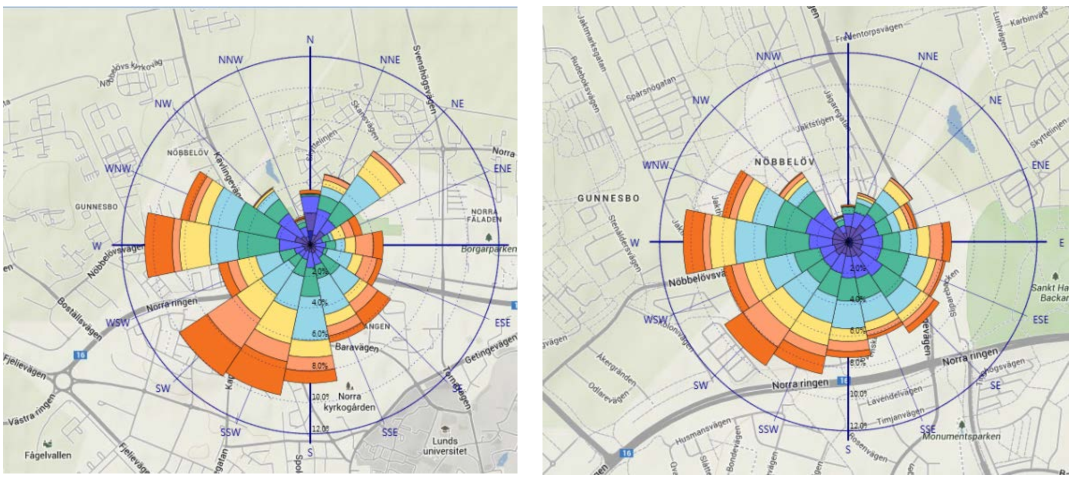


Figure 4, Wind rose of Lund, Sweden (Climate-Data.org, u.d.); Left figure: annually, Right figure: in winter

An optimum orientation and layout of a building in the area of Lund is established using the Weather Tool function in Autodesk Ecotect. The tool relays an estimated heating and cooling demand of a building with given vertical exterior surfaces and compromise these values into an optimal orientation for this building. In Lund, a southerly orientation proves to be favourable (see Figure 5).

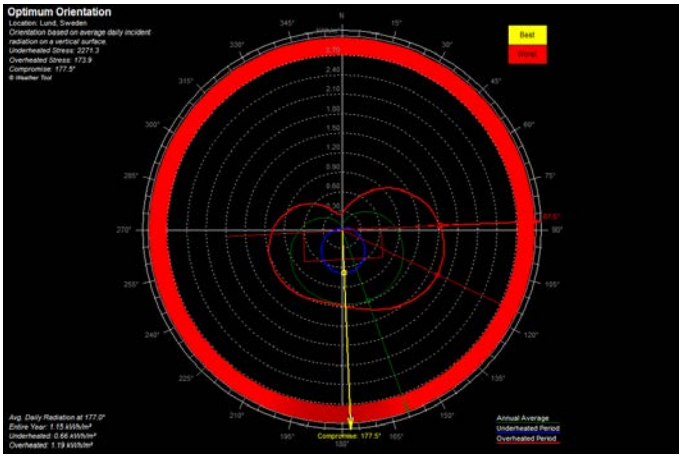


Figure 5, Orientation analysis of a building in Lund

Further, Autodesk Ecotect is used to analyse the solar access and local shading of the site, with respect to trees and surrounding buildings during a summer and a winter period.

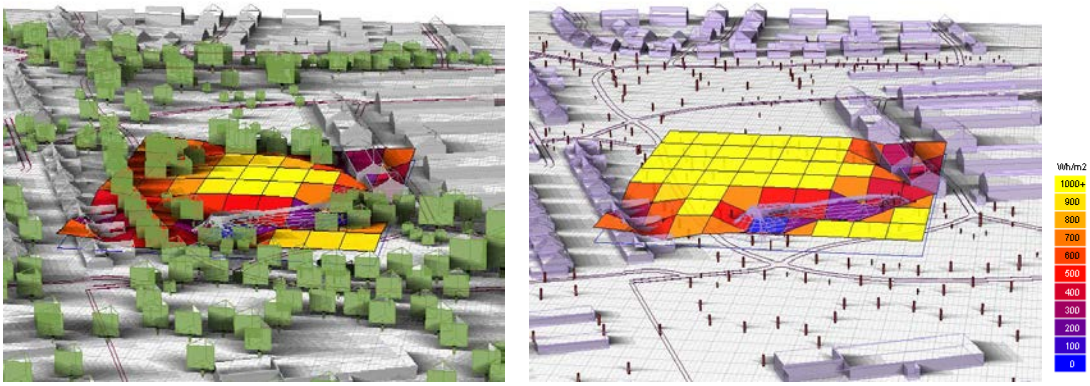


Figure 6, Solar irradiation on the site in the summer and winter scenario. Scale: 0-1000 kWh/m^2

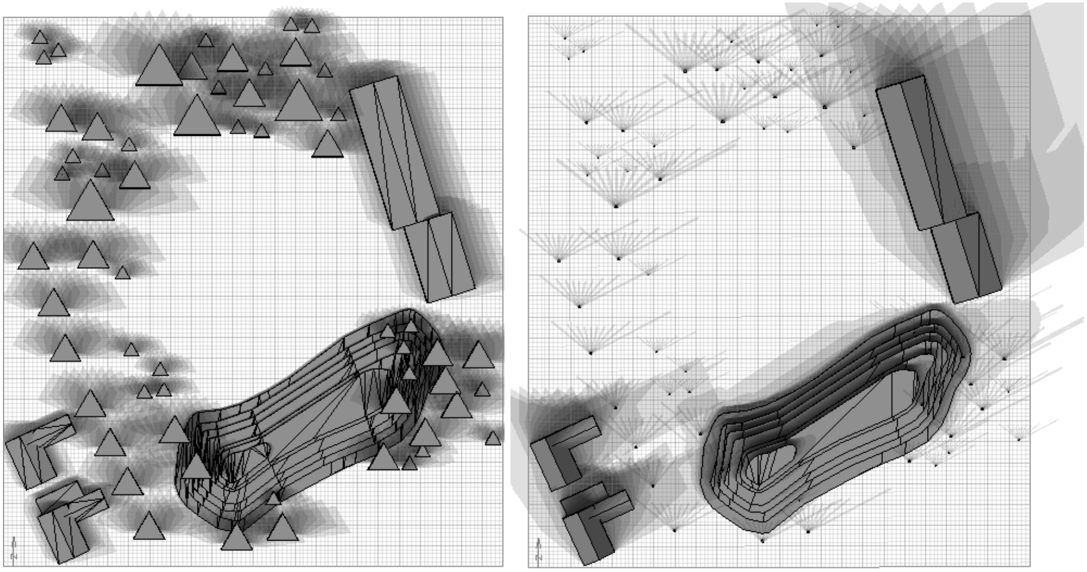


Figure 7, Shadow Range on the site in the summer and winter scenario, 9:00-17:00.

Wind plays a predominant role in the micro climate of an area. By using Autodesk Vasari, wind patterns are illustrated at a larger scale surrounding the site, showing the impact of surrounding trees and buildings on wind speed and direction.

As displayed in the wind roses above, (see Figure 4), the strongest winds derive from the West in winter time and from the SW/W annually. Due to the urban plan of the area, it seems possible for the wind to be accelerated through some sets of surrounding buildings, creating a wind tunnel effect from the W/NW of the site.

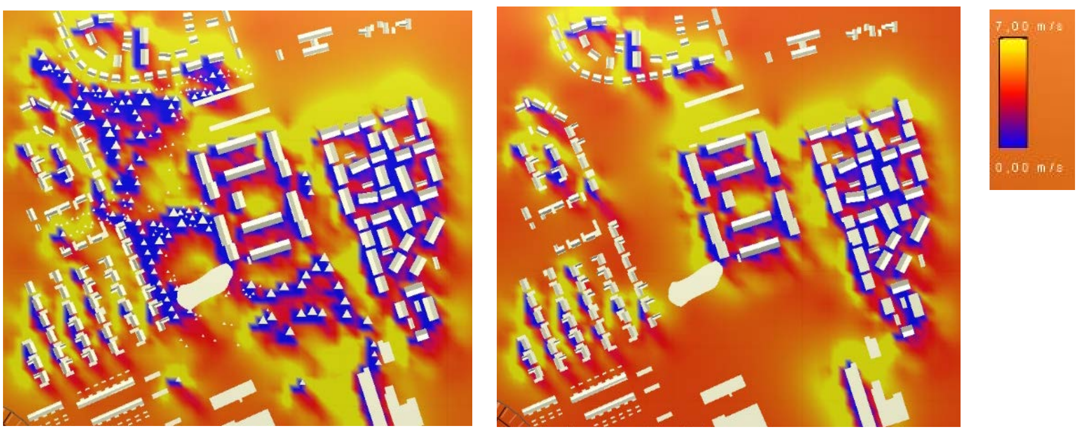


Figure 8, Vasari wind analysis of the site at a height of 1m for NW winds; Left figure: in summer; Right figure: in winter; Initial wind speed= 25 m/s. Scale 0-7 m/s

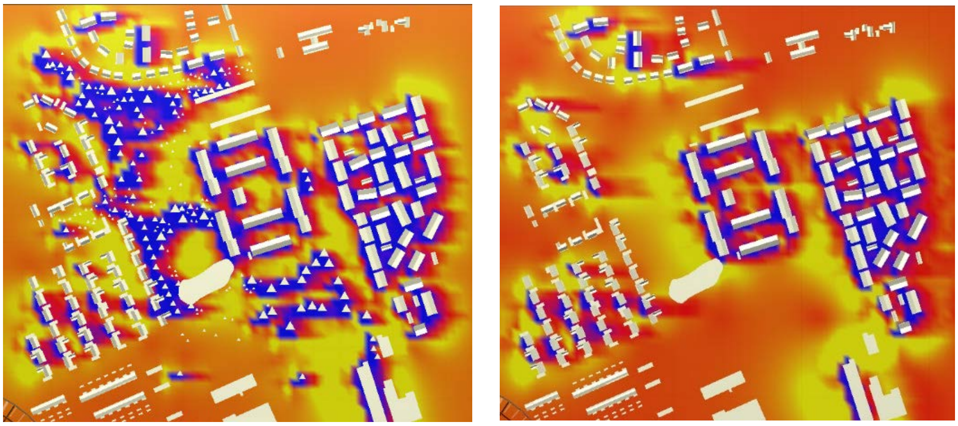


Figure 9, Vasari wind analysis of the site at a height of 1m for W winds; Left figure: in summer; Right figure: in winter; Initial wind speed= 25 m/s. Scale 0-7 m/s

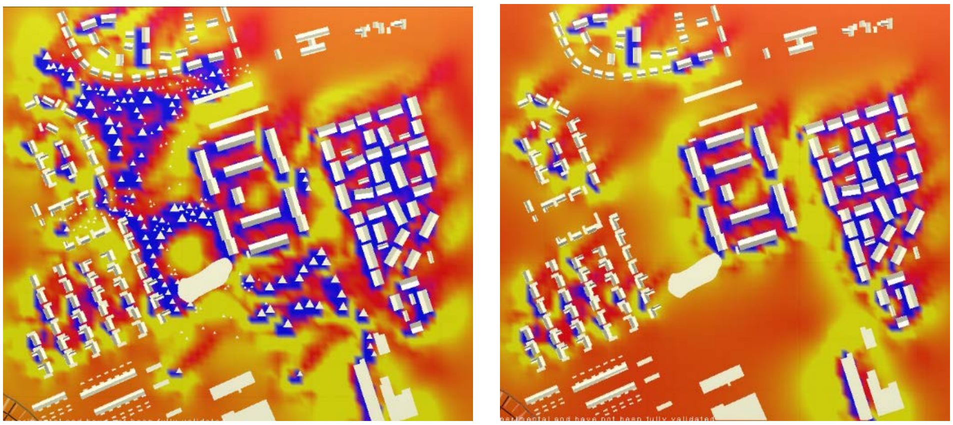


Figure 10, Vasari wind analysis of the site at a height of 1m for S winds; Left figure: in summer; Right figure: in winter; Initial wind speed= 25 m/s. Scale 0-7 m/s

2.4 Architecture

In order to base the design determinants on measurable values, each design step is taken, after carrying out an analysis.

The architectural approach for the passive house project is initiated with a compact shape study based on “passive form factor” ratio as a way of reducing energy losses over the building envelope. The ratio study is performed using a simple calculation method of the total surface area divided with total volume of the houses in different layout for different 3D models of the house unit.

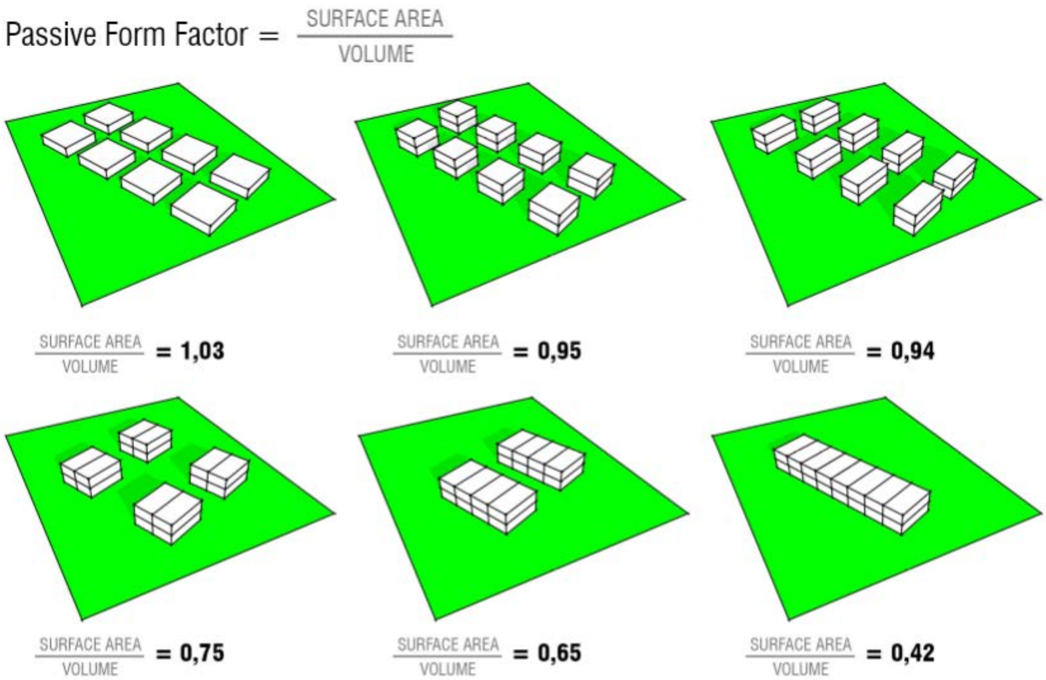


Figure 11, Passive form factor for a 117m² row houses units in different layouts.

Secondly, the optimal compact shape and layout of the row houses are analysed in terms of passive solar potential of the southern facing façade and possibilities to reduce the shadow range on the surrounding buildings and area, especially in winter time.

In subsequent stages of the architectural design, elements such as; window/wall ratio, façade design and room distribution are taken into account simultaneously.

DesignBuilder is used to observe the energy demand for different building unit shapes established. The shadow range is simulated in Ecotect to find the most optimal localisation of housing blocks. Additional models are prepared in programmes such as Revit, SketchUp and Autocad.

2.5 Moisture

The moisture safety analysis of the passive house project is initiated with a moisture risk analysis of the building's envelope. The risk analysis is performed using a excel spread sheet tool, identifying the envelope's risk points and further compiling the probability and consequence of moisture damage occurring at these presupposed points.

Secondly, the slab, wall and roof structures are analysed in WUFI, a transient hygrothermal analysis program, to determine the relative humidity (RH) and temperature profiles through these structures, and unveiling any risk for mould damage of the organic structural components (wood).

Starting 1 April 2013, WUFI simulations are made for three consecutive years. Initial conditions for the structural components are set as follows, emulating a typical spring scenario in Gunnesbo:

Initial RH:	80%
Initial temperature in structural component:	10 °C

To further liken the WUFI simulation conditions with reality, the effect of orientation and inclination on the moisture safety of the walls and roofs are observed. However, secondary-intercardinal directions, namely SSE and SSW, are not available in WUFI. For the purpose of these simulations, the intercardinal directions of SE and SW are instead assumed.

Furthermore, a driving rain factor of 1% of the rainfall is added to the exterior wall simulations, penetrating the wall one centimetre behind the air gap of the cavity wall. This, is however not added to simulation of the roof, since WUFI takes the impact of driving rain onto slanted surfaces into consideration per default.

Moisture risk points, in terms of rainwater run-off off the envelope, are examined and presented in more detail. The details surrounding the risk of moisture damage surrounding window and door joints have not been elaborated upon in this report, since it is assumed that these installations are handled in a moisture safe way.

2.6 Energy

To observe the energy balance at steady state conditions, an Excel spreadsheet is initially used in order to assure reasonable reference values for further dynamic calculations.

The main energy simulations and surrounding parametric studies of the building are performed in DesignBuilder, a complex building simulations software. The software enables the impact of passive strategies on the energy balance to be observed.

To achieve the required criteria given by the FEBY (compare table xx), a detailed parametric energy simulation, based on previous architectural and structural analyses, is performed in DesignBuilder.

The following input data (Table xx) is initially used in DesignBuilder with exception to the U-values and glazing ratio, which are consequently altered as a result of the architectural and structural design of the project.

Table 2, Initial settings for the Design Builder simulations

ACTIVITY		
Occupants	4	$[Person]$
Heating + Setback	21	$[°C]$
Cooling + Setback	26	$[°C]$
Minimum fresh air	7	$\left[\frac{l}{s * person}\right]$
Internal gains	4	$\left[\frac{W}{m^2}\right]$
Domestic hot water demand	25	$\left[\frac{l}{d * person}\right]$
CONSTRUCTION		
Wall*	0,10	$\left[\frac{W}{m^2 * K}\right]$
Roof*	0,08	$\left[\frac{W}{m^2 * K}\right]$
Slab*	0,10	$\left[\frac{W}{m^2 * K}\right]$
n50	0,6	$[h^{-1}]$
OPENINGS		
Window glazing	1,98	$\left[\frac{W}{m^2 * K}\right]$
Wooden window frame	3,63	$\left[\frac{W}{m^2 * K}\right]$
Glazing ratio*	30	$[\%]$
Shading	no	
LIGHTING		
LED	3,30	$\left[\frac{W}{m^2}\right]$
HVAC		
Fan coils	Always in operation	
Heat recovery	70	$[\%]$

2.7 Thermal bridges

Heat loss through the building envelope is an issue which affects both energy demand and moisture safety. Thermal bridges often occur at structural joints, window and door fastenings and may cause unnecessary heat losses, moisture damage and thermal discomfort. Common hot spots for thermal bridges for the back side of the building are analysed to observe the isotherms in the structure and the impact on interior surface temperatures. The thermal bridge analysis is performed in HEAT2, a PC-program for two-dimensional transient and steady-state heat transfer calculations. The impact of thermal bridges on the overall U-value of the structure is not considered.

To simulate the worst possible scenario (winter period) for thermal bridges, the boundary conditions of the simulations set in HEAT2, are as follows:

$T_{inside:}$ 20°C
$T_{outside:}$ -10°C

2.8 Water supply and drainage systems

The fresh water, run-off water and sewage systems of the area surrounding the project site are displayed below, provided by VA SYD, the regional water and sanitary supplier (see Figure 12). This map is used for planning the water supply and drainage systems to and from the row house buildings.

Following the basic idea of an environmental friendly and sustainable building, it is necessary to consider and possibly limit the amount of freshwater used in a common household. Therefore, the buildings utilise a rainwater collection system that allows for rainwater re-use. The positive effect of this concept is not only to reduce the freshwater usage by substituting freshwater with rainwater in certain processes such as washing clothes and flushing the toilet, but also to increase the water retention time. In a more and more urbanized and obstructed environment it is important to handle rain water run-off in order to lower the risk of local flooding and to relieve the capacity of local sewage water treatment facilities.

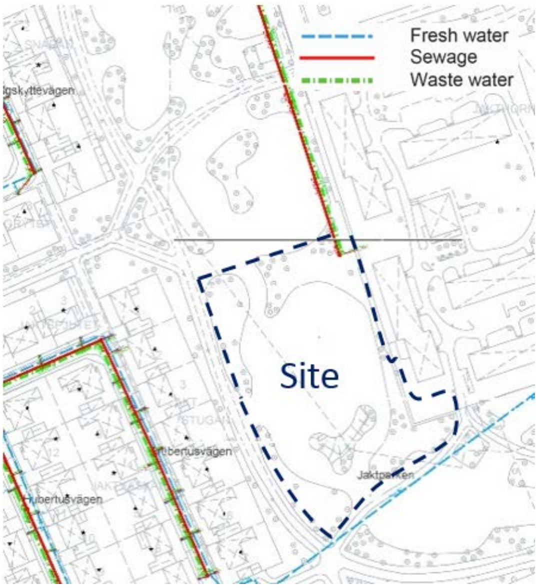


Figure 12, Site plan with water and sewage connection

2.9 Active solar potential

The active solar potential of the building, in terms of electrical production from photovoltaic panels, a solar irradiation simulation is performed in Autodesk Ecotect.

2.10 Daylight potential

Although not required of the project manual, several interior daylight potential studies are performed. The daylight factor is observed in Autodesk Ecotect and Daylight Visualizer VELUX 2, to analyse the impact of window size and interior windows on the visual comfort inside the building. This potential is primarily seen as part of the architectural concept after which energy analysis is too analysed.

3 Concept

3.1 Architecture and site planning

South is established to be the optimal orientation for the passive row house in Gunnesbo, proving that an annual distribution of passive solar gains is a significant passive strategy for the designed houses. This serves as a main inspiration to the conceptual form of the building.

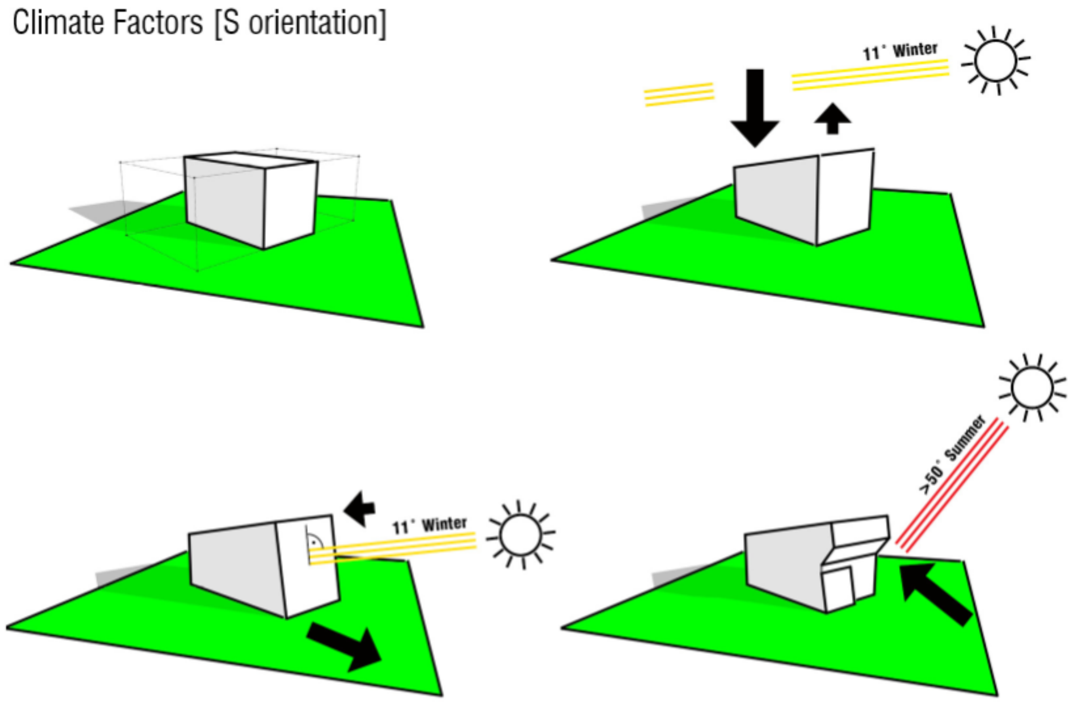


Figure 13, Ecotect shadow range analysis on 1st March between 10:00 – 16:00

Figure 13 summarises the formation of the form concept inspired by southerly oriented solar height, allowing for solar heat gains to be limited during summer and enhanced in winter respectively.

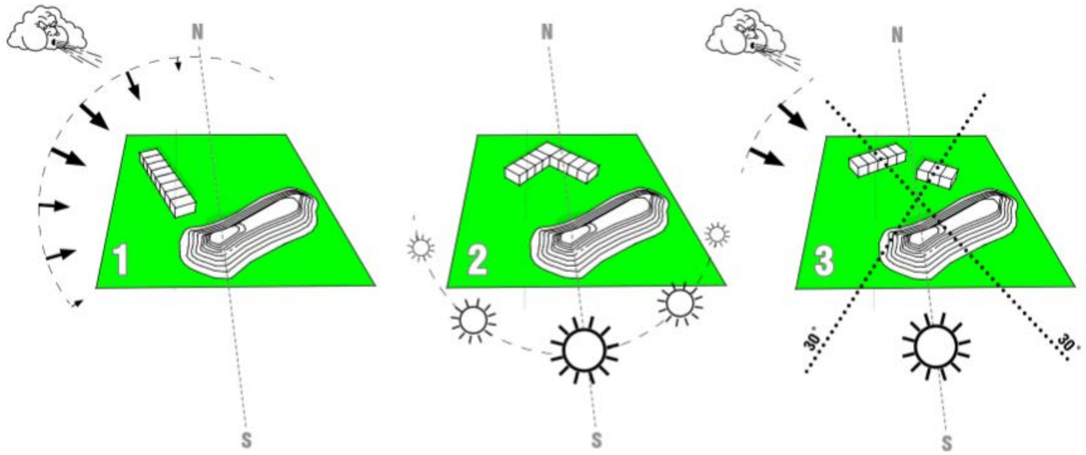


Figure 14, Climate factors influence on site plan layout development.

Results attained in the climate analysis and the passive form factor (see Figure, suggest for the complex to be divided into two double story buildings. One consisting of five units, the other of three with each building diverging 30 degrees of due south. This division and orientation is made in order to attain wind protection from the W and NW and maximum solar exposure to the area in front of the buildings.

Rotating the buildings 30 degrees of due south creates a significant change in the form of the building. This, since the form established from the design guideline following solar height in summer and winter with 50 and 11 degrees respectively, only applies for a due south orientation. Hereby, the form which compensates for a SSW and SSE orientation, would have an altered visual expression as a single unit when grouped together (see Figure 15 below).

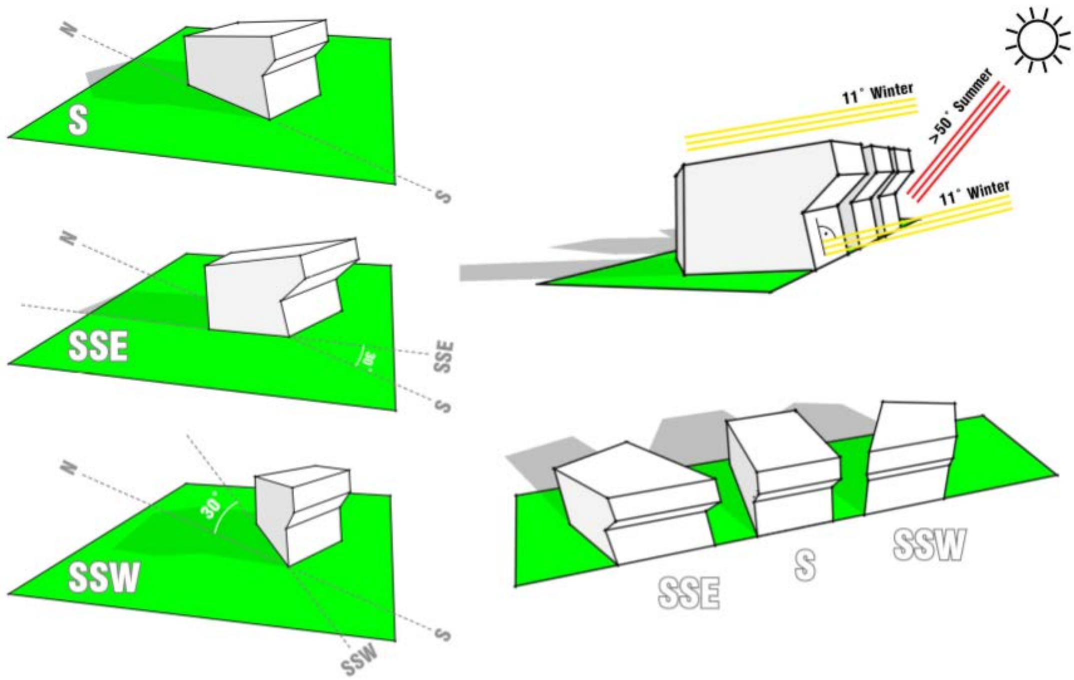


Figure 15, 11 and 50 degree design rule for SSE, SSW and S orientations

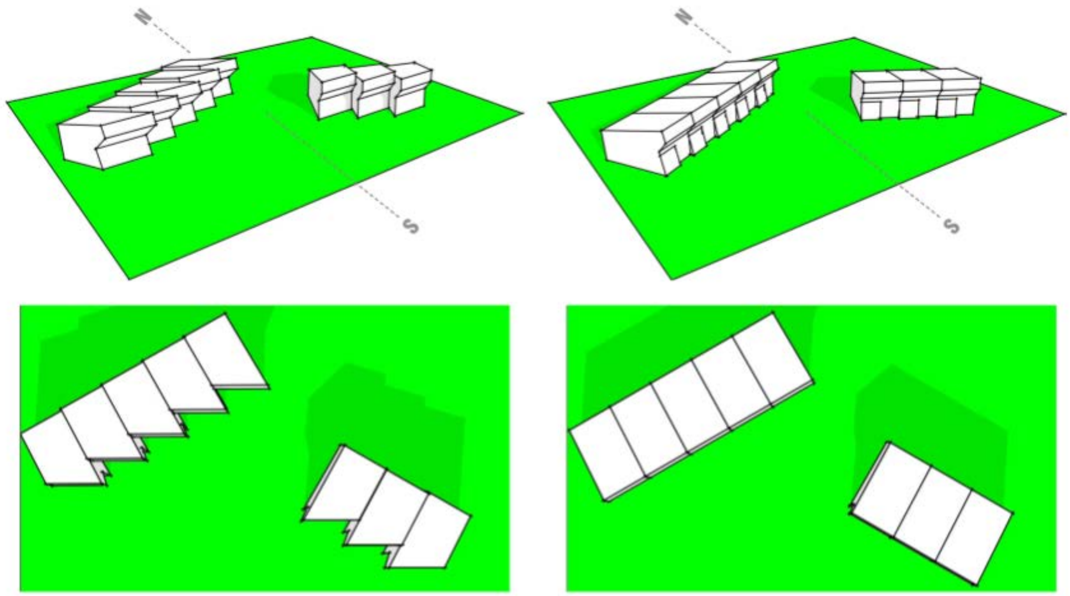


Figure 16, 11 and 50 degree design rule, Left figure: unevenly sloped form for SSE and SSW orientations, Right figure: simple form for S orientation

It is predicted, that a form compensating for the SSE and SSW orientation (as displayed above), would have a negative effect on both moisture safety and thermal bridging. The form factor of these buildings grouped together (see Figure 16a) is increased when compared to the original grouped buildings (see Figure 16b) which is likely to worsen the final energy demand results.

Considering the most optimal design in the perspective of the moisture safety and energy demand results of the houses, it is decided to proceed with the original form concept, and not compensate the form for the cardinal orientation.

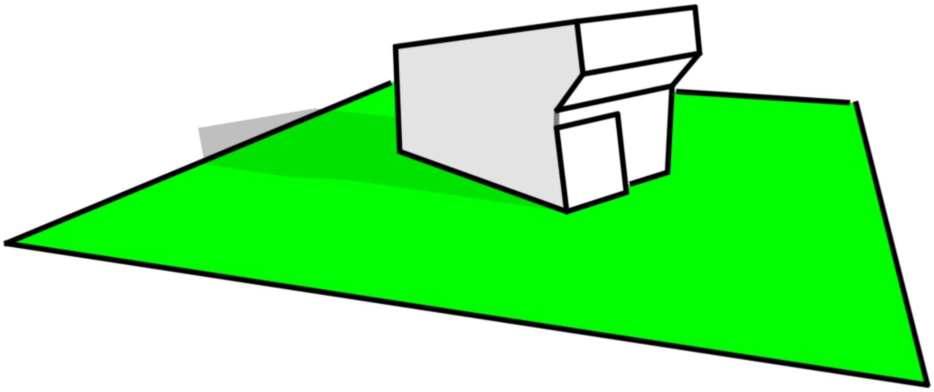


Figure 17, Established design for SSE and SSW orientation

The established formation prevents the buildings from shading one another, even in winter time when the solar height is at its lowest. Furthermore, the formation contributes to the passive solar potential of the complex, allowing for an open, sunny and interactive space infront of the residence without removing any trees from the site.

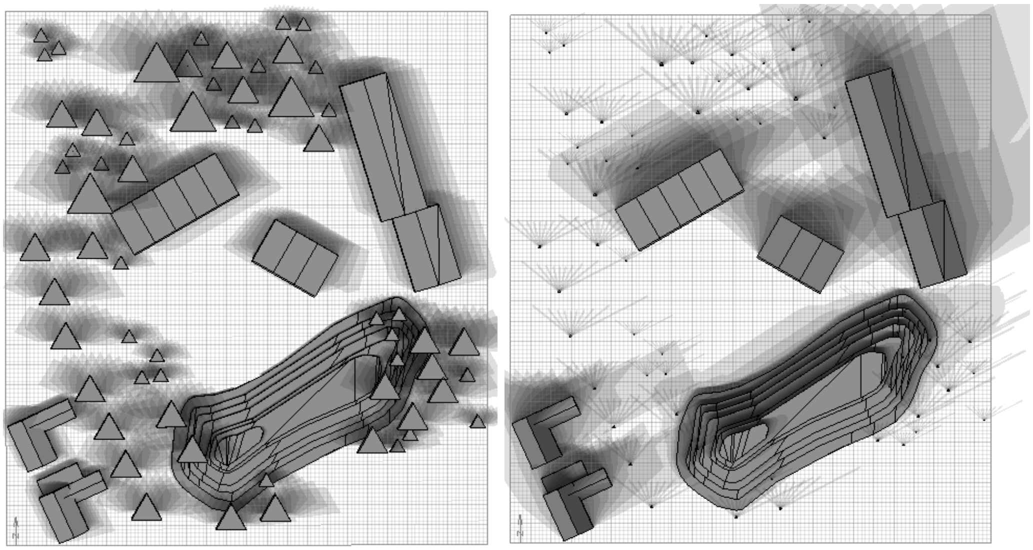


Figure 18, Shadow range on the site with passive house complex in the summer and winter scenario, 10:00-16:00.

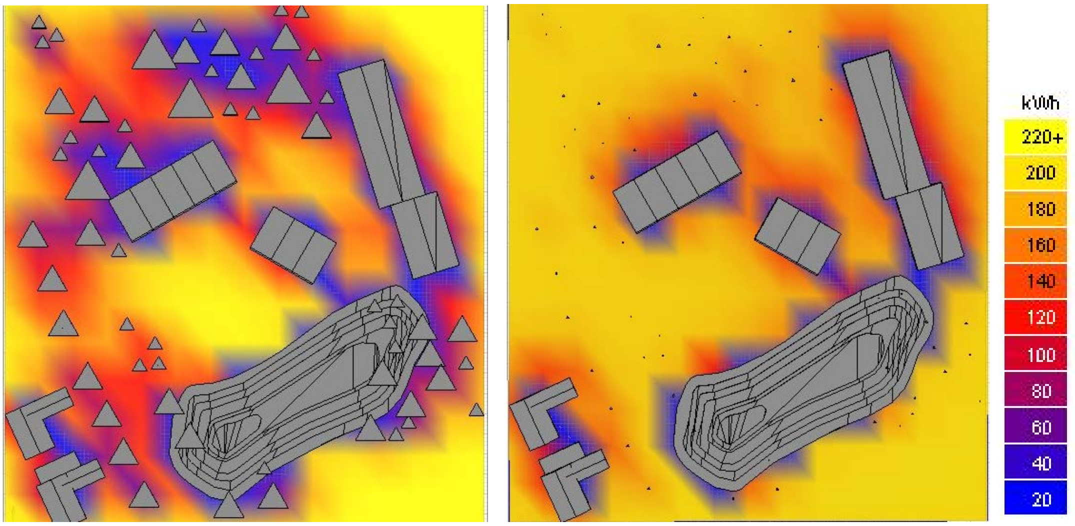


Figure 19, Autodesk Ecotect solar access analysis in summer and winter time.

Daylight and window ratio

As a result of using 11 and 50 degrees inclined windows on the southern façade - it becomes possible to let more daylight in winter when highest sun angle is as low as 11 degrees. In summer time, when solar gains mostly are to be avoided in a passive house, a 50 degree slanted wall creates a self-shading effect, limiting the highest sun rays over 50 degrees, from entering the building.

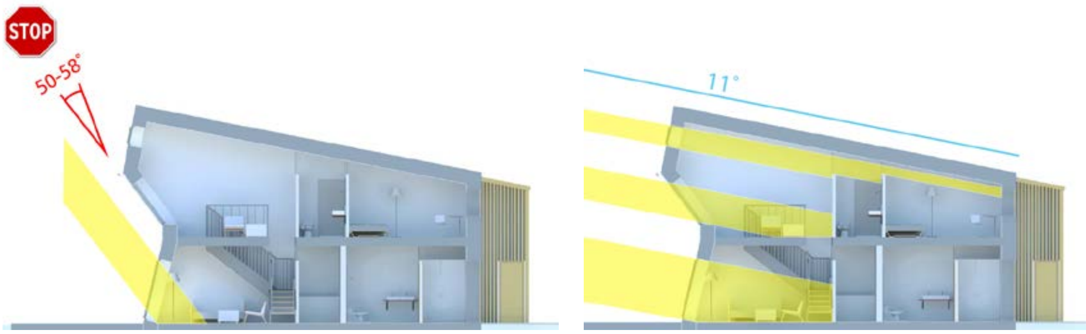


Figure 20, Passive solar potential and daylight as important parameters in passive house design process both in summer (structurally integrated shading) and winter (glazing sloped 11 degrees)

Room Distribution

The room distribution concept is based on the layout which orients the living area to the South while sleeping rooms, corridors and entrance are oriented to the North. Such a layout makes it possible to concentrated rooms which are directly connected to water usage in the middle of the building and above each other.

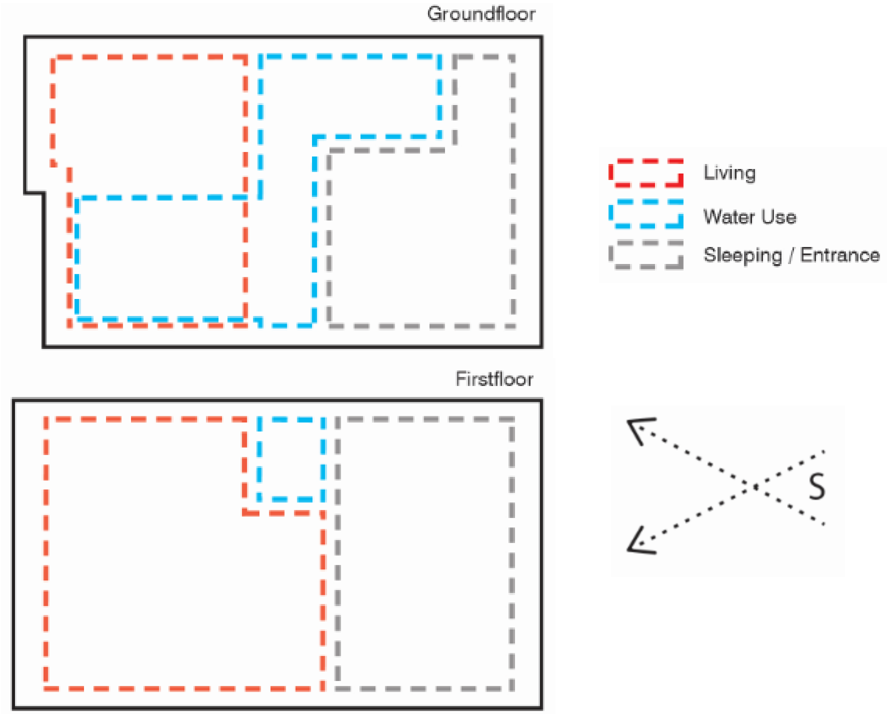


Figure 21, Concept of functional room distribution

3.2 Moisture

The moisture risk associated with the building envelope and have been identified. Three main moisture risks have been identified and graded according to the following risk assessment. (The full risk assessment can be found in Appendix I).

			Value 1=low 4=high/critical				Value 1=low 4=high/critical				Value 1=low 4=high/critical		
Nr	Ambient factor/ Moisture Load	Description of risk	Probability	Consequence	Risk value	Improvments 1	Probability	Consequence	Risk value	Improvments 2	Probability	Consequence	Risk value
	Moisture convection	moisture damage in roof	2	3	6	wind barrier (fasadskiva)	1	3	3	metal sheet at roof ridge, efficient flashing at gutters to prevent water entering at joints	1	3	3
	Moisture diffusion	moisture damage in wall	3	3	9	wind barrier (fasadskiva), airgap to inhibit moisture intrusion due to pressure difference	2	3	6	interior load bearing structure, discouraging condensation on studs due to warmer temperature	1	1	1
	Construction moisture, wood	roof: mould growth on wood studs	3	3	9	control of initial conditions and sufficient drying out period	2	3	6	"diffusion open" membrane to allow for construction moisture in roof to dry out	1	1	1

Figure 22, Main identified moisture risks

The following risk points are schematically identified for the envelope:

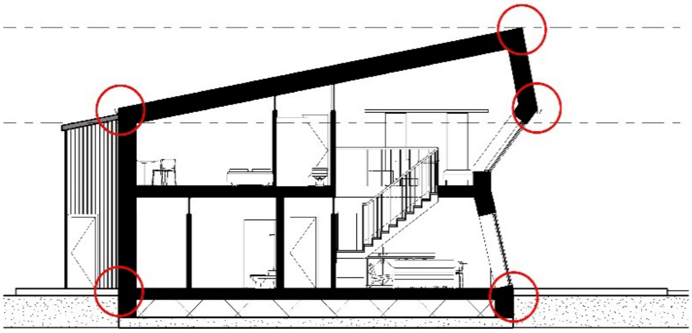


Figure 23, Moisture risk hotspots in a building section

3.3 Energy

To justify the proposed architectural concept, a pre-study of the energy performance of the forms is made. Four conceptual forms, orientated towards the south, are chosen for basic energetic evaluation in DesignBuilder, comparing annual heating and cooling demand.

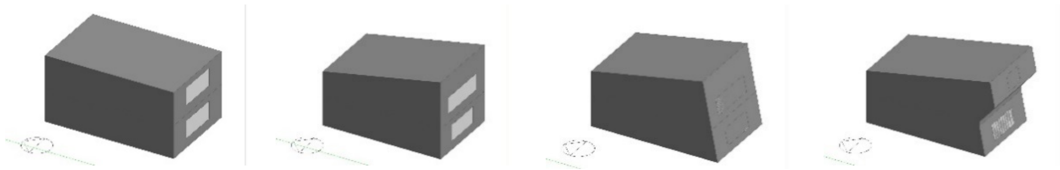


Figure 24, Designs used for the parametric design studies. Left to right: Design 1, Design 2, Design 3, and Design 4.

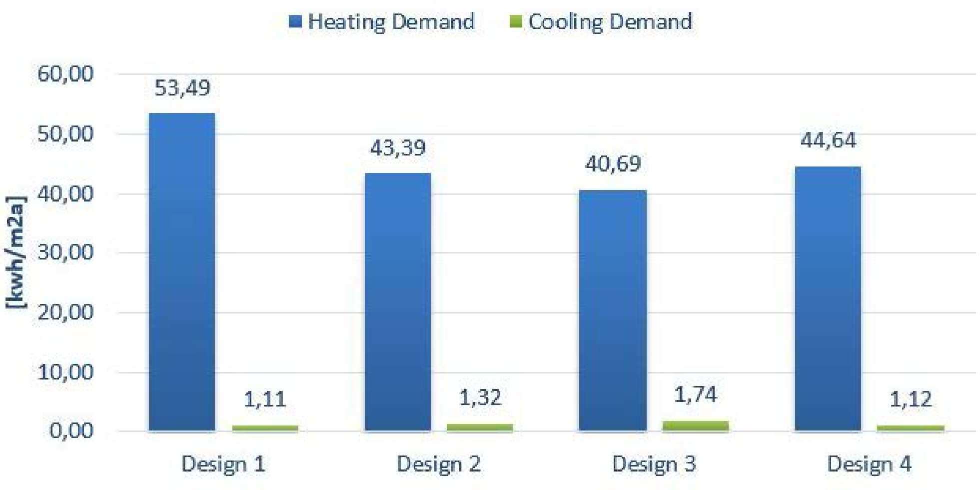


Figure 25, parametric study of different building shapes

The energy demand values do not represent passive house standard (see Table 1), but instead input data of “default” settings in DesignBuilder. This is done in order to have reference cases to compare to in the parametric study. Hereby, this pre-study is used as a conceptual guideline for further evaluation.

Design 3 has the lowest heating demand due to the slanted windows on the southern façade that allow for a greater amount of solar gains during the heating season. Contrarily, the cooling demand of Design 3 is the highest of the four designs. When looking to the total energy demand, Design 3 has the lowest total energy demand.

The cooling demand is rather low in all cases due to initial input data causing a lot of heat losses through the building envelope. Assuming passive house input data according to FEBY, overheating is likely to occur in Design 3 during summer for which Design 4 has better prerequisites.

4 Results

4.1 Architecture and site planning

Site planning

General site layout underlines the importance of southern (SSE and SSW) orientation of the houses blocks. At the same time, such a layout provides a spacious common green area with southern solar access all day long. The bicycle and pedestrian access to the buildings is provided both from the SE and NW. The idea of irregular path layout is due to minimize the effect of wind tunnel, especially from W and SW winds.

Figure 26, General site plan

Parking spaces for cars, street access and garages (one per household) and garbage-compost-recycling collection building are located in the southern part of the plot. I that way a shortest possible street access has been achieved. What is more both garages and garbage collection building are localized inside the southern slope of the hill, to minimize their visual effect on the living site.

Figure 27, Section through the site plan, with garages in the southern slope of the hill

Room distribution

Following the concept of room distribution as a passive strategy, living areas such as living room, dining room and kitchen and the office have been oriented to the South. At the same time all the living functions on the ground floor are directly connected with the southern terrace and common garden / green area.

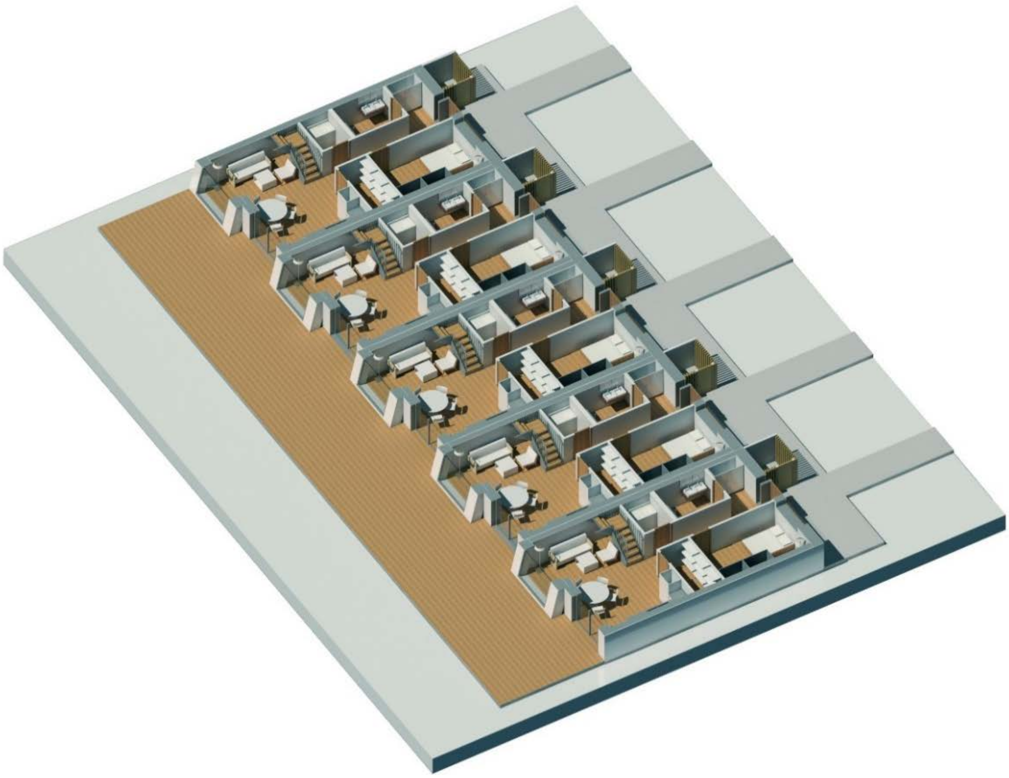


Figure 28, Section with room distribution in 5 houses block

Figure 29, Section of the house, 1 house unit

The main entrance to the building is oriented to the North, where an exterior double-story storage room and individual bicycle parking have been localized.

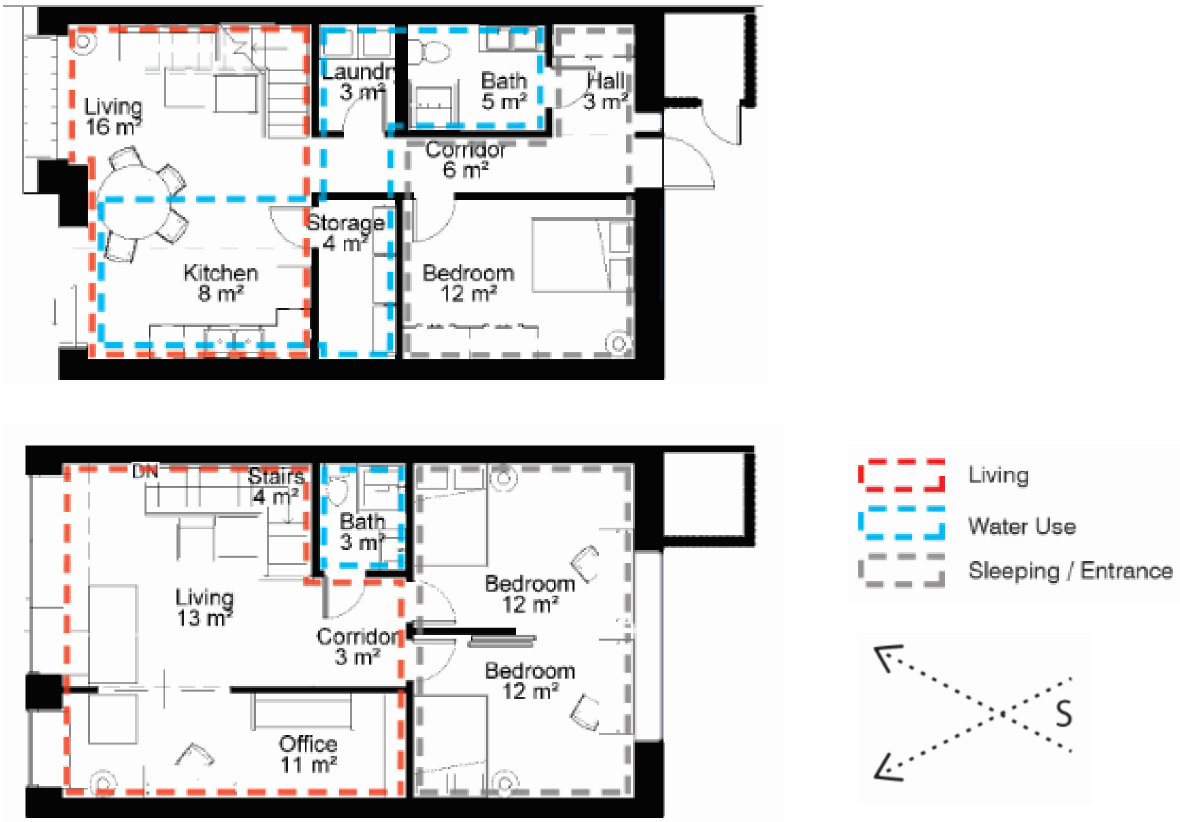


Figure 30, Room distribution with proposed interior arrangement

Window ratio / Façade

In order to obtain energy optimized window ratio in the building envelope and provide the adequate levels of daylight inside the house 80% of the total window area has been localized on the southern façade. The window – wall area ratio of 32% percent is achieved (excl. roof area). While the window – total floor area is 24%.

From the perspective of passive solar potential, it is important that 61% of total wall area is oriented to the South. To achieve this and being aware of very low U-value of the roof, a decision to the slope the roof to the North, has been made.

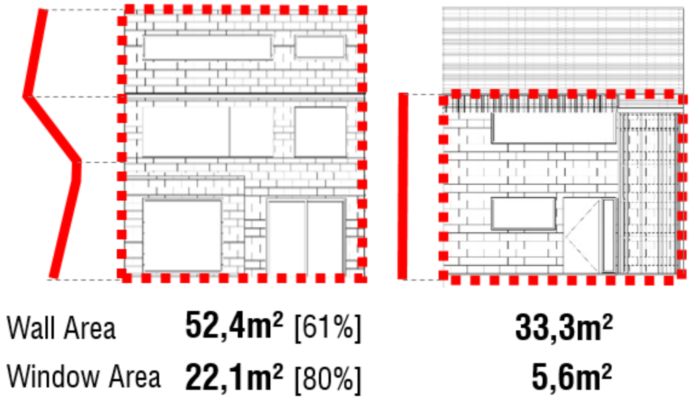


Figure 31, Window – wall layout on the facades

Figure 32, South East façade – 5 blocks

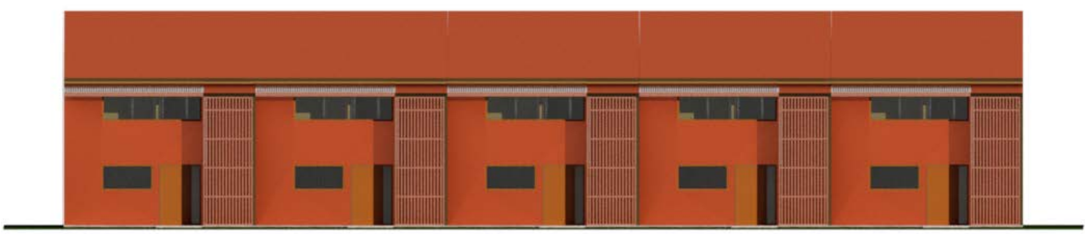


Figure 33, North West Façade – 5 blocks

Despite of the high windows ratio on the southern façade, the structurally integrated shading imposed by the form reduce the heat gains and direct solar access insolation in the summer time. On the other hand, and as predicted, the structural shading maximize the heat gains through the southern glazing sloped 11 degrees in winter time.

The effect of the form shading itself is clearly displayed in Figure 34 and 35 below.

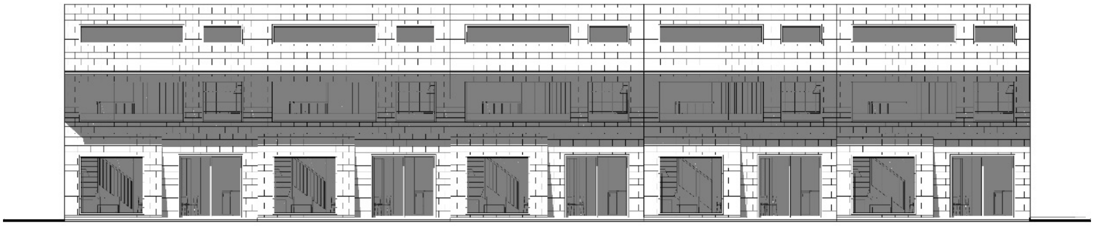


Figure 34, Shadow range on the South East façade at summer solstice at 12:00

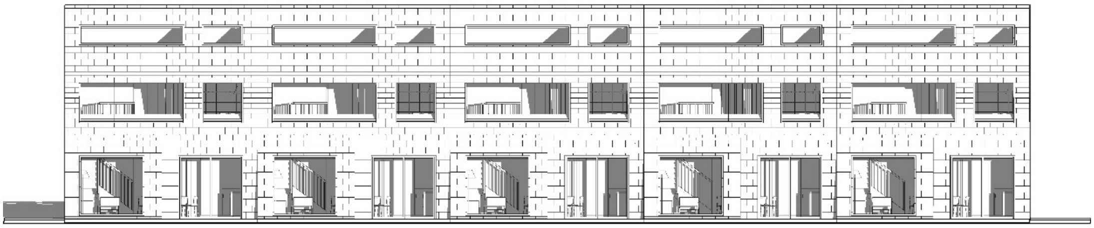


Figure 35, Shadow range on the South East façade at winter solstice at 9:00

Daylight and luminance

Considering the final façade design and established optimal window ratio and in order to simulate the daylight potential of the building, a daylight analysis for 3 options with different solutions for top windows have been made. Models used for daylight simulations in Daylight Visualizer VELUX 2 are shown in Figure 36 below.

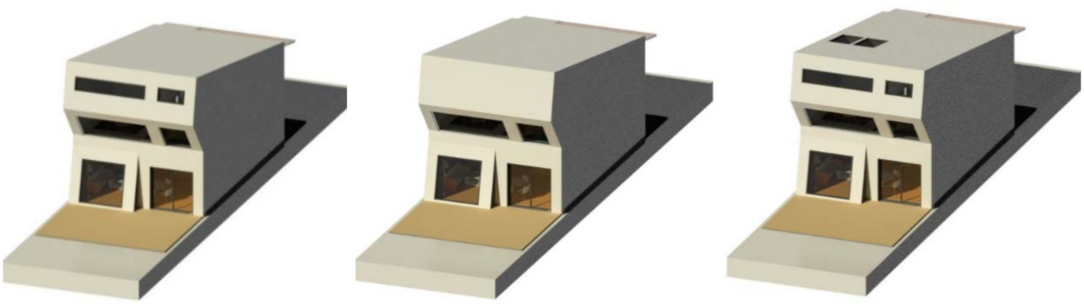


Figure 36, Models for daylight simulation: a) final design, b) final design without southern top windows and c) final design with roof skylights

Option a) – final design:

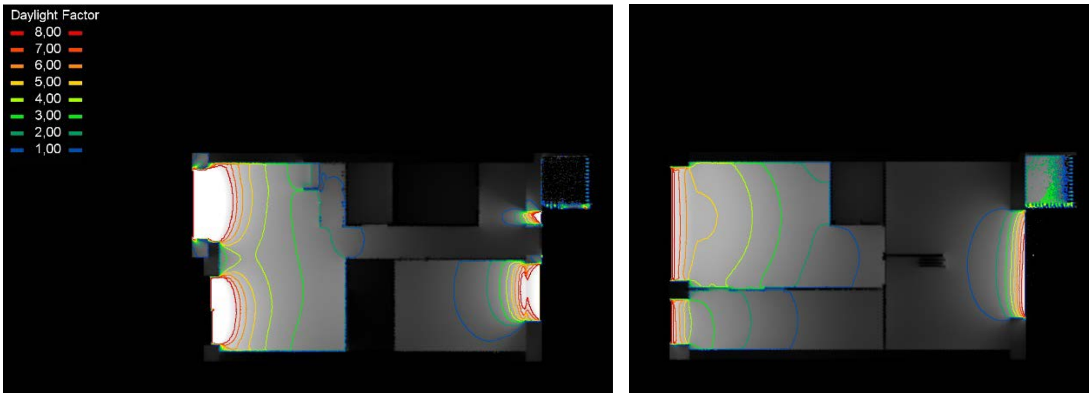


Figure 37, Daylight Factor values for the ground floor and first floor in March, 12:00

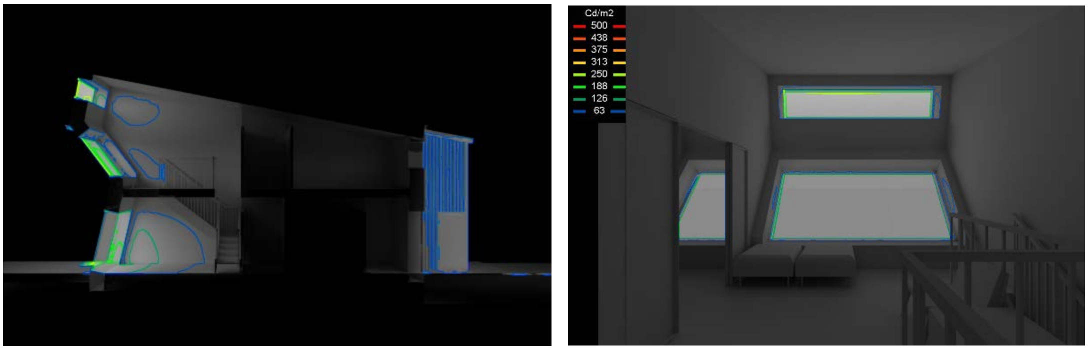


Figure 38, Daylight access, December 12:00, Left figure: section, Right figure: 1st floor

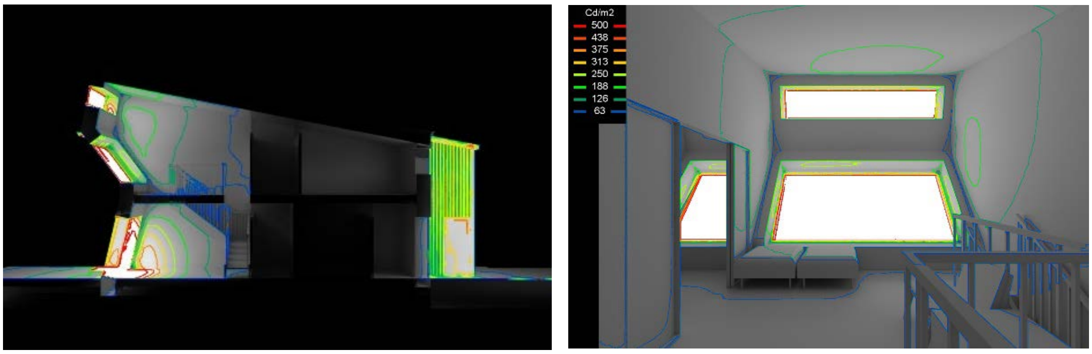


Figure 39, Daylight access, June 12:00, Left figure: section, Right figure: 1st floor

Option b) – final design without southern top windows:

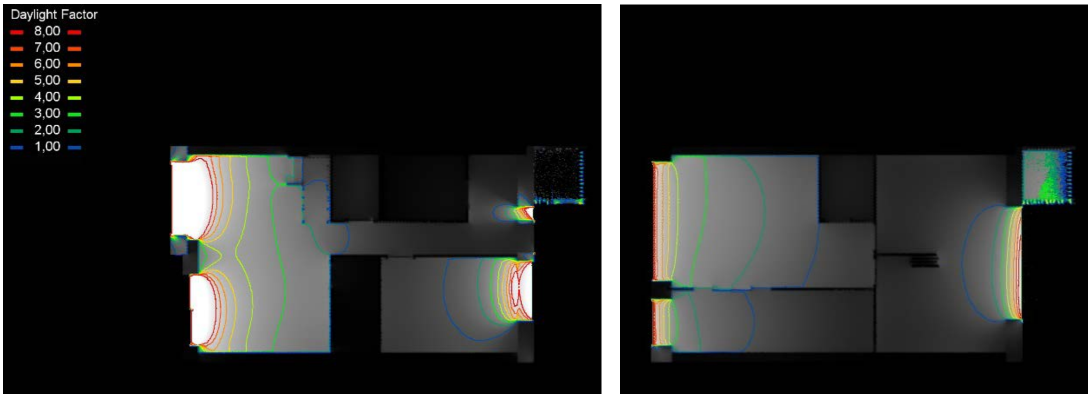


Figure 40, Daylight Factor values for ground floor and first floor in March, 12:00

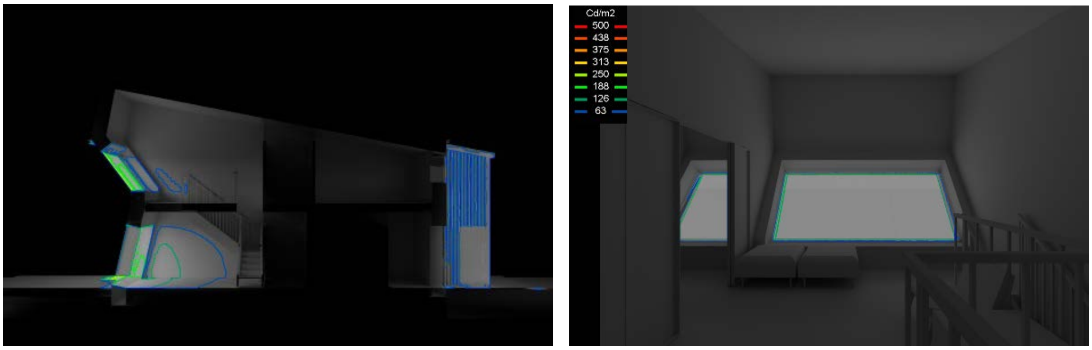


Figure 41, Daylight access, December 12:00, Left figure: section, Right figure: 1st floor

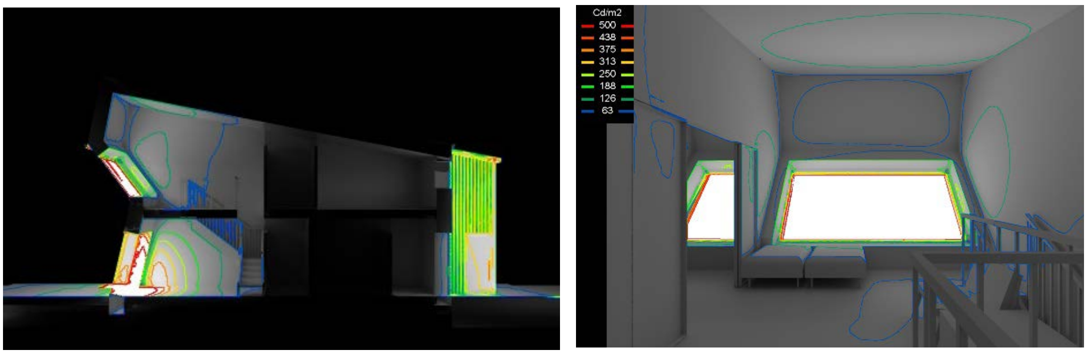


Figure 42, Daylight access, June 12:00, Left figure: section, Right figure: 1st floor

Option c) – final design with roof skylights:

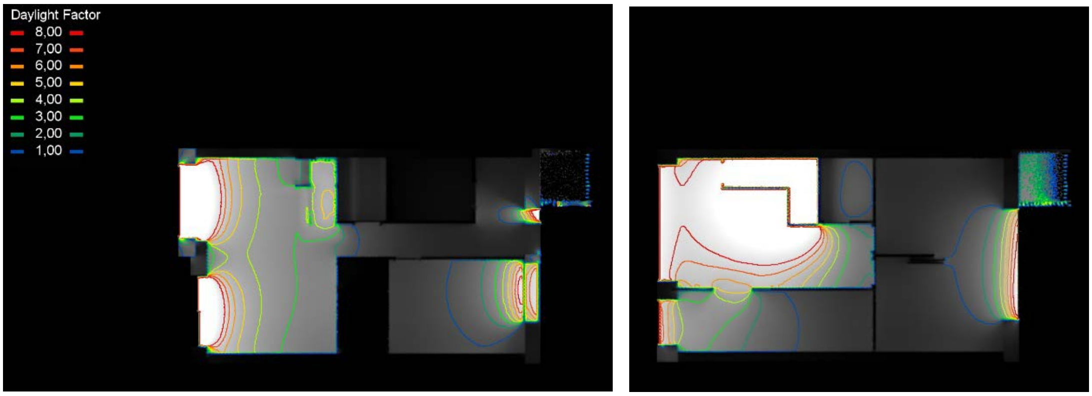


Figure 43, Daylight Factor values for the ground floor and first floor in March, 12:00

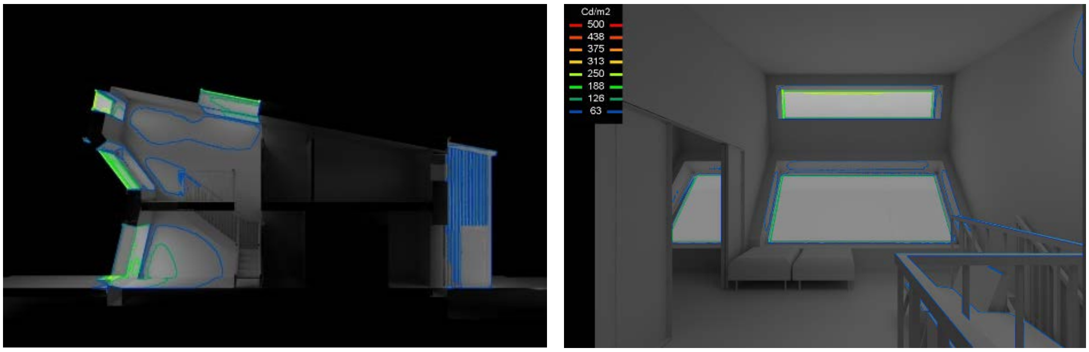


Figure 44, Daylight access, December 12:00, Left figure: section, Right figure: 1st floor

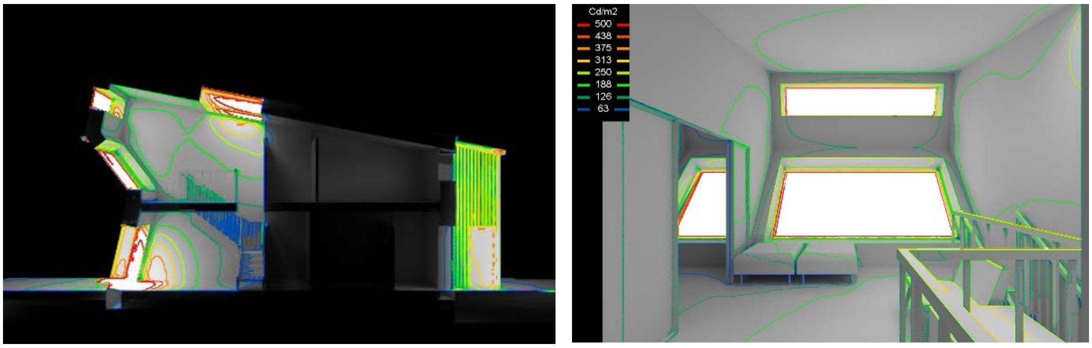


Figure 45, Daylight access, June 12:00, Left figure: section, Right figure: 1st floor

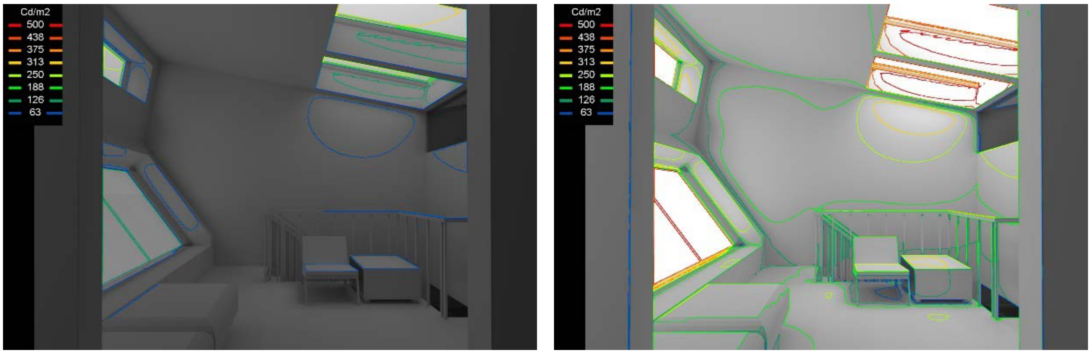


Figure 46, Daylight simulation in winter and summer at 12:00, 1st floor

Above simulations proves that with the use of southern top windows, better daylight results are achieved, especially in winter time. The best daylight situation both on the first and ground floor can be achieved with the use both of southern top windows and roof skylights, however in that situation heat gains in summer time and heat losses in winter time are increased. Detailed energy results for options a), b) and c) are displayed in Figure 59.

To verify the results given by Daylight Visualizer VELUX 2 and to show the impact of orientation on daylight factors, Autodesk Ecotect is used to analyse the final design, see Figure 36a).

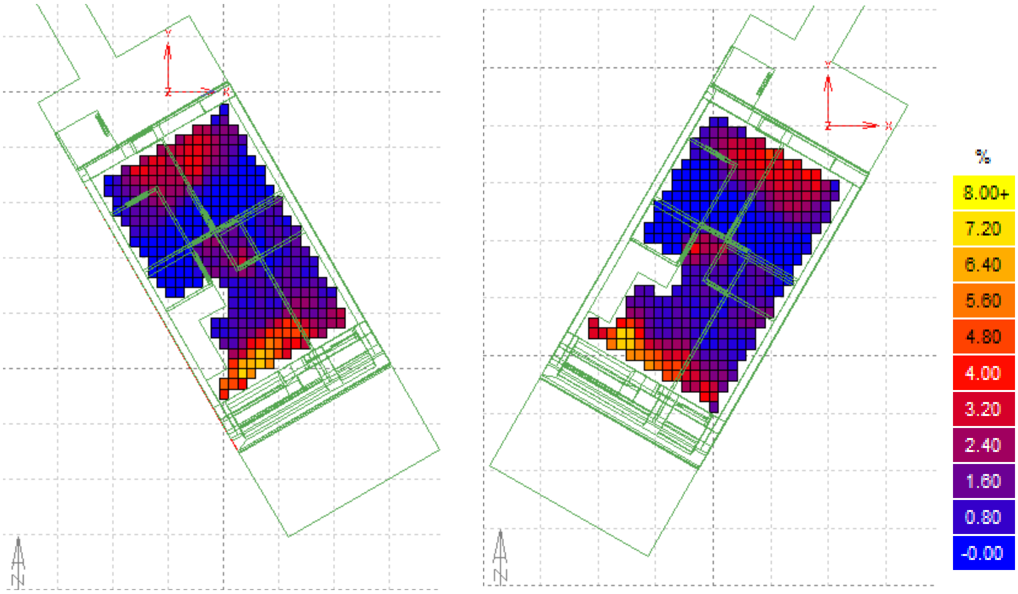


Figure 47, Daylight factor on the 1st floor, SSE and SSW orientation comparison

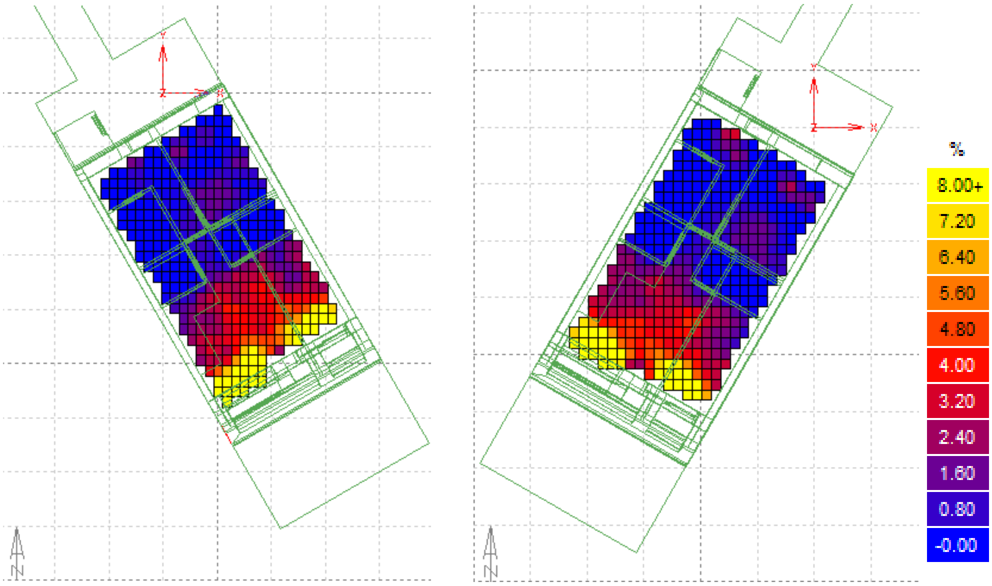


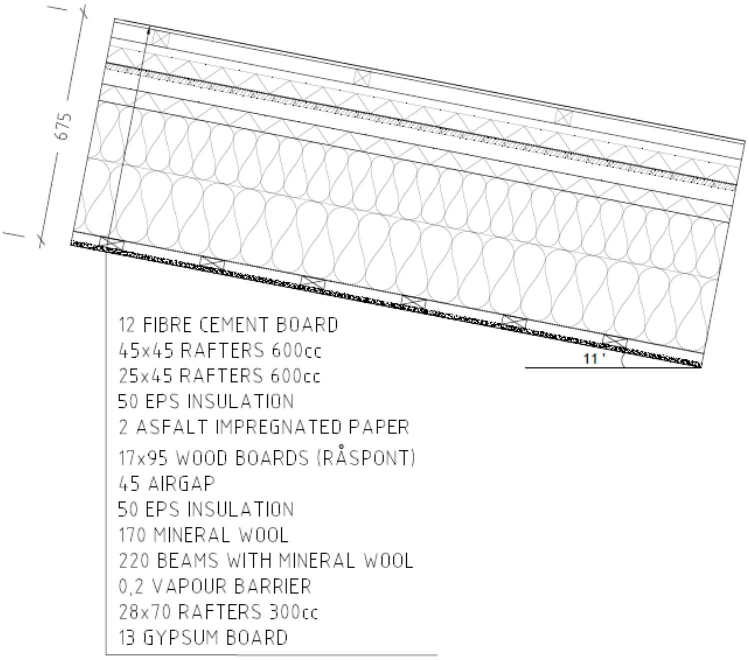
Figure 48, Daylight factor on the ground floor, SSE and SSW orientation comparison

4.2 Structural details & material choice

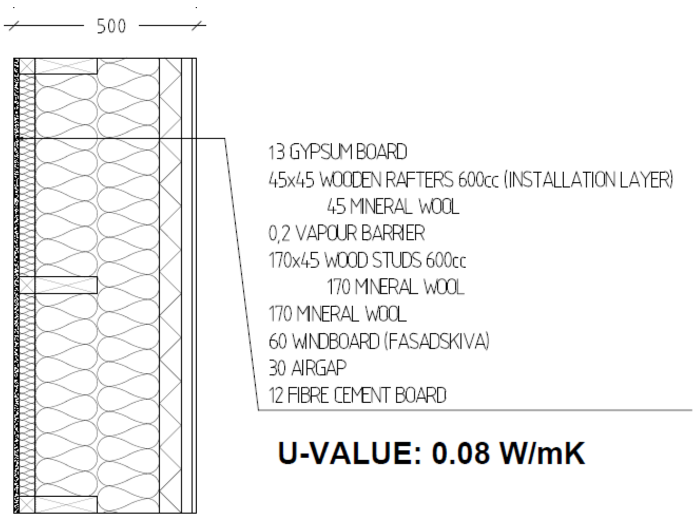
The wall and roof are both cavity structures, with well-ventilated air gaps (≥30 m/s). The thickness of the cavity wall and roof is 500 mm and 675 mm respectively, accounting for a high thermal resistance with two thick layers of thermal insulation. The load-bearing structural material is chosen to be wood. The wooden structure is an interior structure, with the second insulation layer placed on its exterior side. (Fig 50 a), b)). The placement of the load bearing structure serves to keep the wood studs warm, hereby reducing the risk of mould growth on the studs. Additionally, an interior load bearing structure helps to minimize thermal bridges around windows, since the window is mounted further into the structure, increasing the depth of the window sill and hereby decreasing the transmission losses from the window. (Mikael Granbrom, 2007)

The façade material is a fibre cement board (Figure 49), chosen due to its moister deterring attributes, wide colour spectra and its adaptability to form. The board is mounted as a typical rain screen cladding (see Appendix II), acting as a skin for the buildings. The colour of the fibre cement board is chosen to be Faluröd, a paint strongly associated with traditional Swedish building heritage. (Eternit (Schweiz) AG, 2013)

Figure 49, Fibre cement board (Equitone, 2013)



U-VALUE: 0.08 W/mK



U-VALUE: 0.08 W/mK

The slab junction includes a U-element, inspired from solutions given by SuperGrund of the type Passivhus grund. (Super Grund, n.d.)

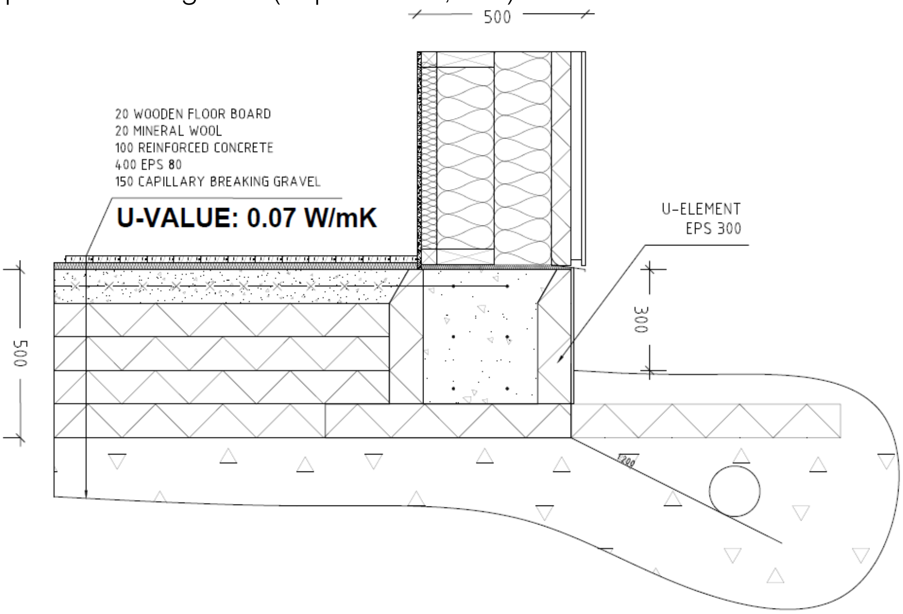


Figure 50, Structural details of the exterior facade components; top left: roof construction; top right: wall construction; bottom: slab with foundation and drainage

4.3 Moisture

The temperature and moisture profiles for all roof and wall profiles are displayed below. The results are separated into walls and roofs for the SSE and SSW oriented building. Since the buildings have an interior wooden load bearing structure, the RH in the wood stud layer is of interest, especially if the wood studs reach a value of ≥ 75%, which is considered favourable for mould growth on wood. The monitor position in WUFI is illustrated below, see Figure 51.

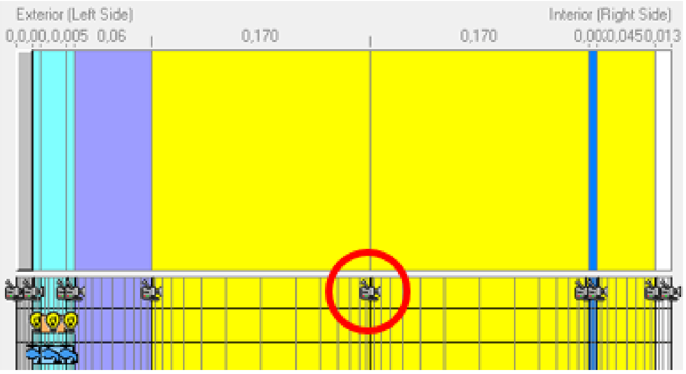


Figure 51, Examined spot within the construction in WUFI

SSW oriented building

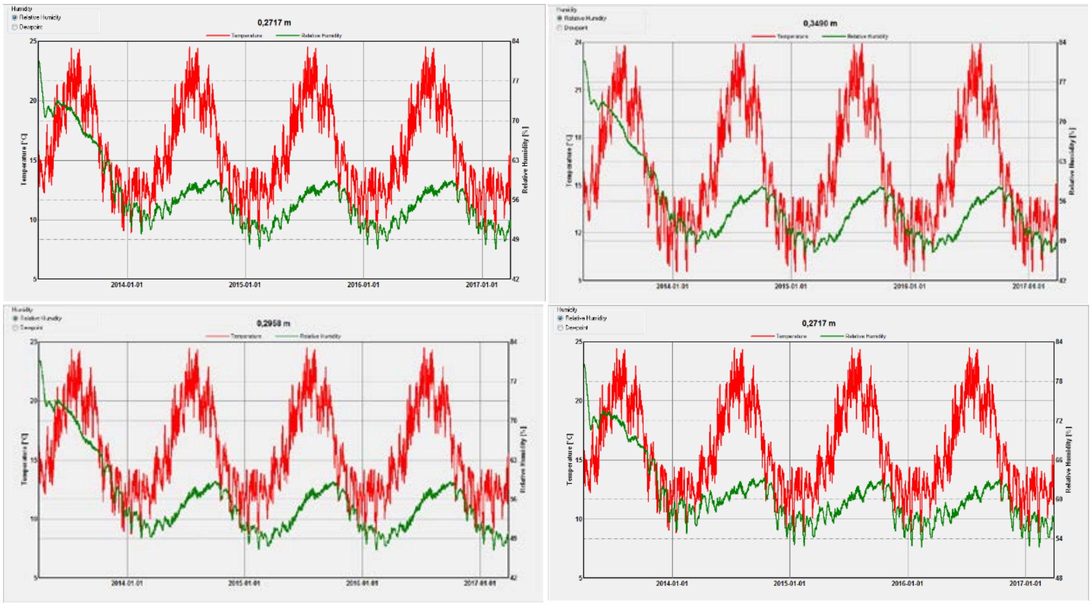


Figure 52, WUFI results of the different construction types in the SSW oriented building; red curve: temperature; green curve: relative humidity; top left: NNE-exterior wall; top right: NNE-roof; bottom left: SSW-11°slanted-roof; bottom right: SSW-exterior wall

SSE oriented building

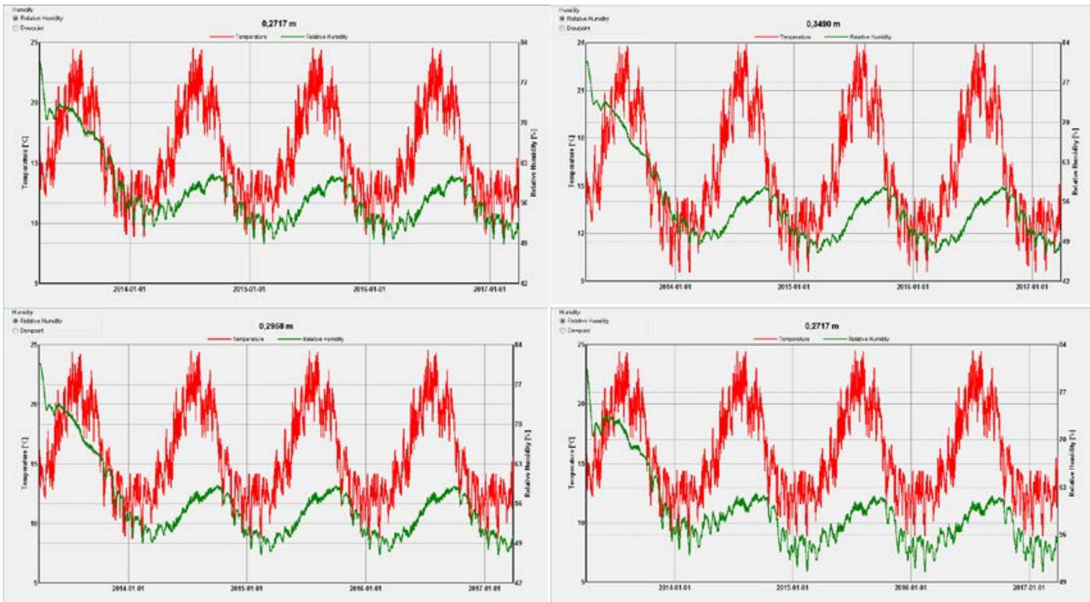


Figure 53, WUFI results of the different construction types in the SSE oriented building; red curve: temperature; green curve: relative humidity; top left: NNW-exterior wall; top right: NNW-roof; bottom left: SSE-11°slanted-roof; bottom right: SSE-exterior wall

The following details show how the previously identified moisture risk points (see Figure 23), are been designed to (hopefully) prevent moisture damage to the structure. The gutter solution for the back of the building is exposed, placed above the overhang. The flashing element is dimensioned to not allow for water to splash into the structure. The overhang aims to shield from driving rain coming from the north. The rain sheet in the roof is so-called "diffusion open", to allow for any construction moisture built into the structure, to get out.

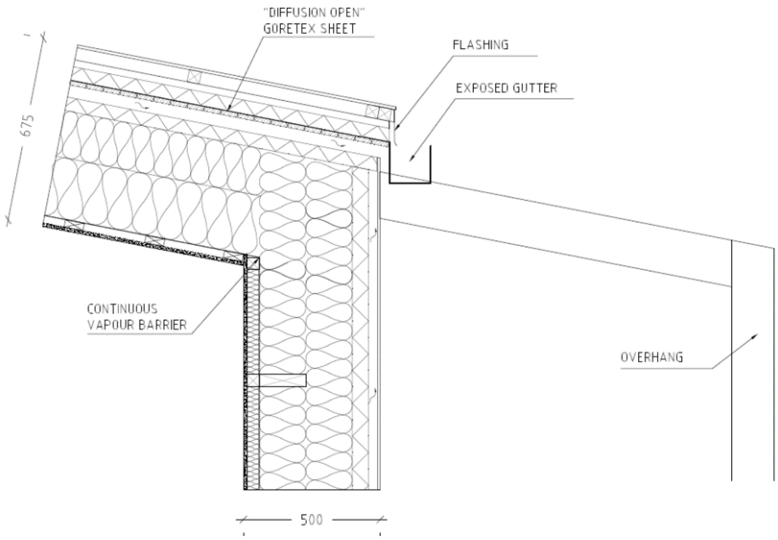


Figure 54, Elements for moisture safe construction on the back of the building

The wall/slab junction has the moisture precautions of a sealant (of mineral wool) between the slab and the load bearing structure, sufficient drainage flashing and 300 mm to the ground (see Figure 55).

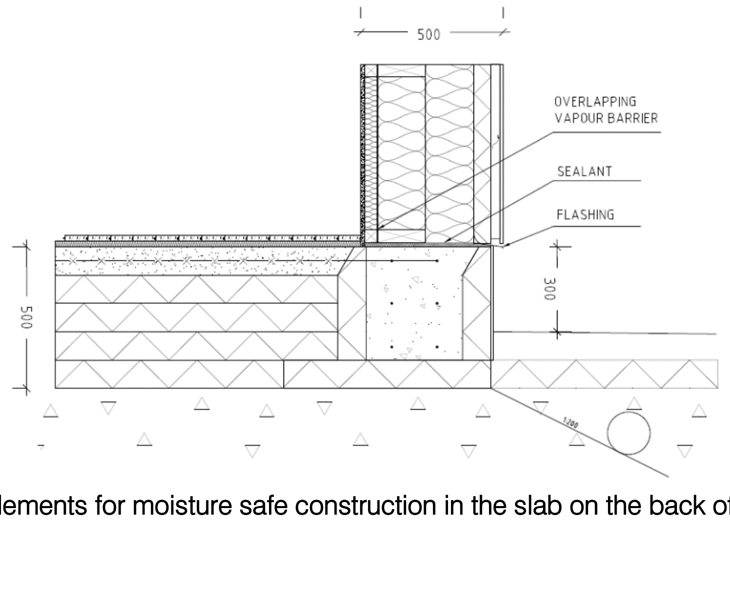


Figure 55, Elements for moisture safe construction in the slab on the back of the building

The roof- ridge is covered in a metal plate, to disable water intrusion. The front façade has a hidden gutter to handle run off from the front of the building. This is a roof structure with the same "diffusion open" membrane leading the run-off water into the hidden gutter. Below the gutter, it is a wall structure.

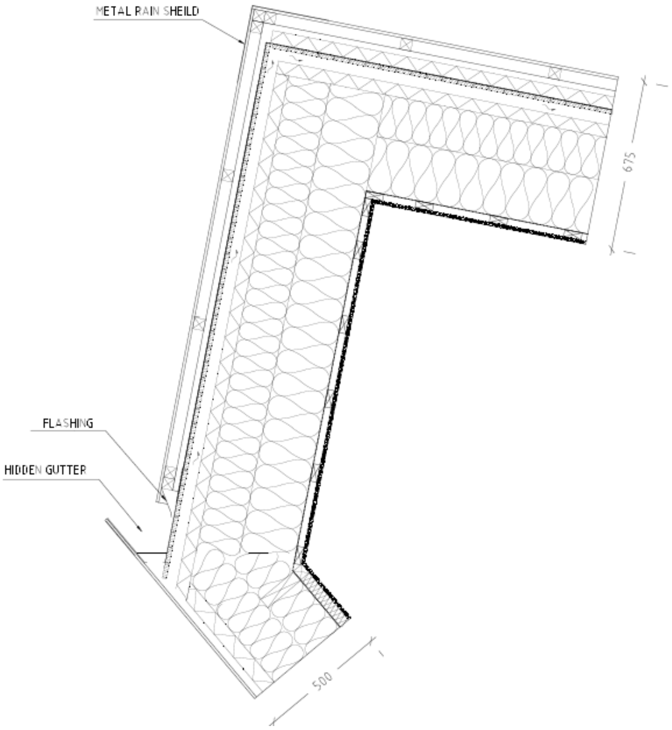


Figure 56, Elements for moisture safe construction in the front of the building

In the slab/wall junction on the front of the building, a hidden gutter is placed below the floor boards to handle run-off water from the southern façade and from the air gap.

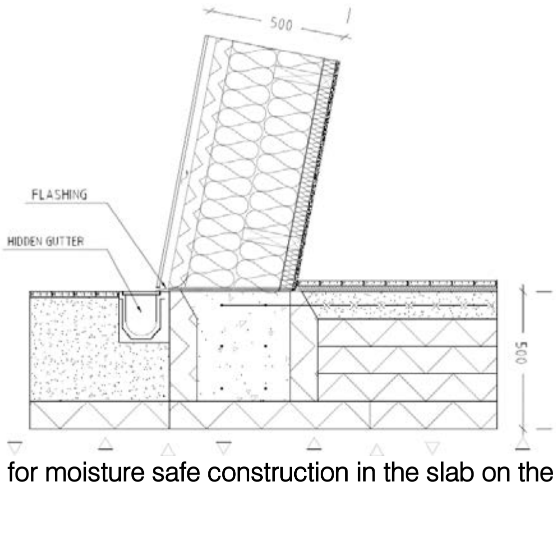


Figure 57, Elements for moisture safe construction in the slab on the front of the building

Moisture safety in the production phase
In order to maintain moisture safety during the production phase, precautions of material logistics should be taken, namely control of initial moisture content of building materials, craftsmanship and sufficient drying out period of wood and concrete prior to building assembly. During assembly, a rain shield covering the entire construction site is recommended.

4.4 Energy

In the parametric approach towards a high quality passive house, different measures aiming on lowering the annual energy demand have been taken. The main focus is on the heating demand. The cooling demand can basically only be used as a reference value to estimate the overheating issue during the summer, since active cooling is not allowed in a residential passive house. Nevertheless, the cooling demand and the collateral operative temperature are of important quality value and are therefore treated in the last part of the parametric study, to insure a satisfactory indoor climate and thermal comfort throughout the whole year.

Only results of the SSW oriented building is displayed, since the performance between the two orientations hardly varies.

4.4.1 Doors, Glazing and Frames

The next step towards an energy efficient building was to improve the thermal qualities of the openings in the constructions. Since openings are the worst part of a buildings envelope and therefore a big but necessary thermal bridge in every building, it is essential to improve them as much as possible.

In the studies, three different types of glazing and frames have been assessed:

- Wooden window frame, double glazing, low-e coating, Argon filling
- Wooden window frame , triple glazing, low-e coating, Air filling
- Passive house frame, triple glazing, low-e coating, Argon filling

Figure 58, Parametric study on the thermal properties of the openings

As it can be seen, the better the thermal properties of the windows, the better the energy performance of the building. Hence, option 3 with a total U-value of 0.8 W/m²K was chosen. This window is in accordance with FEBY requirements, see Table 1.

4.4.2 Window distribution

In order to achieve satisfying results of daylight distribution, different variances of the window distribution are assessed. The models consist of the building without any additional openings, with an extra row of top windows on the southern façade and, finally the combination of skylights and top windows. The detailed daylight analysis of these options can also be found in Figure 37-48.

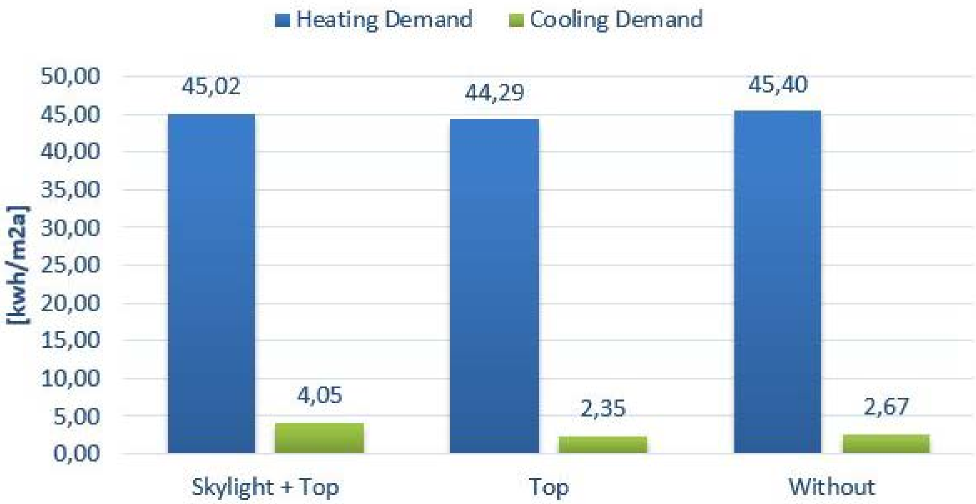


Figure 59, parametric study on different window distributions

Looking at the simulation results in the graphs above, it shows that the option with additional top windows is the most energy effective solution (middle bar). Considering the daylight analysis made of the different solutions (see Figure 37, 38, 39), it can be concluded that this is the best solution.

4.4.3 Heat Recovery

Three different heat recovery efficiencies are observed for the HVAC system. This is performed in 5% steps up to a total efficiency of 85 percent which is a reasonable value of passive house heat exchangers for the certain building size. (Hoval GmbH, 2012)

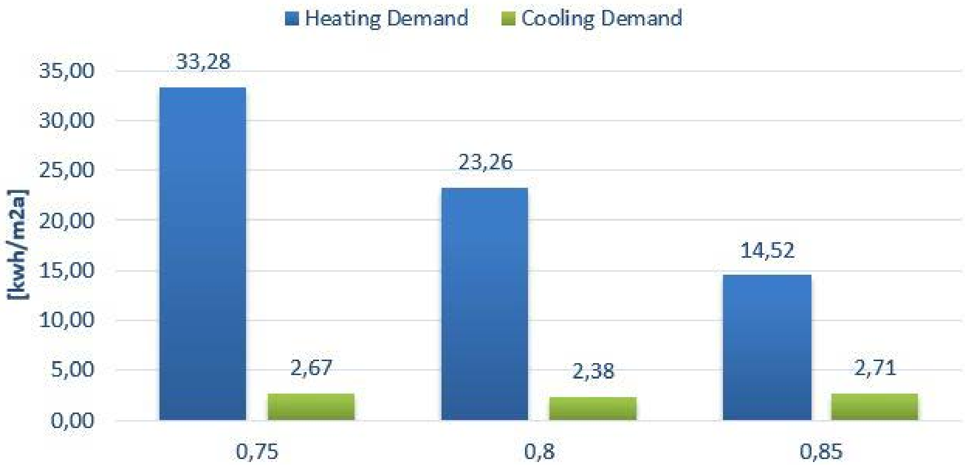


Figure 60, Parametric study of the heat recovery efficiency

The improvement of the heat recovery efficiency majorly contributes towards a lower heating demand. With all the previous steps and an efficient heat exchanger with an efficiency of 85 percent, the thermal requirement for reaching passive house quality (heating demand <17 kWh/m²a) are already achieved.

Nevertheless, there are still other components that can be adjusted towards an energy efficient building.

4.4.4 Thermal Mass

Thermal mass within the buildings envelope is a passive strategy which allows a building to buffer extreme climate conditions. In terms of heating, this includes a rapid temperature drop outside, in sense of cooling to avoid overheating of the building. Six different scenarios are examined:

- Concrete ceilings and internal walls
- Concrete ceiling
- Concrete internal walls

- Concrete ground flooring
- Internal walls of expanded clay (“Leca”) (Lecablock Gmbh, 2012)
- Internal walls with concrete on the ground floor and “Leca” on the first floor

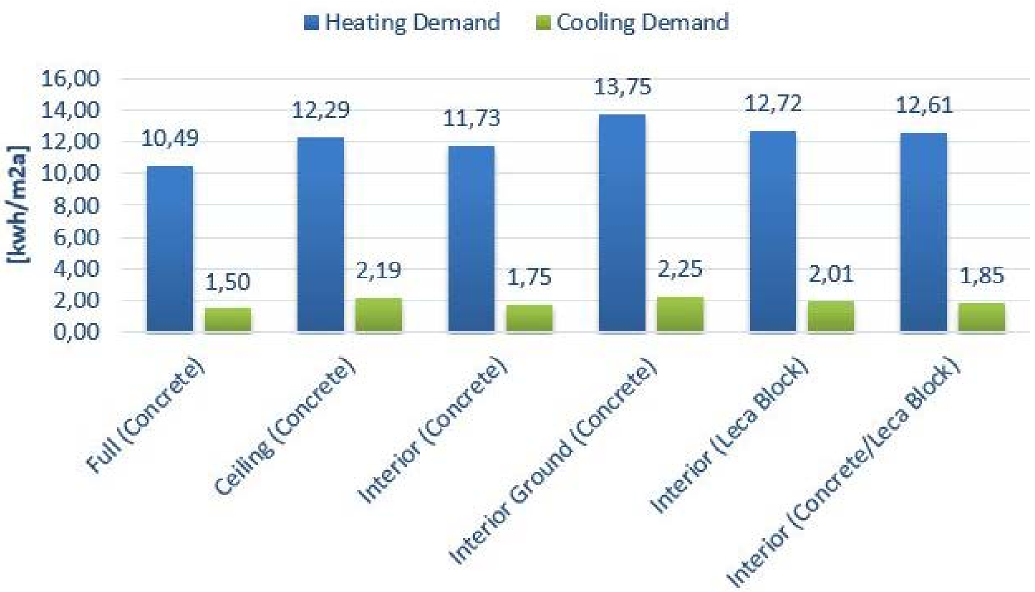


Figure 61, Parametric study on the amount of thermal mass within the building envelope

Generally, it can be concluded that the more thermal mass is used, the better the energy performance of the building. However, using concrete for the ceiling might cause structural issues in the joint of the ceiling with the load bearing exterior wall. In order to avoid these issues, a compromise is made, consisting of a wooden construction in the ceiling, internal walls on the ground made of concrete and internal walls on the top floor made of Leca-blocks to reduce the load on the wooden construction.

4.4.5 Airtightness

Airtightness contribute both to lowering the heating demand and improving the moisture safety design.

From a staring value of 0.6 h^{-1} it is reduced stepwise by 0.1 h^{-1} until 0.3 h^{-1} is reached. The results can be seen in Fig 62.

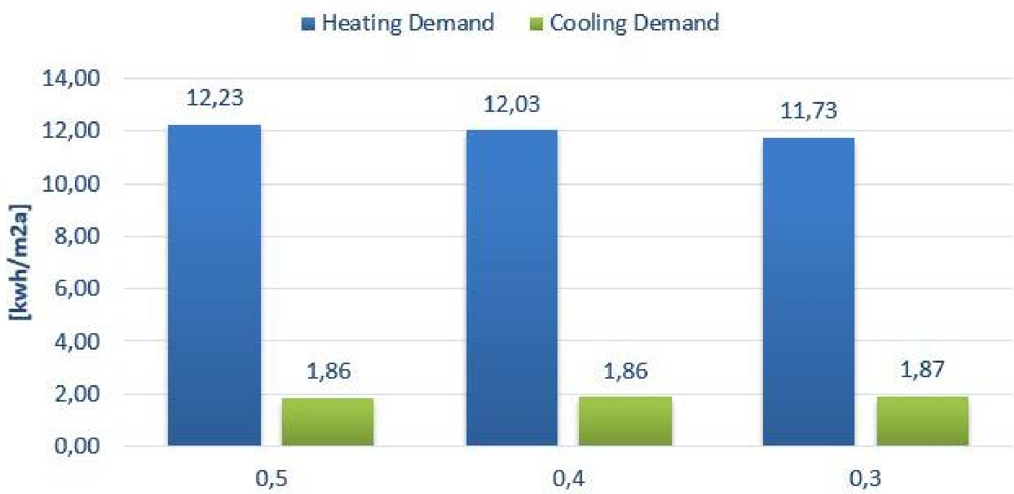


Figure 62, parametric study on the airtightness of the building

Since the thermal envelope is already highly optimized, the airtightness factor does not impact that much on the energy performance. Nevertheless, it is best to make the building as airtight as possible of moisture safety issues.

4.4.6 Shading devices

Since a main requirement of passive house is not to be dependent on any active cooling measures, it is important to keep operative temperatures within the allowed thermal comfort zone. In this case, it is limited to 26.0 degrees Celsius. After the last parametric optimization of increased airtightness, the operative temperature peaks at 27.1 °C in August, causing the need for external shading devices during this period. Therefore, a shading analysis with three different options consisting of

- Outside, highly reflective blinds
- Outside, opaque shade rolls
- Indoor temperature-controlled outside, opaque shade rolls is performed.

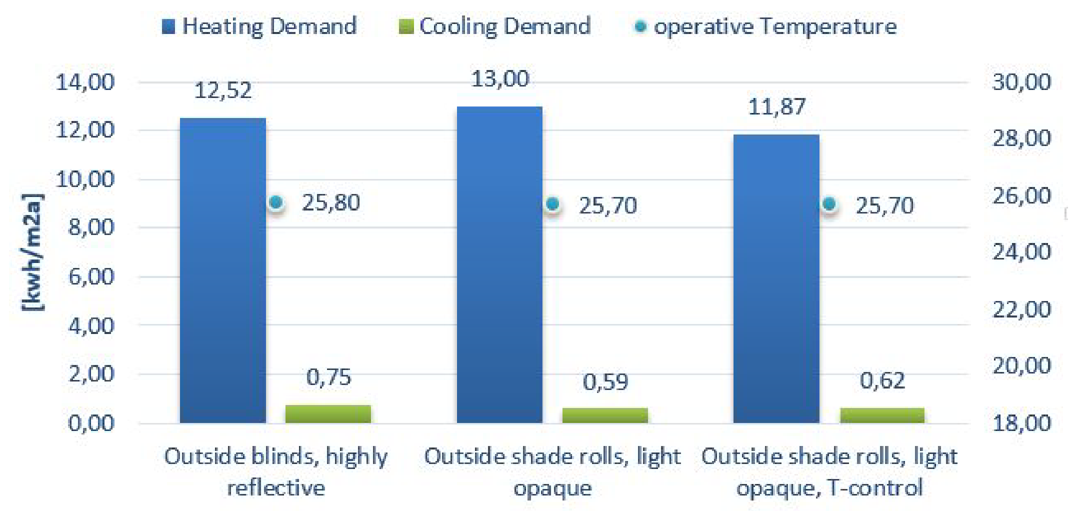


Figure 63, parametric study on different external shading options

As it is shown in Figure 63, all the blinds are sufficient enough to lower the operative temperature below 26.0 °C. The best solution in total energy demand is the indoor temperature controlled shading system, where the blinds are closed over an operative temperature above 24 °C. The slight increase of the heating demand can also be explained by the different control modes of the shading system where solar gains in the intermediate time (spring and autumn) are blocked.

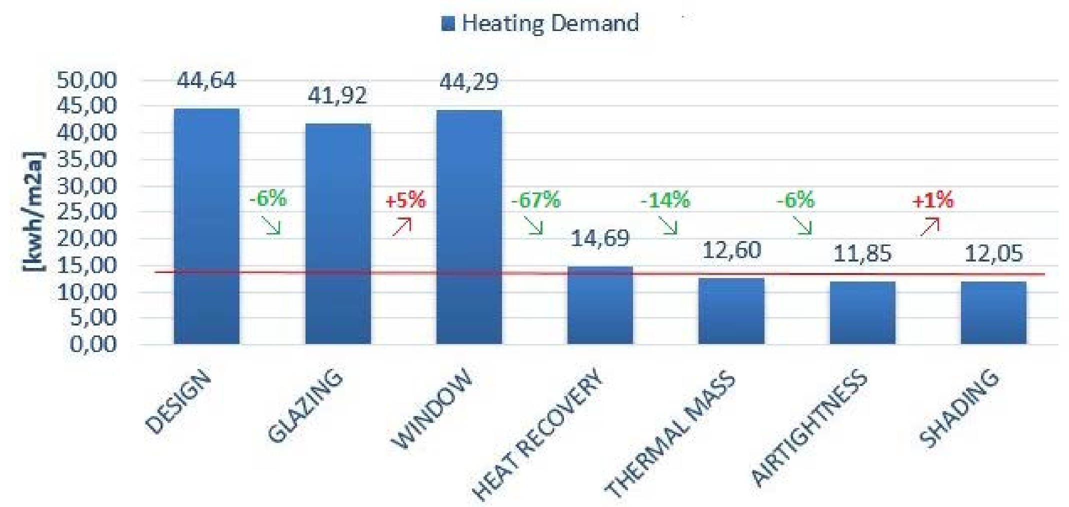


Figure 64, Parametric approach on the heating demand showing the achieved differences in percent

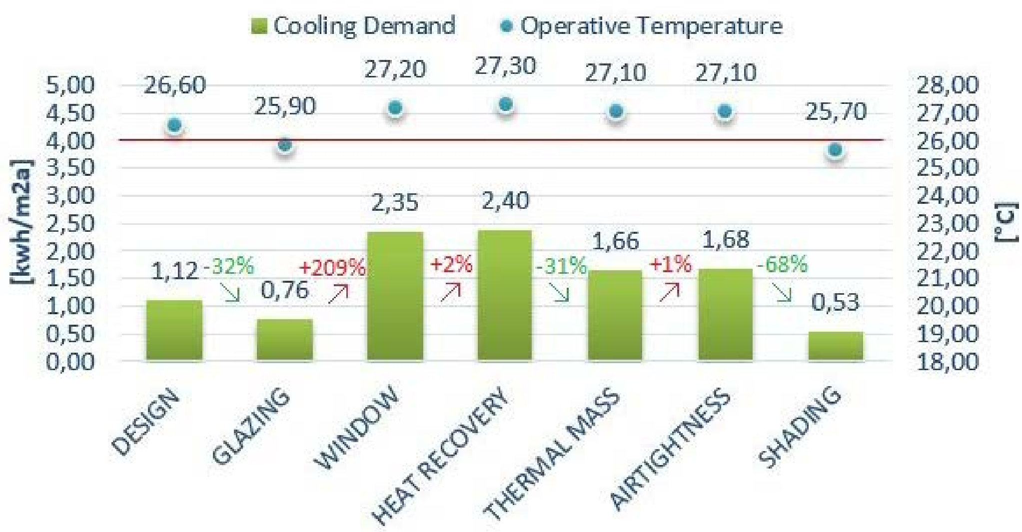


Figure 65, Parametric study on the cooling demand showing the achieved differences in percent including the maximum operative temperatures

4.4.7 Summary of energy performance

All the requirements for reaching passive house standards according to FEBY are now fulfilled. A comparison for both orientations, SE and SW with all the relevant key figures can be found below in Figure 66.

Figure 66, Comparison of the final energy key values for a single unit

Up until now, only the energy performance of a single unit building is assessed in the parametric study. The energy balance of the whole building complex is also relevant and can be found in the chapters below. In addition to the heating and cooling demand, the energy demands for artificial lighting, household electricity and the domestic hot water demand are added in order to which the total required site energy can be displayed.

4.4.8 3-unit building, SSW

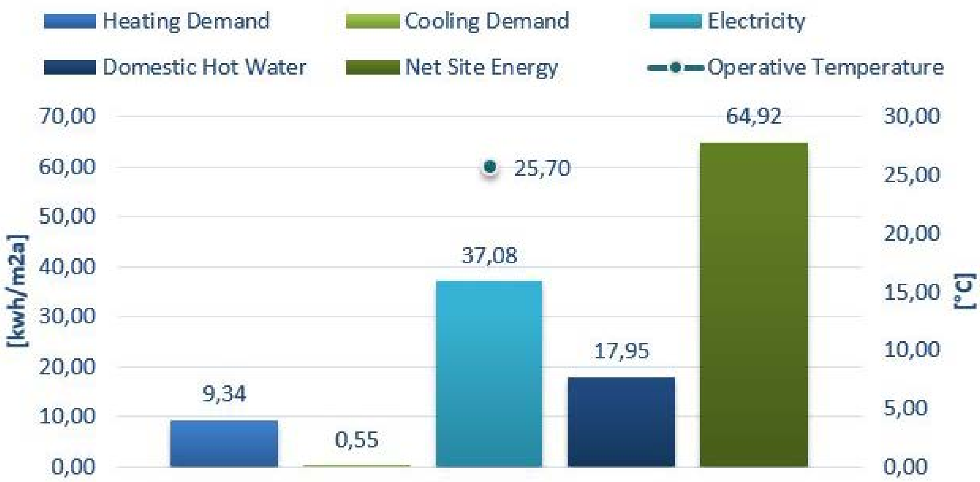


Figure 67, Energy balance of the 3-unit building block towards the South-West

4.4.9 5-unit building, SSE

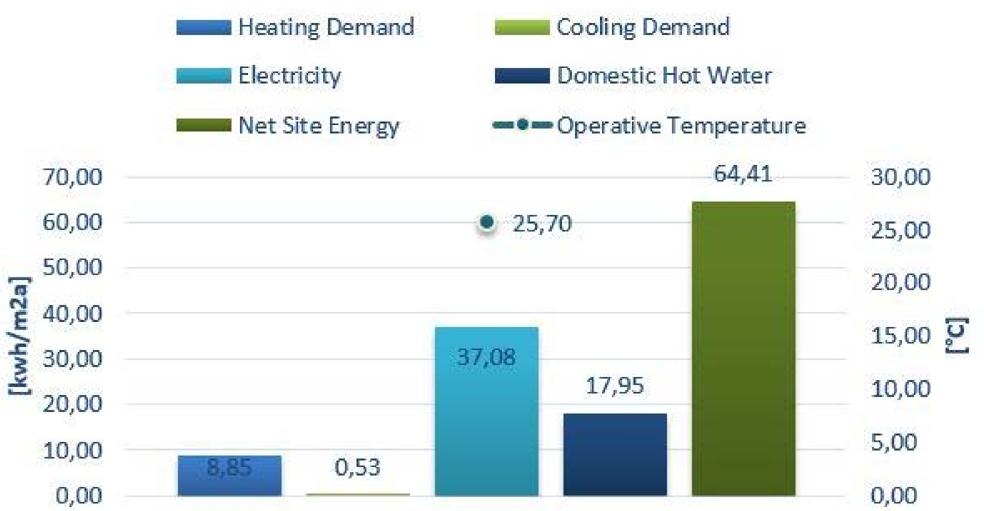


Figure 68, Energy balance of the 5-unit building block towards the South-East

4.5 Thermal bridges

The temperature profiles and surface temperature of identified thermal bridges are as follows:

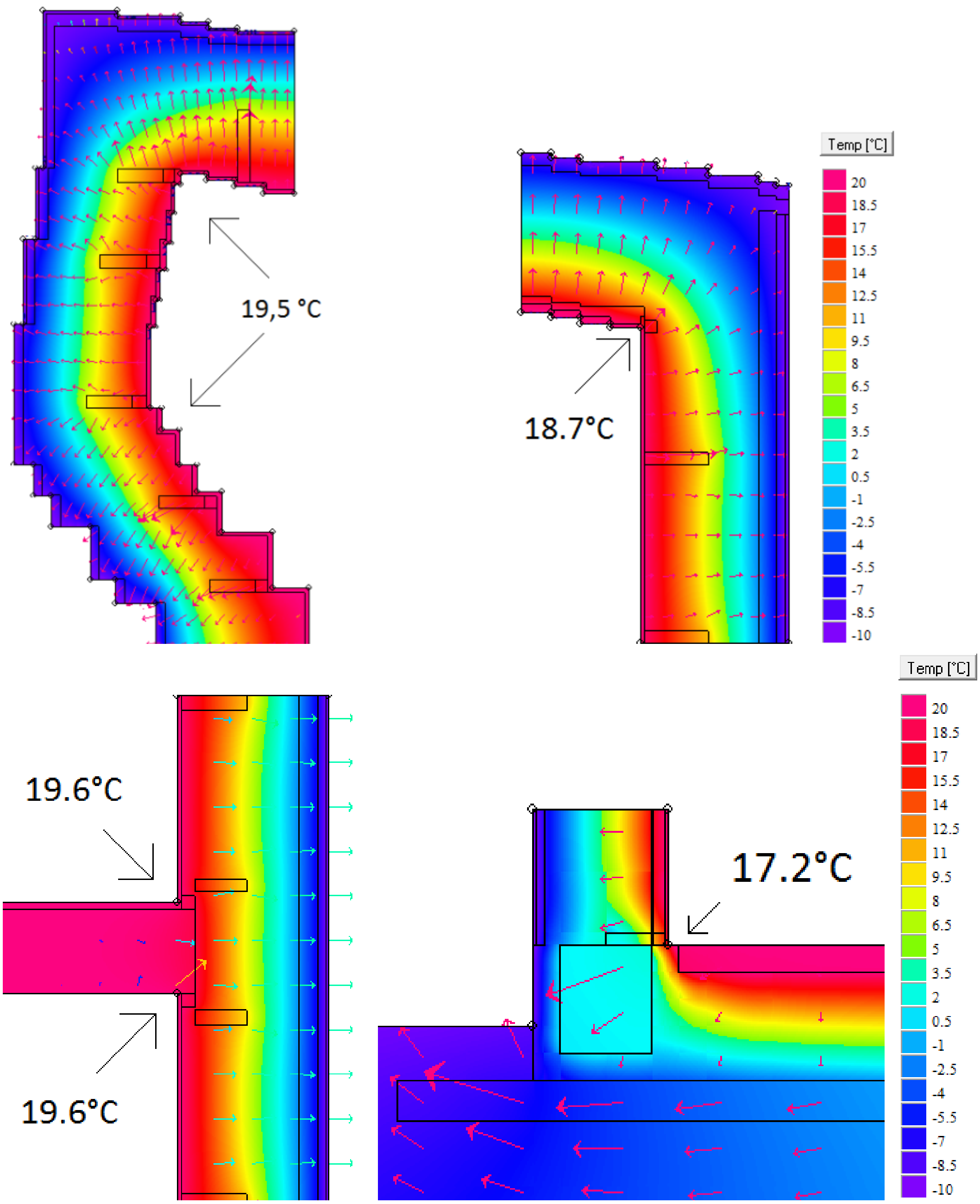


Figure 69, Temperature profiles with minimum interior surface temperature in certain construction "hotspots"; top left: Top corner on the S; top right: top corner on the N; bottom left: junction of ceiling with exterior wall on the N; bottom right: slab

4.6 Water supply and drainage systems

Figure 71 shows the location and connection of the buildings to the necessary water systems. In order to ensure a standardized appliance system for each housing unit in the complex, all the pipes are attached to the northern façade of the buildings.

The freshwater pipe is coupled to an existing junction located towards the SE corner of the site. In order to simplify the construction and maintenance of the pipes, they will follow the pathway of bike/pedestrian paths behind the buildings.

The nearest existing junction for sewage and wastewater disposal is located directly N of the site, where the respective pipes can be connected.

Figure 70, Connection of the passive house complex to the public water grids

The rainwater will be collected both on S and N façade of the buildings (see Figures 54, 56 for gutter details), filtered and stored in an underground cistern located between the building blocks. From the cistern, the water can be distributed to the housing units. In case that the rainwater level reaches a certain minimum due to a drought, the cistern contains a water level control system, which is directly connected to the local freshwater distribution system. A schematic image of the rainwater collection and distribution system can be found in Figure 72.

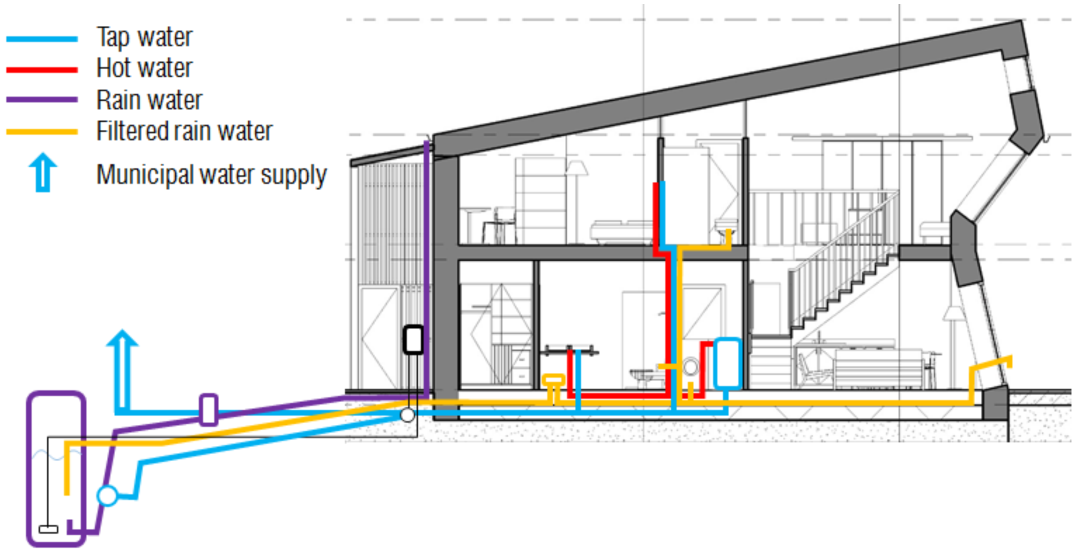


Figure 71, Principle of the rainwater usage and distribution in a unit

4.7 Active potential

Since the European Performance of Buildings Directive (EPBD) by the European government declares that by 2020 all new buildings have to be a nearly zero energy building, it is interesting to also display the active potential of the buildings for implying solar thermal collectors or photovoltaic panels (European Parliament, 2010), even though it is not considered in the original design concept.

The final design of the building with the top windows is not suitable. The best solution for combining active solar systems and daylight utilization is adding skylights over the open staircase.

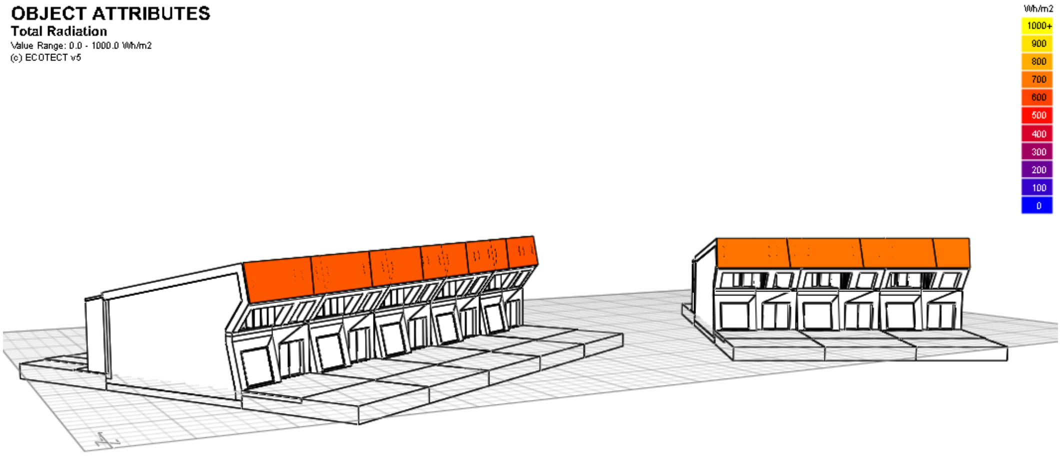


Figure 72, Ecotect solar irradiation analysis for the active potential

Considering the annual energy demand of the building blocks, as well as the geometry and technical properties of a certain PV panel (UHC Solar, 2013), it is possible to calculate the energy balance when PV panels are applied to the building as in Figure 73.

Figure 73, Total energy balance of the passive house complex including the active potential and additional PV needed for reaching NZEB-standard

Figure 74 shows that by replacing the top windows with PV modules, a total amount of 6253 kWh of electrical energy can potentially be produced in a year, which surmounts to roughly 72% of the annual heating demand. In order to reach the standard of a NZEB, an additional surface of 614 m² of PV would be needed.

5 Discussion/conclusion

The somewhat unconventional design of this passive house project has evoked profound and multidisciplinary challenges. The aim of creating a well-justified and informed passive house row house design proved to be architecturally challenging and bringing with it accentuated issues of energy and moisture modelling. A steep learning experience if any.

Initially, it was realised that the climate analysis tools used were not able to handle the terrain elevation of the area, for which the elevations effect of the local climate was eliminated, simplifying the results of the climate analysis.

Architecturally, one of the biggest challenges proved to be combining local climate conformity with maximum passive solar potential and structurally integrated shading. These factors were merged into the form concept by incorporating solar height in summer and winter as main guidelines.

It came to our attention that the consequences of rotating the buildings SSE and SSW, were not fully considered before advancing with the energy and moisture analysis. This, because if the solar height (50 degrees in summer and 11 degrees in winter) was kept as a main guideline, the optimum form of the building would be altered noticeably with a rotation of 30 degrees from due south. If this impact of rotation were to have been considered from the beginning, it would most likely have influenced the design considerably. An analysis of the situation was made retrospectively, enlightening the fact that when the units are grouped together, the rotated form would be exposed to increased moisture risks and thermal bridging, supporting the decision of further developing the original concept.

An initial restriction of the

A factor significantly influencing moisture analysis results attained in WUFI, is the ambiguity of how WUFI accounts for driving rain on an inclined surface. Since driving rain factors automatically change when a surface is sloped, it is clear that the program does take driving rain into consideration, leading to the assumption (and possible misinterpretation) of that no moisture source needs to be added when a surface is sloped. With this assumption applied to WUFI's input data, the moisture conditions of the sloped structures are improved, for which the feasibility of the results can be questioned.

Another improvement to the moisture situation was to move the wooden load bearing structure to the interior, placing the additional insulation layer on the wood studs' exterior side. This interior placement enables a warmer structural layer, reducing the risk of mould growth on the wood studs considerably. However, subsequently placing the windows further into the structure, may cause structural difficulties with respect to the suggested architectural form.

An interesting result which can be observed in the detailed energy performance results of both buildings, is the notable effect of compact building shape as a passive design strategy. For a single unit oriented to the SSW, the results show a clear reduction in heating demand, due to the increased solar gains towards the west. However, when the single units are grouped together, the building's energy demand display an adverse effect, increasing for the three unit building oriented to the SSW, despite increased solar gains.

This comes as a direct result of the passive form factor of the buildings, allowing for the five unit building oriented to the SSE to loose less heat through its envelope, than the three unit building oriented to the SSW. The difference in heating demand of the buildings is marginal, amounting to a 5 % reduction per square meter for the five unit building, however noteworthy to declare. The impact on cooling demand is negligible.

Further, the passive house is warily designed to minimize thermal bridges. Innovative solutions have been suggested to avoid the impact of thermal bridges, with results showing a rather evenly spread temperature profile around the building envelope. However, in order to achieve more accurate results showing the impact of thermal bridges, the numeric impact should be incorporated into the U-value of the envelope. Heat loss through thermal bridges is not considered in DesignBuilder simulations of this project, representing a potential source of error.

Another aspect impacting the results in DesignBuilder, are the operational schedules influencing parameters such as DHW and internal gains of lighting sources and occupancy. In reality, these parameters are strictly connected to functionality and behavioural patterns in a zone or room. In DesignBuilder, however, these parameters are steered by common circulations schedules (per default); implications of which are not acquainted with in this project, leading to questionable accuracy of final results.

In terms of energy performance of the project in general, the passive measures implemented all have a notable effect on the energy demand, proving the fact that a compact, airtight building can be theoretically regulated with precise effect. Besides several results being subject to practical uncertainty, the theoretical outcomes are respectable and have cumulated into results which are much better than initially expected.

Finally, reflecting on the work process of this project, each decision made, throughout the project has been considered, reconsidered and justified by all members of the group, leading to results which each member understands and is able to motivate on his or her own. This too reflects the work ethic of the group as a whole, with ambitious and mutual goals allowing for a well-developed integrated design.

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Appendix

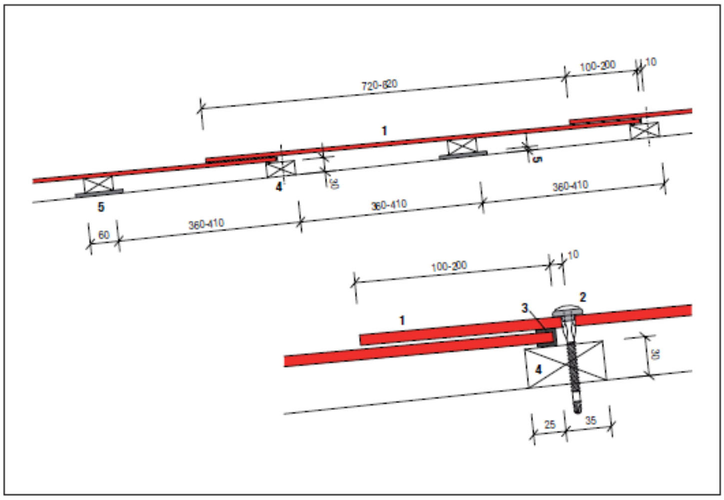
Risk value	Low risk = 1-5	Medium risk = 6-8	Hign risk = 9-11	Extrem risk =12-16

	Ambient factor/		Value 1=low 4=high/critical				Value 1=low 4=high/critical				Value 1=low 4=high/critical		
Nr	Moisture Load	Description of risk	Probability	Consequence	Risk value	Improvments 1	Probability	Consequence	Risk value	Improvments 2	Probability	Consequence	Risk value
1	Driving rain	corrosion of metal anchors	3	2	6	treated galvanized steel	1	2	2				0
		frost, corrosion due to water accumulation in gutters	2	3	6	maintain gutters, sufficient size and inclination (1:200)	1	3	3				0
		leakage into wall structure due to insufficient gutter/ flashing details	3	3	9	craftmanship, large enough gutters, correct placement of gutters&flashing	2	3	6	overhang on the northern facade	1	3	3
	Precipitation	ice formation in eaves	2	3	6	sufficient ventilation in airgap, vapour tight envelope	1	3	3				0
2	Water film, run off	water accumulation in junction wall/ground floor slab	2	3	6	fibre cement board as water repellent facade material	1	3	3	sufficient drainage detail	1	2	2
3	Water splash from ground	water accumulation in junction wall/ground floor slab	2	2	4	efficient detail, suffiecint distance from ground (>300mm) and conscious choice of ground material	1	2	2				0
		degredation of facade material	2	3	6	conscious choice of ground and facade material (fibre cement board)	1	1	1				0
4	Moisture convection	moisture damage in wall	2	3	6	wind barrier (fasadskiva)	1	3	3				0
		moisture damage in roof	2	3	6	wind barrier (fasadskiva)	1	3	3	metal sheet at roof ridge, efficient flashing at gutters to prevent water entering at joints	1	3	3
5	Moisture diffusion	moisture damage in wall	3	3	9	wind barrier (fasadskiva), airgap to inhibit moisture intrusion due to pressure difference	2	3	6	interior load bearing structure, discouraging condensation on studs due to warmer temperature	1	1	1
		moisture damage in roof	3	3	9	wind barrier (fasadskiva), airgap to inhibit moisture intrusion du to pressure difference	2	3	6	"moisture repellent" membrane for rain runoff	1	3	3
6	Construction moisture, concrete	wood stud damage at junction wall/ground floor slab	2	3	6	sufficient drying out period efficient sealant detail	1	2	2				0
7	Construction moisture, wood	wall: mould growth on wood studs	3	3	9	control of initial conditions and sufficient drying out period	2	3	6				0
		roof: mould growth on wood studs	3	3	9	control of initial conditions and sufficient drying out period	2	3	6	"diffusion open" membrane to allow for construction moisture in roof to dry out	1	1	1
		structure movements and deformation	1	3	3	type of wood used (ie tangential, radial or longitudinal)	1	3	3				0
8	Leakage from appliances and building services	moisture damage	2	3	6	installation layer in front of moisture barrier, careful installation procedure	1	3	3	moisture safe precautions in wetrooms	1	2	2
9	Leakage through windows and doors	momisture damage in junction	2	3	6	detail in window to wall fastening, folded insulation sealant	1	2	2				0
10	Material logistics	high initial moisture load in materials	3	2	6	allow for sufficient drying out period	1	2	2	moisture safe building procedure	1	1	1
12	Roof construction and junction	Winter night time radiation causing condensation within the structure	2	3	6	Apply EPS outside the air gap (detail)	1	3	3				0

Planung **I Einteilung**

Dachsystem INTEGRAL PLAN

Modul XM 2500×920 mm



1 Dachplatte INTEGRAL PLAN
2 INTEGRAL PLAN-Schraube SCFW-S-BAZ 3 6.5×77 mm
3 Aufsteckprofil L 2320 mm
4 Dachlattung 30×60 mm
5 Zwischenlatten 30×60 mm mit Schiftunterlage 5 mm