A Design Approach towards Energy Efficient Building in case of KAMD!

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ACKNOWLEDGEMENT

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A heartfelt gratitude to my brother Teddy, for his unconditional support throughout this journey and beyond, my partner for always believing in me and his unwavering support, and my two little girls who continued to be my strength, without you all I might not have executed this.

I also thank all my family and friends for encouraging my academic performance and playing a role!

Glory To God!

SUMMARY

Due to the steady growth of population in urban cities, we tend to keep building and densify our built environment as never seen before. As this remains true and only continues to accelerate, it is imperative to act more responsibly and vigorously toward minimizing the greenhouse gas emissions (GHG) that the construction sector shares.

Being a major contributor, the construction sector, involves a massive account of 39% of all the carbon emissions according to the green building Council. This comprises so many detailed inquiries amongst all the processes of manufacturing, transportation, engineering, constructing, and the end-user process could be mentioned.

This thesis will design a campus building and approach a holistic manner through the process of minimizing greenhouse gas emissions. Various design and simulation tools have been implemented along the way to notify, optimize, and maximize on-site renewable energy generation and increase the energy efficiency of the building.

Table of Contents

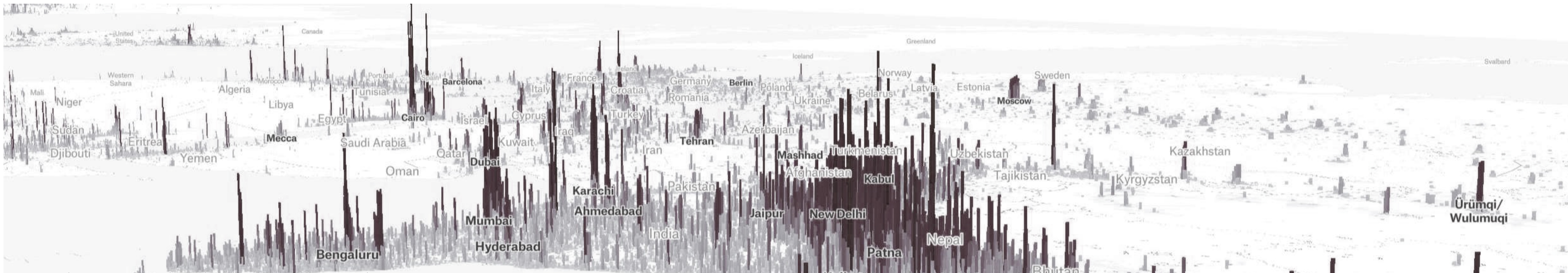
INTRODUCTION

MOTIVATION

The greenest building is the one that is already built and retrofitting of existing buildings is critical to prevent building-related emissions from rising. However, this doesn't hold always true for a world that has an exponentially population growth rate of around 1.05% per annum. That is approximately 81 million inhabitant per year according to (worldometer, 2022). For this reason, cities of the world are developing drastically, and such development has its climatic challenges. The new buildings are constructed from carbon-intensive materials produced on an industrial scale. Heavy machinery that consumes fuel is used on construction sites and all the possible reasons that is causing the environmental impact attributes mostly to the evolving construction sector around the world.

A report from the World Green Building council (2021) shows the building and construction sector account a massive 39% of all carbon emissions in the world. 28% being related to building operational carbon footprint and 11% from the embodied carbon which is the energy used for producing this building material.

Though, there has been positive indicators of a decreasing GHG emission trend of 29% over the period of 2005-2019. In Europe alone the building sector is a key contributor to GHG emissions which accounts nearly one third of EU'S energy related emissions (Envi-ronment E., 2021). The decarbonization strategies in the member states is key for the improvement and yet needs to accelerate strongly to meet the overall 2030 GHG emissions target. Meaning to reach the overall EU objective of 55% emission reduction, the building sector would need to cut its own emissions with 60% by 2030.



Population growth visualization https://pudding.cool/

STATE OF THE ART

When it comes to Norway, being one of the member states of EU; the country is determined to realize a considerable reduction in its emissions. For this reason, the countries research center ZEB (Zero Emission Buildings) and ZEN (Zero Emission Neighborhood) comes forefront in establishing a set of concepts and strategies to help achieve the country's goal towards an environment-friendly construction sector.

Established in 2009 the Norwegian ZEB research activities lay on to developing competitive products and solutions. This will lead buildings with zero greenhouse gas emissions related to their production, operation, and demolition (Dokka, 2013). A ZEB building is a building which offsets the carbon footprint of the building in a life cycle perspective by producing and exporting of renewable energy. The center defined five ambition levels (Fig-1) which can be described as from ambitious but yet most attainable of ZEB O-EQ to the what seem difficult and the most ambitious ZEB-COME.

The ZEN concept of zero emissions builds on the work from the research center ZEB and expands the scope from carbon footprint to a total of seven assessment criteria (FMEZEN, 2018) (Fig-2). A ZEN neighborhood aims to contribute to a low carbon society by accounting both the direct and indirect emission towards zero over the analysis period (FMEZEN, 2021). The center outlined key performance indicator (ZEN KPI) to help practitioners document through the process of achieving a zero-emission neighborhood. With this tool, one can identify which building resulted in higher GHG emissions in an early phase to help target improvements in implementation and operational phases (Wiik, 2019).

The city of Trondheim is known mainly for being the educational and technological center of Norway. And it is going under a massive future urban transformation in terms of Zero-Energy Neighborhoods (ZEN). One of the pilot projects being Knowledge Axis it will work to facilitate the various NTNU's educational buildings in connection with the city. This pilot projects focuses on ZEN criteria of GHG emission, Energy, Power, Mobility, Economy, Spatial qualities, Innovation and work in an interconnective way with each other.

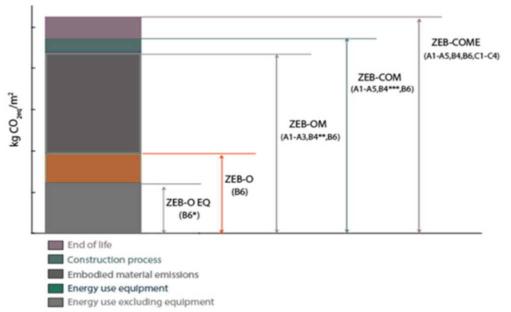


Fig-1

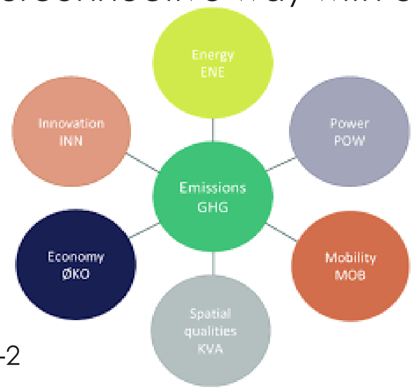


Fig-2

- Illustration from KAMD-NTNU official web page

GOALS AND SCOPE DEFINITION

Besides being under the zero-emission neighborhood program, NTNU's future development goals clarifies gathering around Gloshaugen to realize a unified estate and promote city-campus relation. Out of the total future development a high share of 70% is going to be new construction and the remaining 30% renovation of existing buildings. The University will later have an infrastructure that strengthens interdisciplinarity and provides good conditions for extracting synergies.

The project site for KAMD is proposed around Høgskolebakken in the area that extends from student samfudent building towards Gloshaugen. Kunst Architec-ture Music and Design (KAMD) is ideally situated in this area where it best fit to help realize the city-campus relationship in the future. The entire KAMD proposal covers a total area of 29100m2. This thesis project is proposed in a plot area of 2500m2 inside the KAMD zone. The proposed campus building comprises a total of five floor and covers heated gross internal area (BRA) of 8900m2.

In this thesis project a holistic approach of Integrated Design Process (IDP) will be applied to inform the design from early on stage to get the best building performance in terms of lowering GHG emissions from its operational use. As per the assessment criteria and key performance indicators of energy efficiency in buildings the result will be documented by simulations and calculations. The project is set out to have an environmental goal of ZEB-O which relates to emis-sions from all operational energy 'O' and equipment shall be compensated from the onsite renewable energy generation according to the description of ZEB ambition levels to NS-EN 15978:2011.

REQUIRMENT
5 FLOORS ABOVE GROUND
MAXIMUM HEIGHT SET TO 20M
8900 M2 BRA

DEPARTMENT
ARCHITECTURE
ART
DESIGN

PROGRAM INCLUDES:
Drawing room (studios)
Lecture halls
Library
Reading rooms
Hub
Exhibition/gallery spaces
Workshops (wood, model)
Laboratories (Computer, Climate, Light)
Cafeteria/Canteen
Offices

ENVIRONMENTAL SUSTAINABIITY

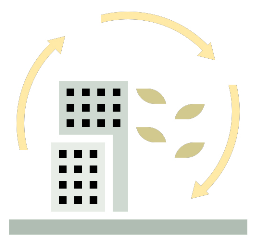
Compactness

Passive Design Methodologies

Consideration Of Low Embodied Material Choice

Reduce Heat Loss and Cooling Demand

ARCHITECTURAL QUALITY



Thermal Comfort

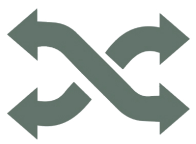
Quality Of View Interaction

Daylight Quality

Aesthetically Compliment Neighborhood

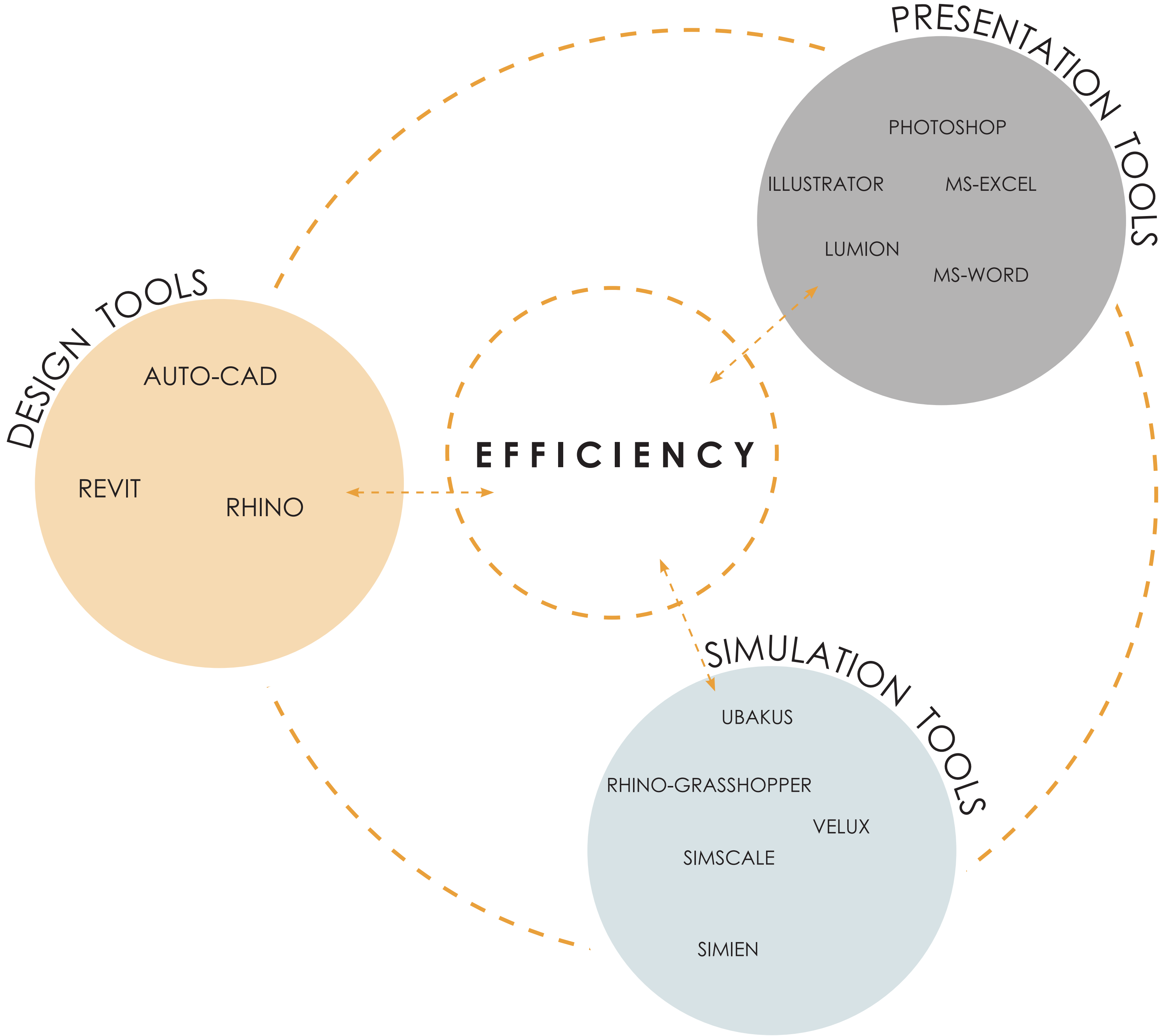
Attractive Spaces

FLEXIBILITY

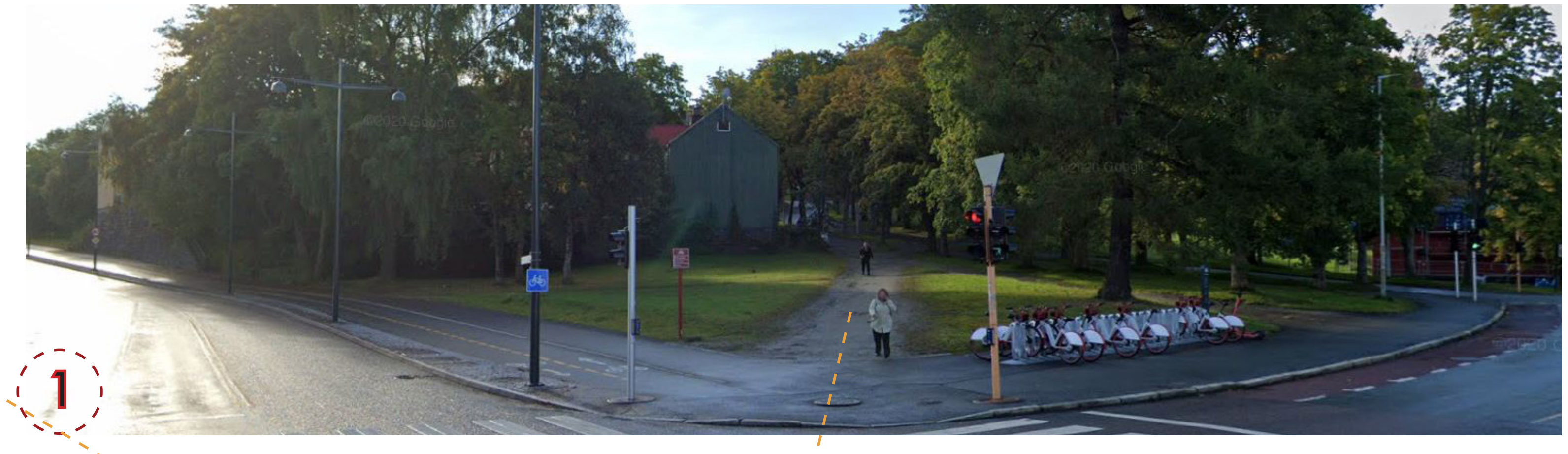


Adoptable Design To Future Changes

METHODOLOGY



PRELIMENARY ANALYSIS



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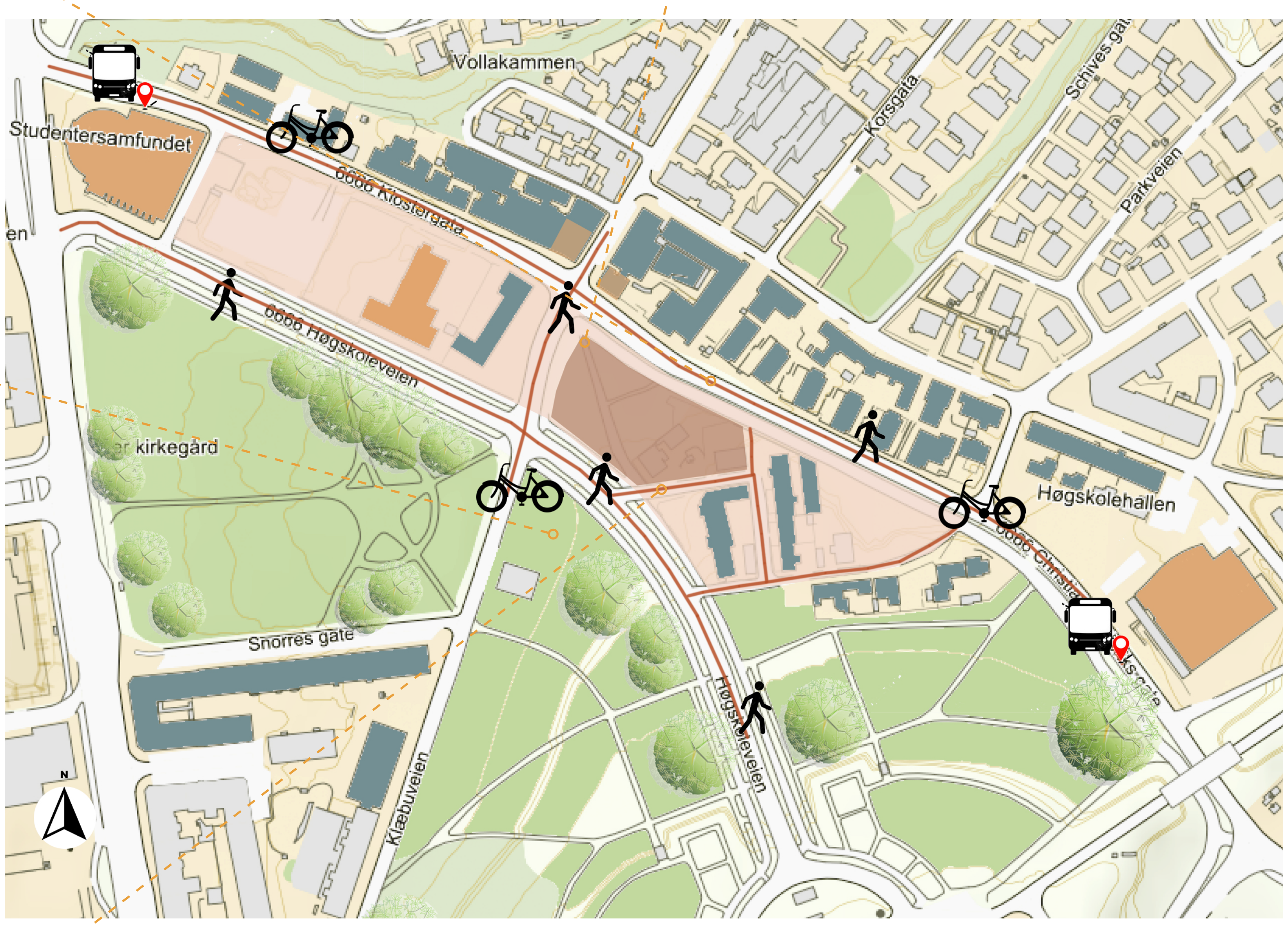


URBAN CONTEXT

The site location is surrounded with park areas in the south and mostly residential buildings in the north side. The adjacent buildings height varies between 2 to 3 story. The plot has a level difference of 3.5m from South to North and approximately 8m difference from East to West direction.

The site is accessible from all four directions three being primary roads with car access. All adjacent roads are incorporated with both bicycle lanes and pedestrian roads. Two Public bus stops near the site gives good connectivity to and from the city center making mobility easy for the users.

LEGEND

- SITE
- RESIDENCE
- SERVICE
- KAMD AREA

CLIMATE

Climate responsive architecture has been practiced and yet has gotten special attention to mitigate the changing and often unpredictable weather patterns. While reducing the carbon footprint of our architecture, a great focus should be given to climate informative design to play an important role. (Andrzej zarzycki, 2019)

As previously mentioned, the location of the project is set to be in Trondheim. The climate type is dominated by the winter season, a long cold period with short, clear days and has less precipitation and low humidity. According to Koppen climate classification subtype this climate is Continental subarctic climate (Dfc) with average annual temperature of 4.8^{0}c. Fig-3 illustrates the annual temperature range in Trondheim is between -15^{0}c to 10^{0}c in winter times and 25^{0}c to 7^{0}c during summer.

In this project the climate analysis is carried out with the help of ladybug grasshopper, which is a parametric interface for Rhinoceros. This tool help visualize the basic input climatic data in a clear and informative way to implement the useful strategies to the design. In order to assess and implement passive strategies, the psychometric chart has been evaluated. As can be seen in (Fig-4) most of the time during the year the comfort zone falls short way below. However, by using passive strategy measures like surface solar heat gain, internal heat gain and sun shading, improvements can be done. As a result the temperature and humidity conditions increase the comfort hours to 41.7% annually (Fig-5). Moreover, active design strategies like heating and humidification should be implemented to significantly increase the thermal comfort hours in this climate.

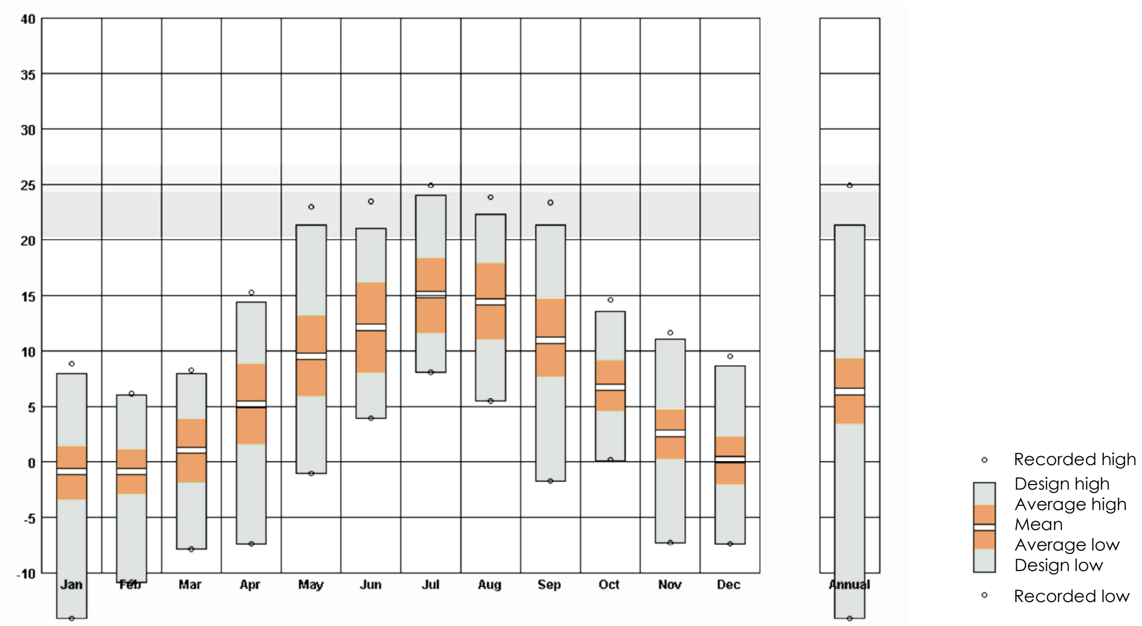


Fig- 3- Temprature Range(Trondheim voll) weather data

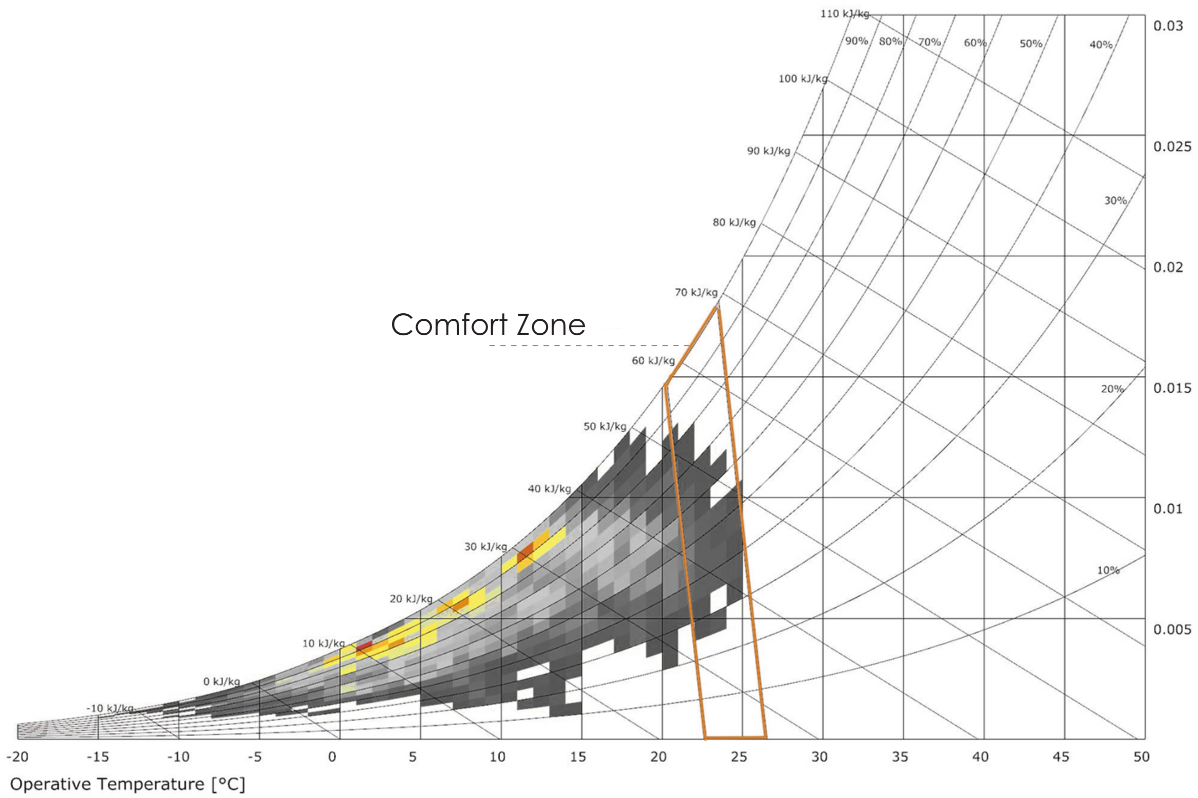


Fig-4- Psychrometric chart(Trondheim-voll weather data)

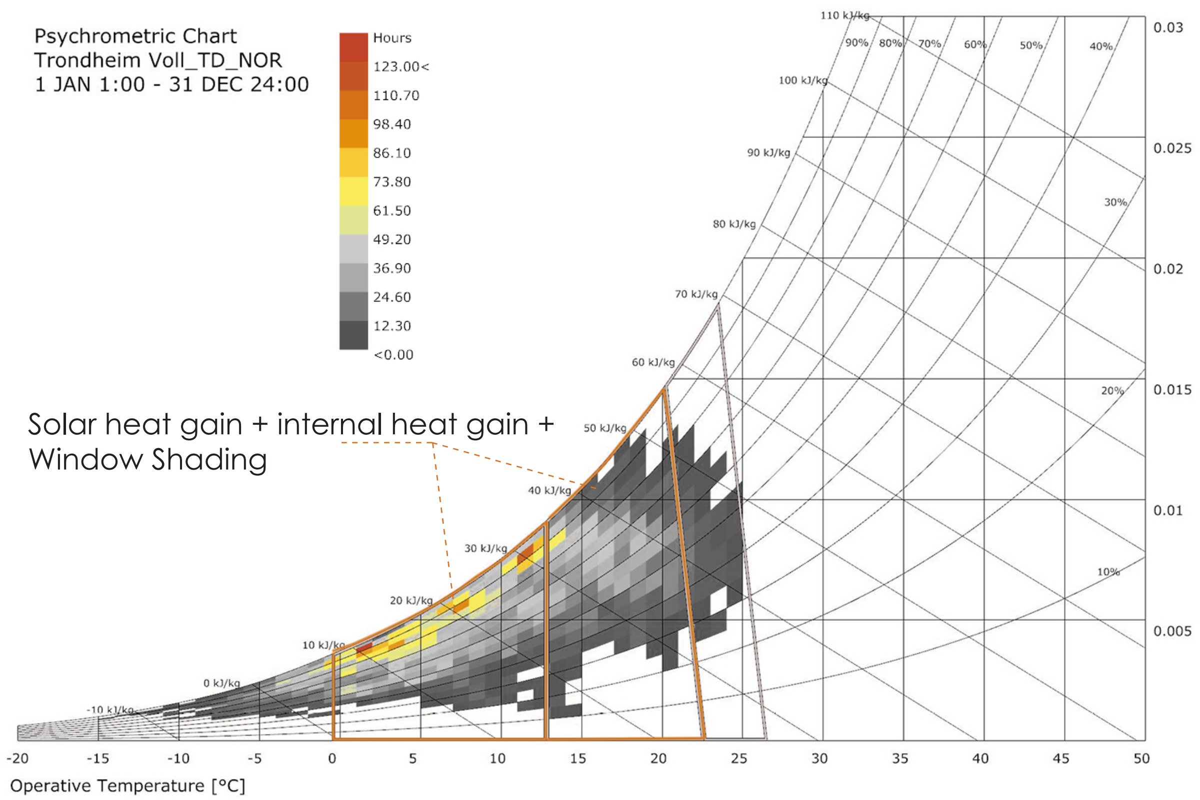
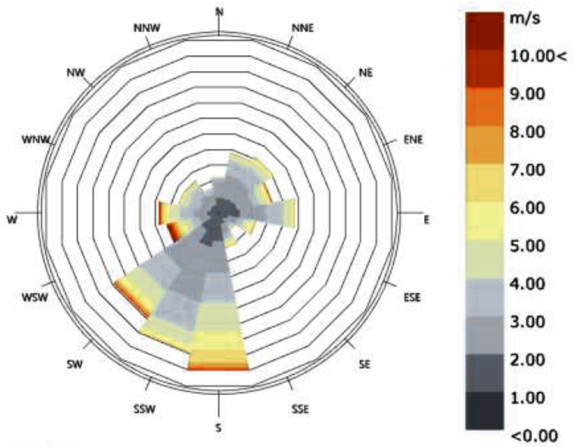


Fig-5- Psychrometric chart with Passive strategies(Trondheim-voll weather data)

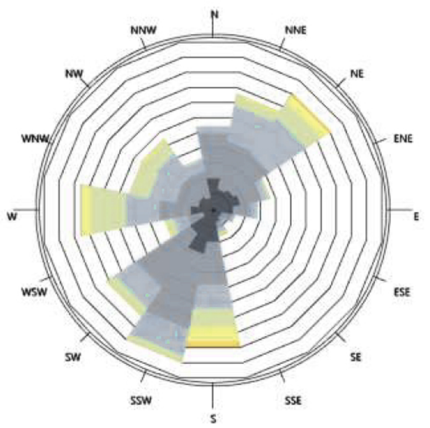
WIND AND SOLAR

As can be seen from the annual wind rose diagram at the left top corner here most strong wind speed correspond towards south and southwest direction. The prevailing wind during summer time with an average frequency of 6m/s blows mostly from South, Southwest, and northeast directions. This could be utilized as passive cooling strategy to help decrease the cooling demand during the overheating periods. Meanwhile harsh wind with average frequency of 10m/s blows during winter times mostly from south-west direction. The adjacent site towards this direction functions as a park area and it is surrounded with large trees and shrubs. This could strategically act as a buffer zone to undesired winds during the winter times.

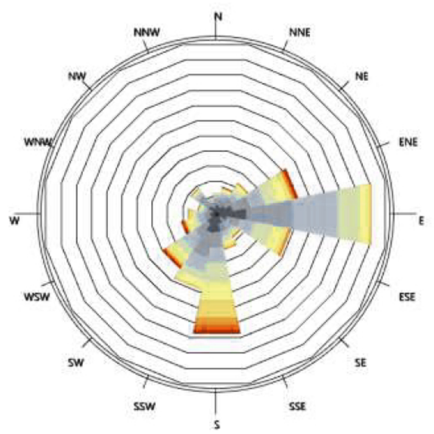
From the sun path diagram Fig-6, it can be understood the solar angles are too low in this climate. Therefore, the solar radiation study will help analyzing the surface solar heat gain that can be utilized with the proposed building. In the total radiation diagram to the right top, the total annual radiation for Trondheim is illustrated and can be seen a maximum radiation value as 800kwh/m2 is positioned to the south direction. The low radiation as 150kwh/m2 is corresponded to the northeast and northwest directions.



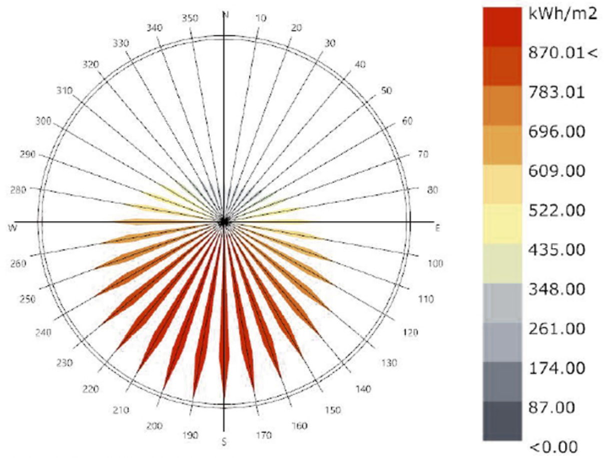
Wind-Rose
Trondheim Voll_TD_NOR
1 JAN 1:00 - 31 DEC 24:00
Hourly Data: Wind Speed (m/s)
Calm for 1.62% of the time = 142 hours.
Each closed polyline shows frequency of 1.5%. = 133 hours.



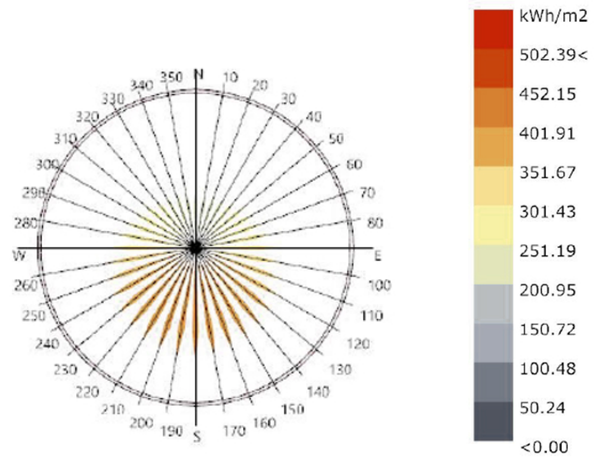
Wind-Rose
Trondheim Voll_TD_NOR
1 JUN 1:00 - 31 AUG 24:00
Hourly Data: Wind Speed (m/s)
Calm for 2.26% of the time = 50 hours.
Each closed polyline shows frequency of 1.1%. = 25 hours.



Wind-Rose
Trondheim Voll_TD_NOR
1 DEC 1:00 - 28 FEB 24:00
Hourly Data: Wind Speed (m/s)
Calm for 4.26% of the time = 92 hours.
Each closed polyline shows frequency of 1.8%. = 38 hours.



Total Radiation(kWh/m2)
Trondheim_Voll_TD_NOR_2007
1 JAN 1:00 - 31 DEC 24:00



Diffuse Radiation(kWh/m2)
Trondheim_Voll_TD_NOR_2007
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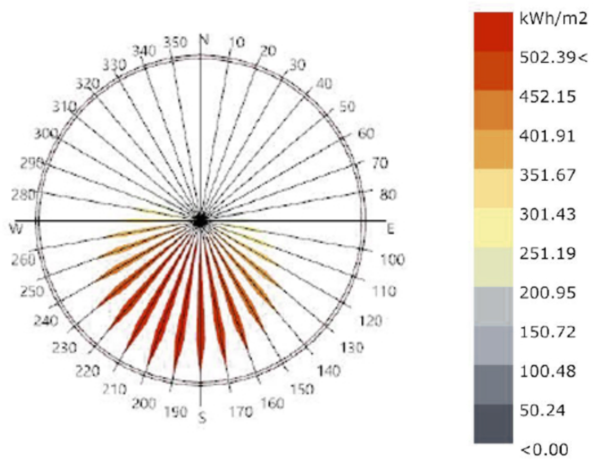

Direct Radiation(kWh/m2)
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1 JAN 1:00 - 31 DEC 24:00

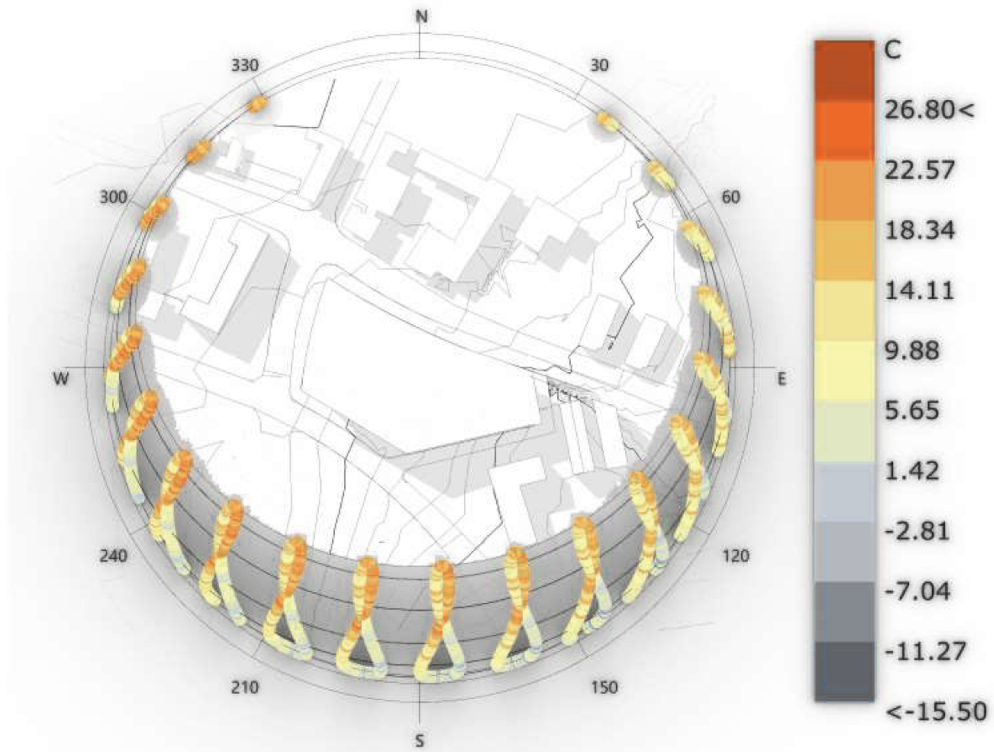
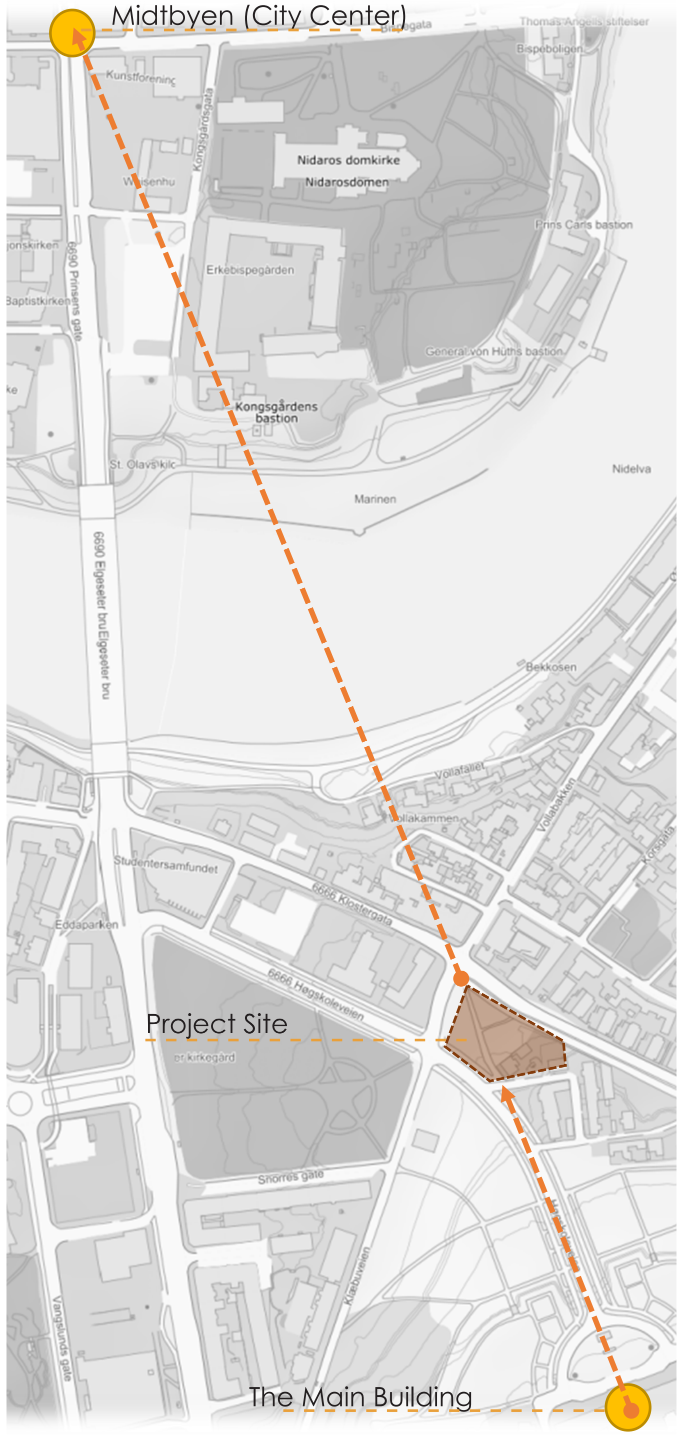


Fig-6- Solar Path (Trondheim Voll weather data)

Hovedbygningen - The Main Building(Campus NTNU Gloshaugen)

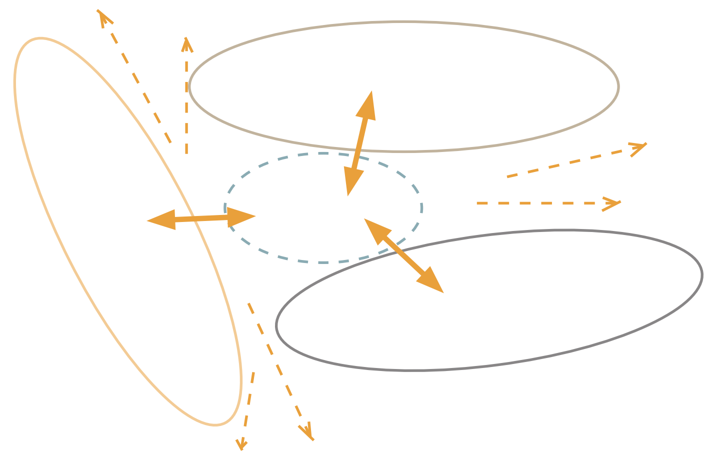
Line of sight connection



CONCEPT DEVELOPMENT

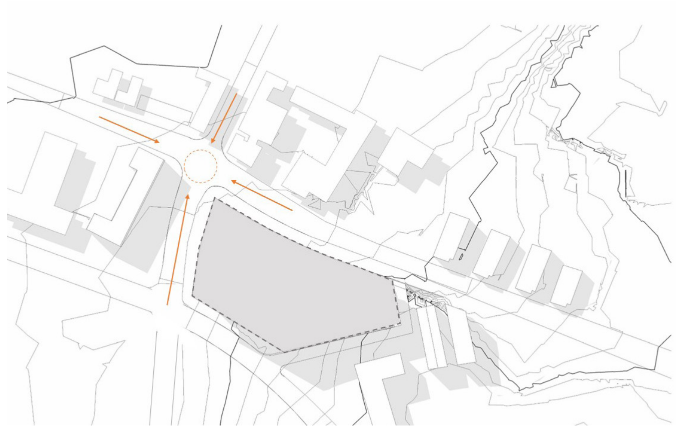
The main building (Hovedbygningen)at campus NTNU Gloshaugen sits predominantly high in the skyline of Trondheim. The line of sight from the main building to the city center has always shared an important part in Trondheim's history. For this reason, this new campus building height is set to a maximum of twenty meters high which is approximately five floors by the city administration. Hence maximum utilization of the plot area was mandatory to accommodate the campus program. Besides thinking of a compact shape which can help realize the environmental aspect and functional character of the building program, having an interaction with the city was given emphasis.

This line of the axis that defines the building was chosen with two main factors; one being hypothetical, the line-of-sight connection between the main building and the city, and the other is the informal pedestrian shortcut path that goes through the site towards the campus. These two lines together allocate the building into two main zones and create the bold definition that connects inside out.

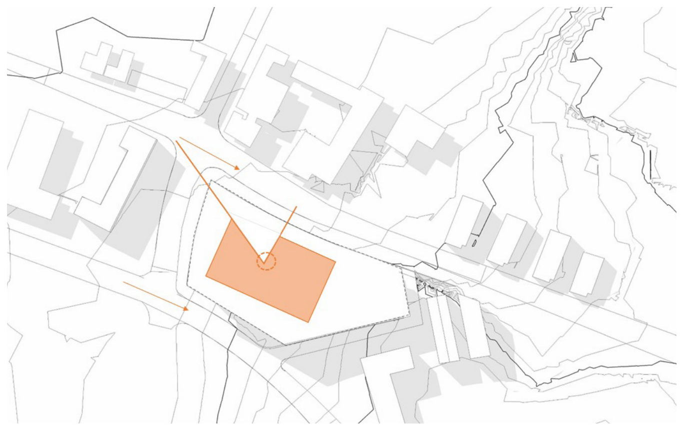


Inside out - Synergies - Zones

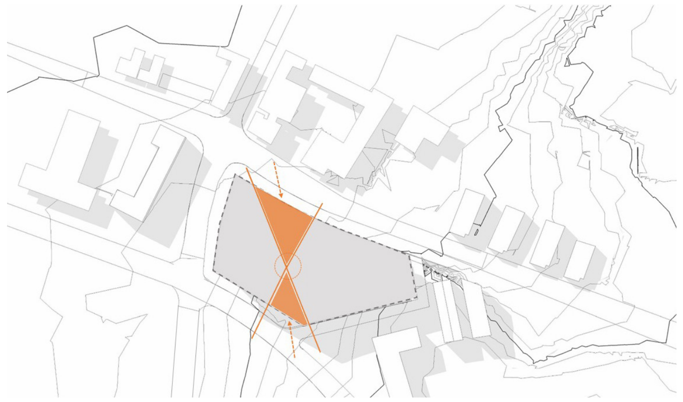
Main focal point



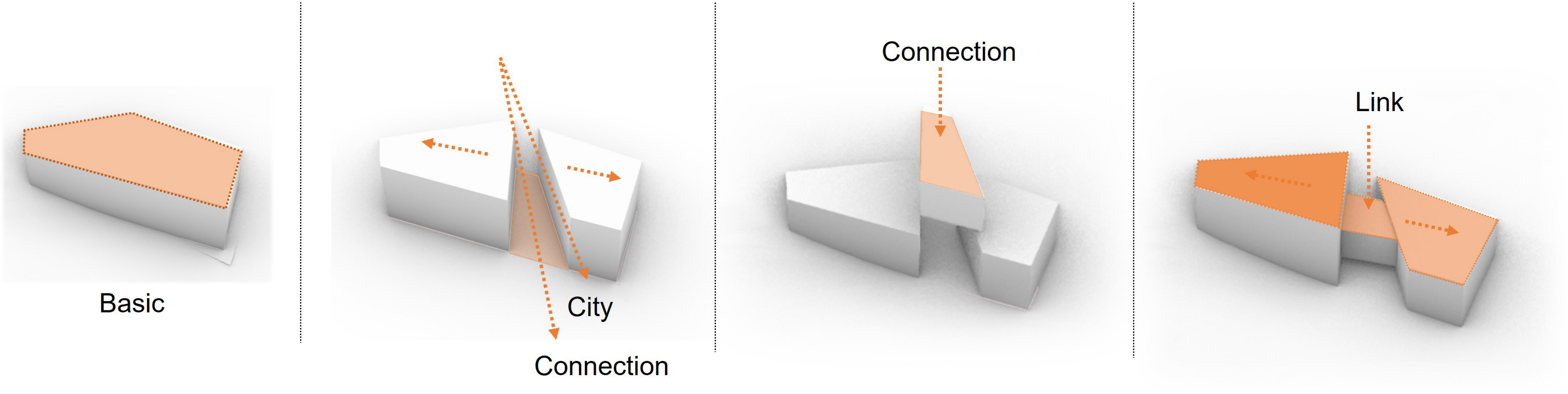
Access



Corridor



FORM DEVELOPMENT



CLIMATIC DESIGN

FORM AND CLIMATE (Solar)

The parametric Ladybug tool, a plugin for Rhino grasshopper is used in this analysis. It was performed to better understand the solar relation with the preliminary form of the building. It assists to evaluate the solar access, how the form is affecting the neighboring buildings and how these adjacent buildings affecting it. Furthermore, this analysis gives a preliminary data of how much radiation is the facades receiving. Furthermore, it differentiates which surfaces can perform best in terms of energy production from in-stalling Building integrated photovoltaics. As a result, the dotted line in Fig-7 interprets the one that receives more radiation than 500kwh per year. Hence the roof area has a high potential and nearly half of the south area is shaded as it is partly under the soil and from the building's shade adjacent to it. The southwest facade on the other hand has a better potential in terms of energy production from building integrated PV facades.

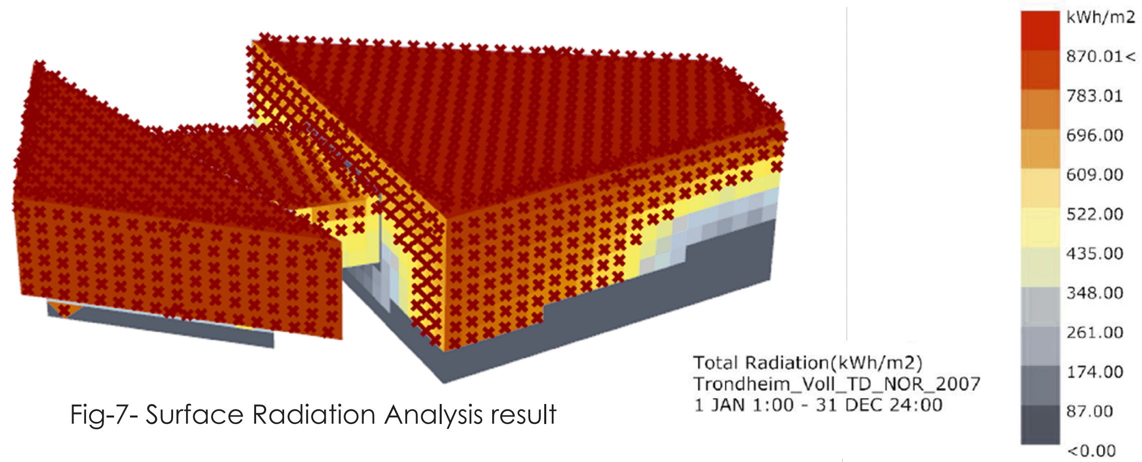


Fig-7- Surface Radiation Analysis result

Fig-8 shows the neighboring buildings solar access and radiation received before the building was placed and fig-9 illustrates after the generic form of the building is optimized and plotted on the site. Fig-10 illustrates the illuminance inside the building with 70% glazing ratio. From this It can be seen even though the window-wall ratio kept as 70% the middle part of the building falls short below the standard. And with this ratio the outer part of the building could have glare issues as well therefore, further study should be implemented. Meanwhile the preliminary daylight study also helps visualize that a roof opening could potentially be used as a daylight strategy to help improve the daylight penetration in the middle part of the building. The planning phase also uses this analysis while designing room arrangements. zoning spaces that do not require more light could be located in the darkest zone, such as the circulation shaft, technical rooms, stores, workshops and others.

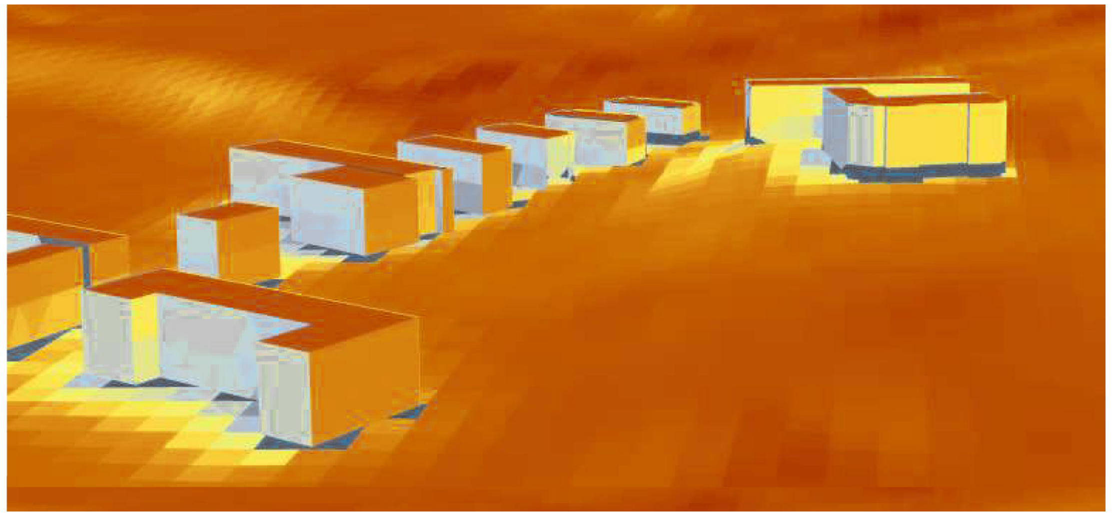


Fig-8- Site Surface Radiation Analysis result (Before)

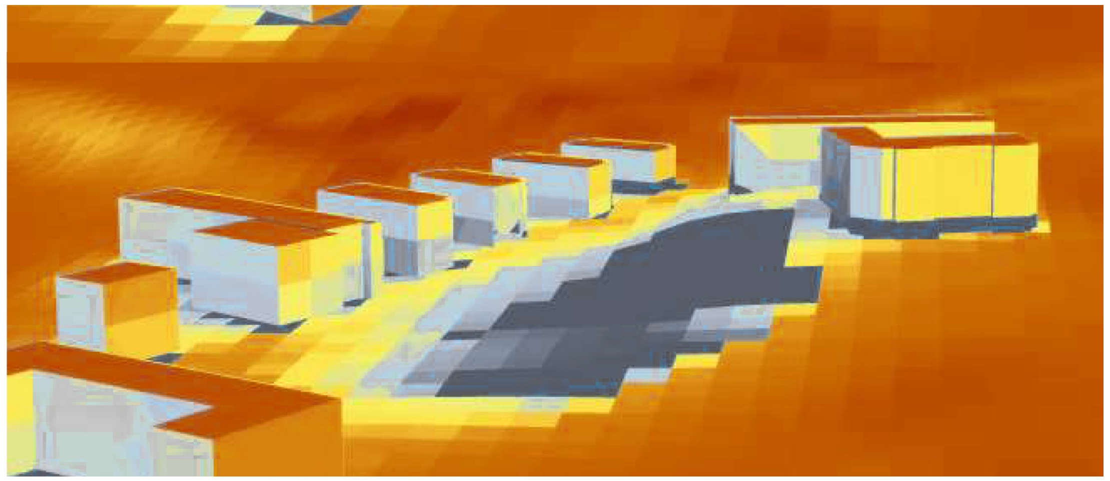
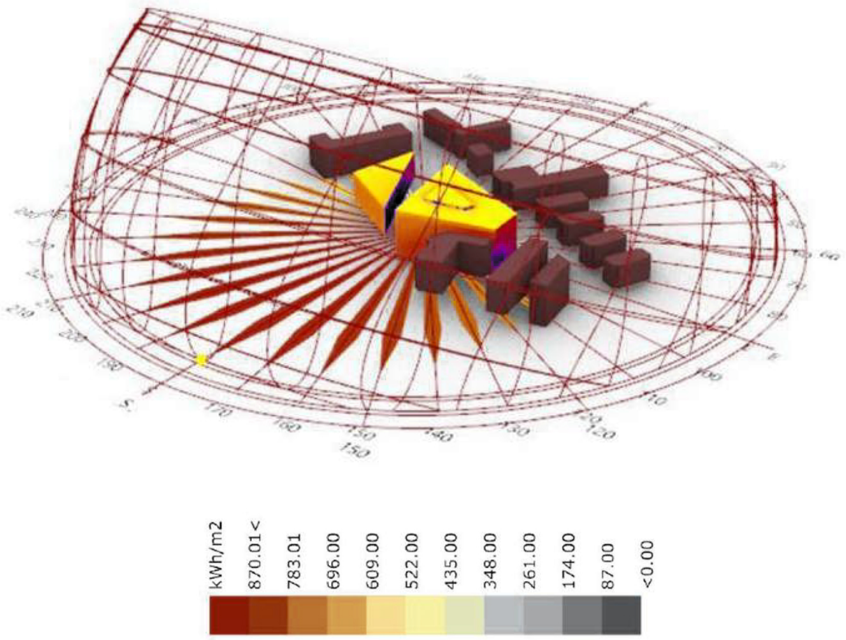


Fig-9- Site Surface Radiation Analysis result (After)



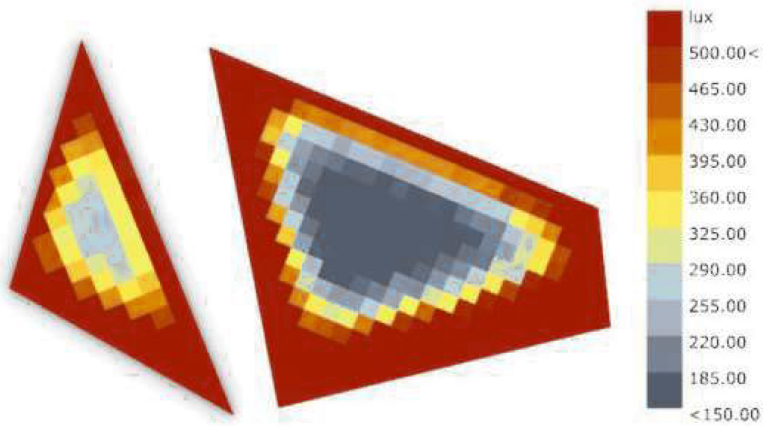


Fig-10 Day Light Access (70% glazing ratio)

FORM AND CLIMATE (Wind flow)

A cloud computing engineering software called SimScale was used to further analyze the wind flow in the building site. Fig-11 shows the air ve-locity distribution in the study area. The col-ors represent the level of wind speed where as close to dark blue interpreted as the lower the wind speed followed by the yellow-green when closer to Red the wind speed is getting higher.

From the result it was understood that the space that was created be-tween the two blocks might have unfavored wind flow with wind velocity higher than4.5m/s specially during the winter seasons. The volume that was designed between the blocks was aim-ing to enhance the connec-tion at the higher levels while leaving the lower level open to public access. It however resulted to be very shallow with high wind pressure most of the time. Therefore, in order to make the space more habitable it was later decided to enclose this area and create an indoor space that could benefit the occupants all year round.

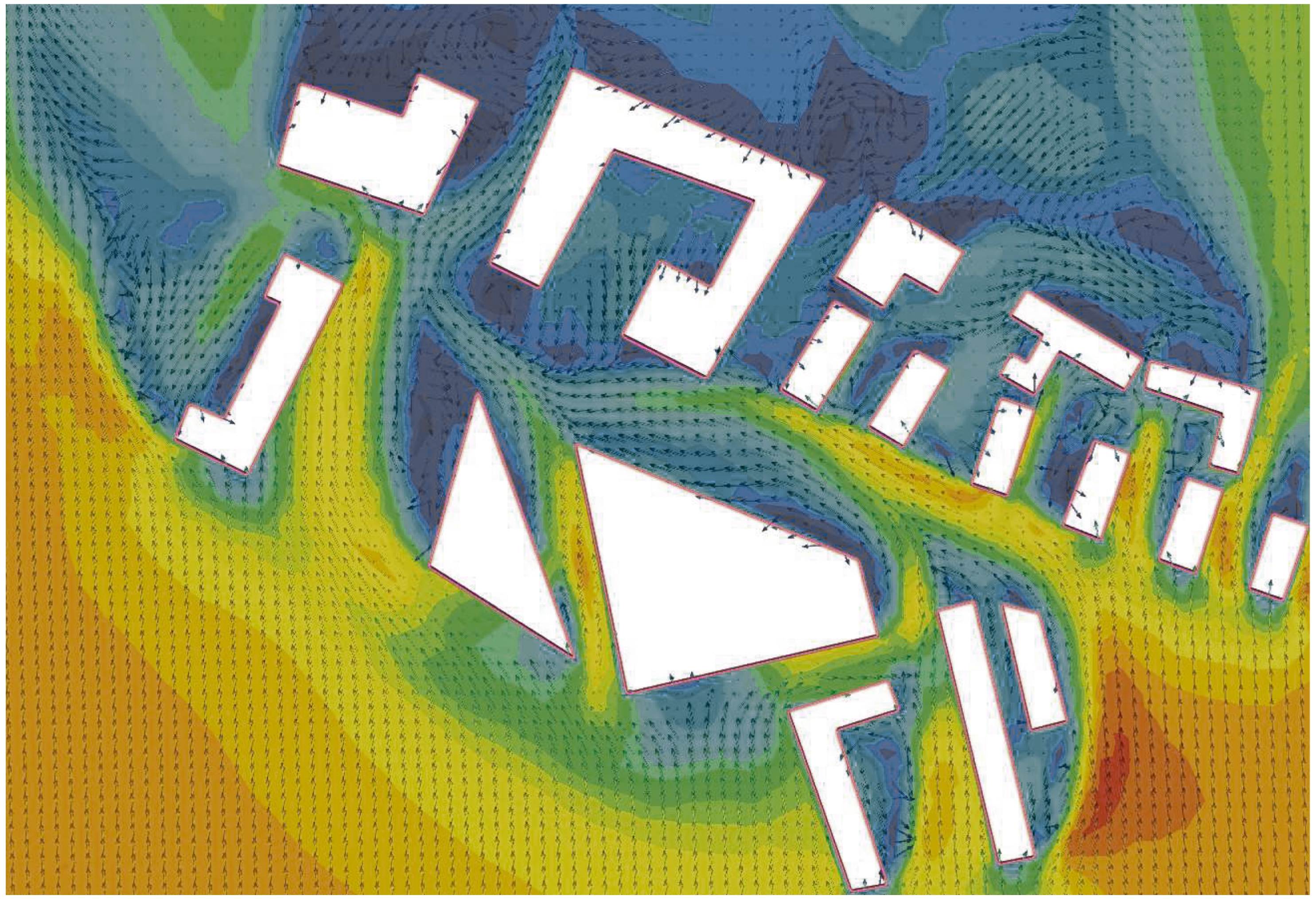
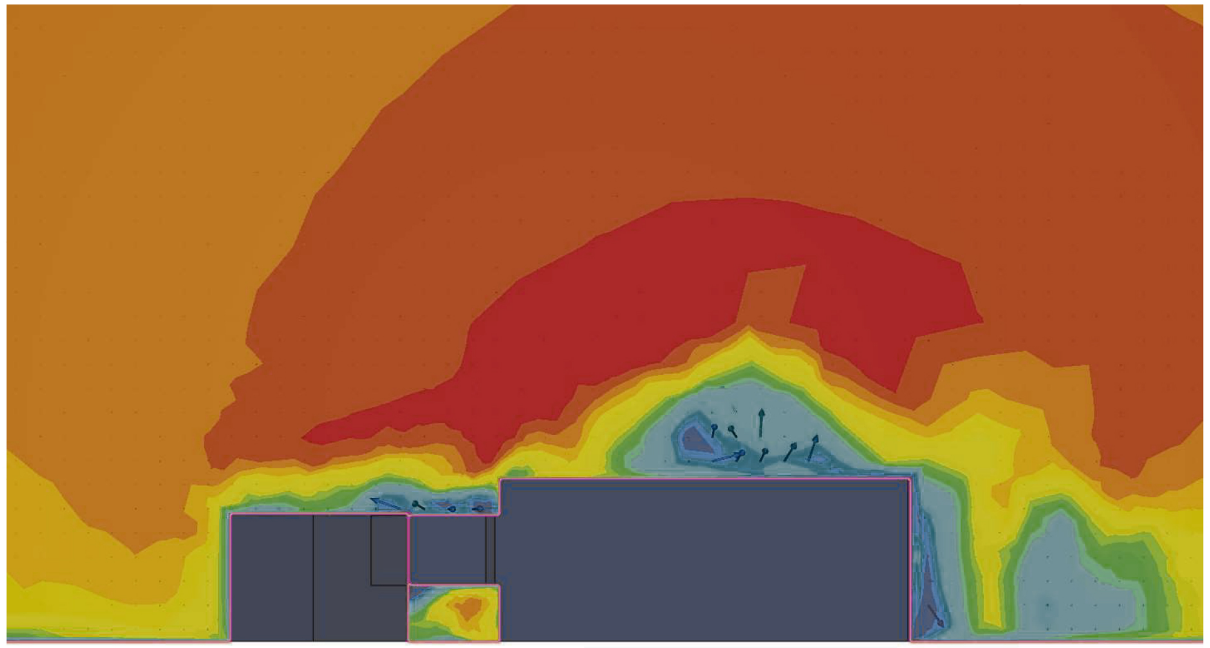
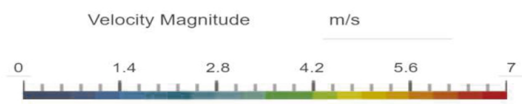
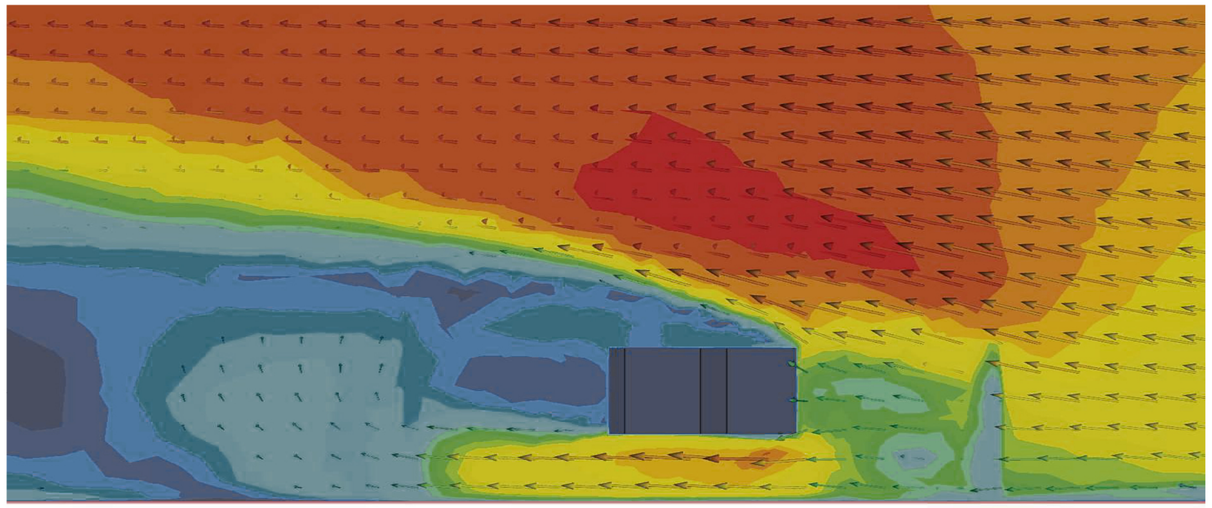


Fig-11- Site Surface Radiation Analysis result (After)

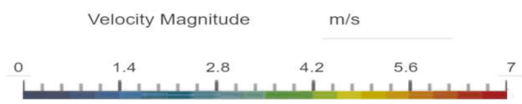


Wind pressure illustration under the bridge.





Wind pressure illustration under the bridge.



SPATIAL ARRANGEMENT

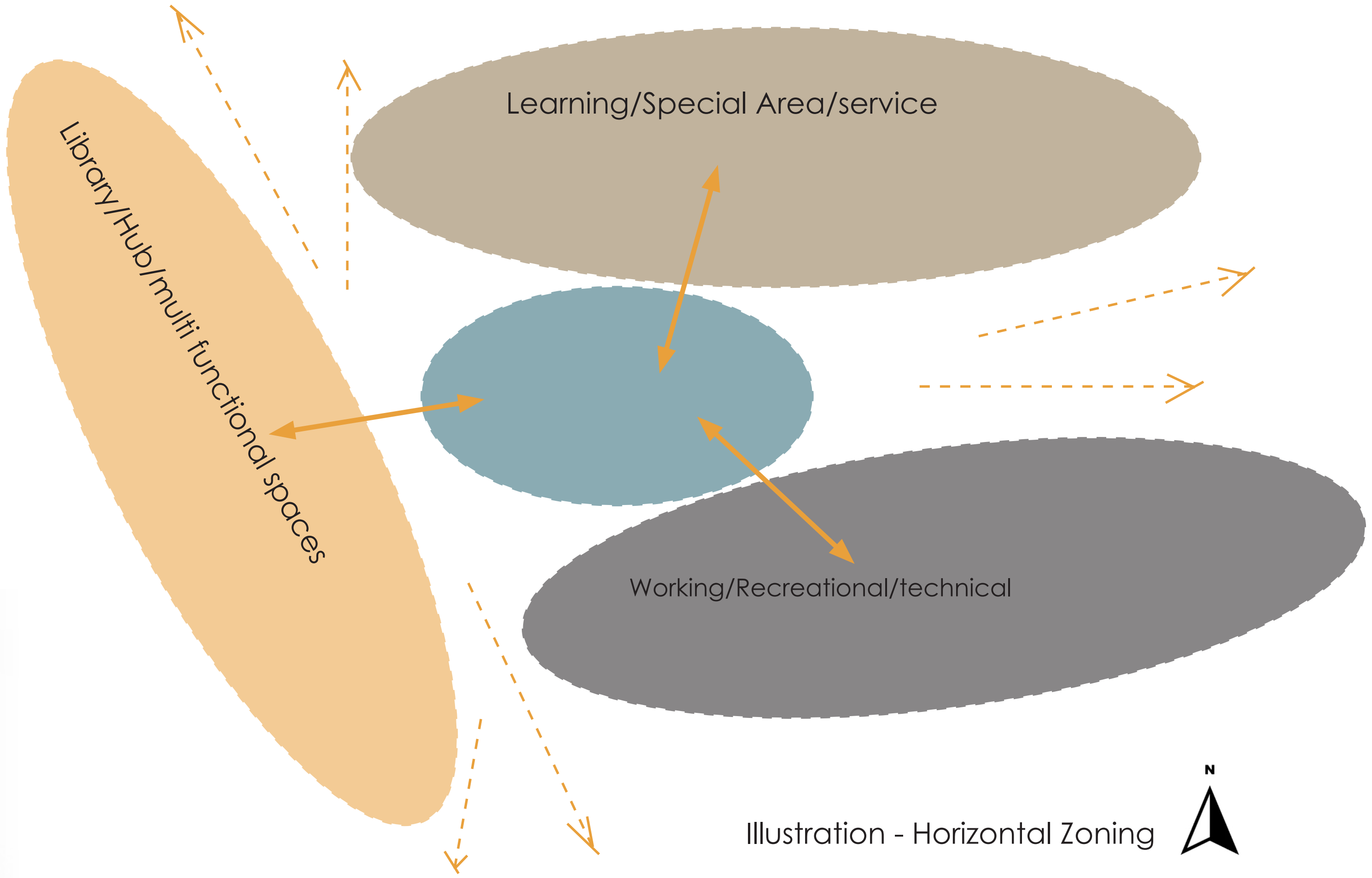


Illustration - Horizontal Zoning

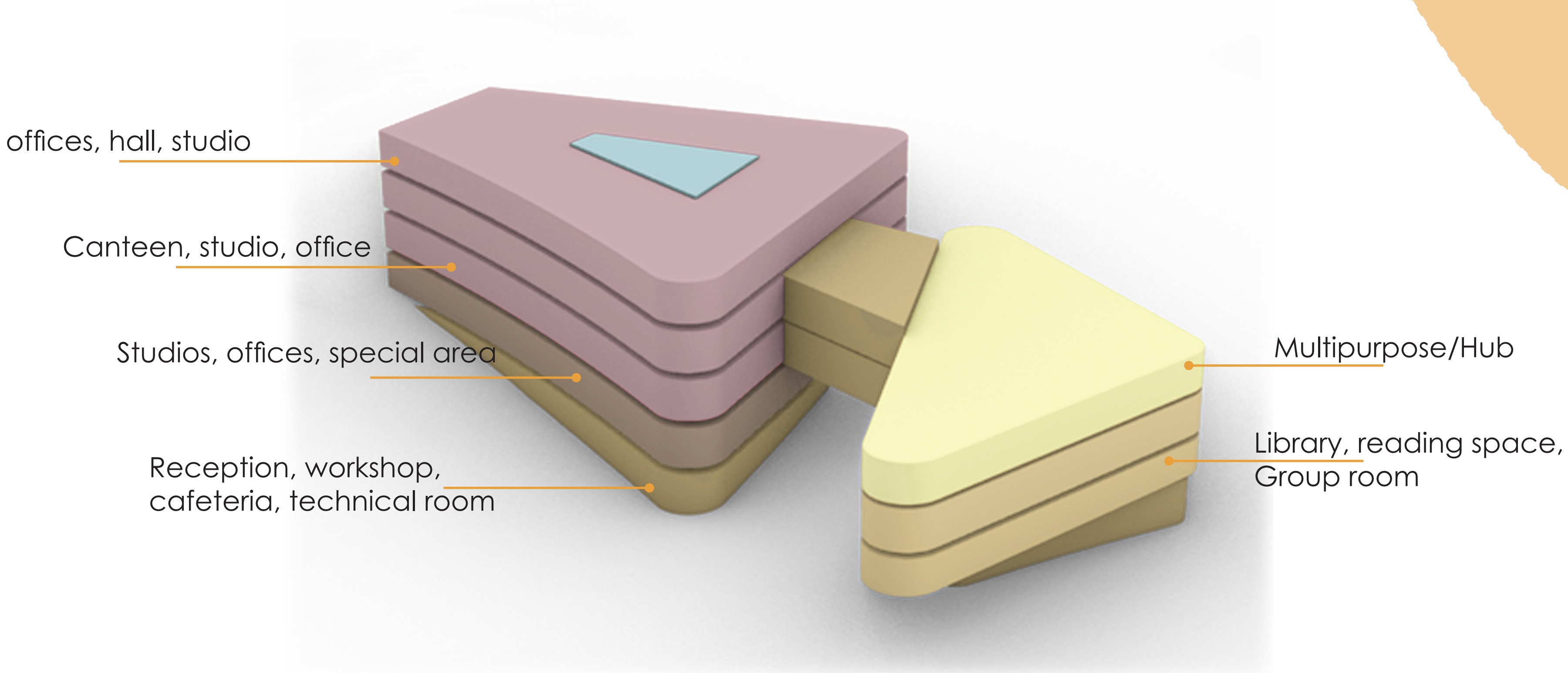
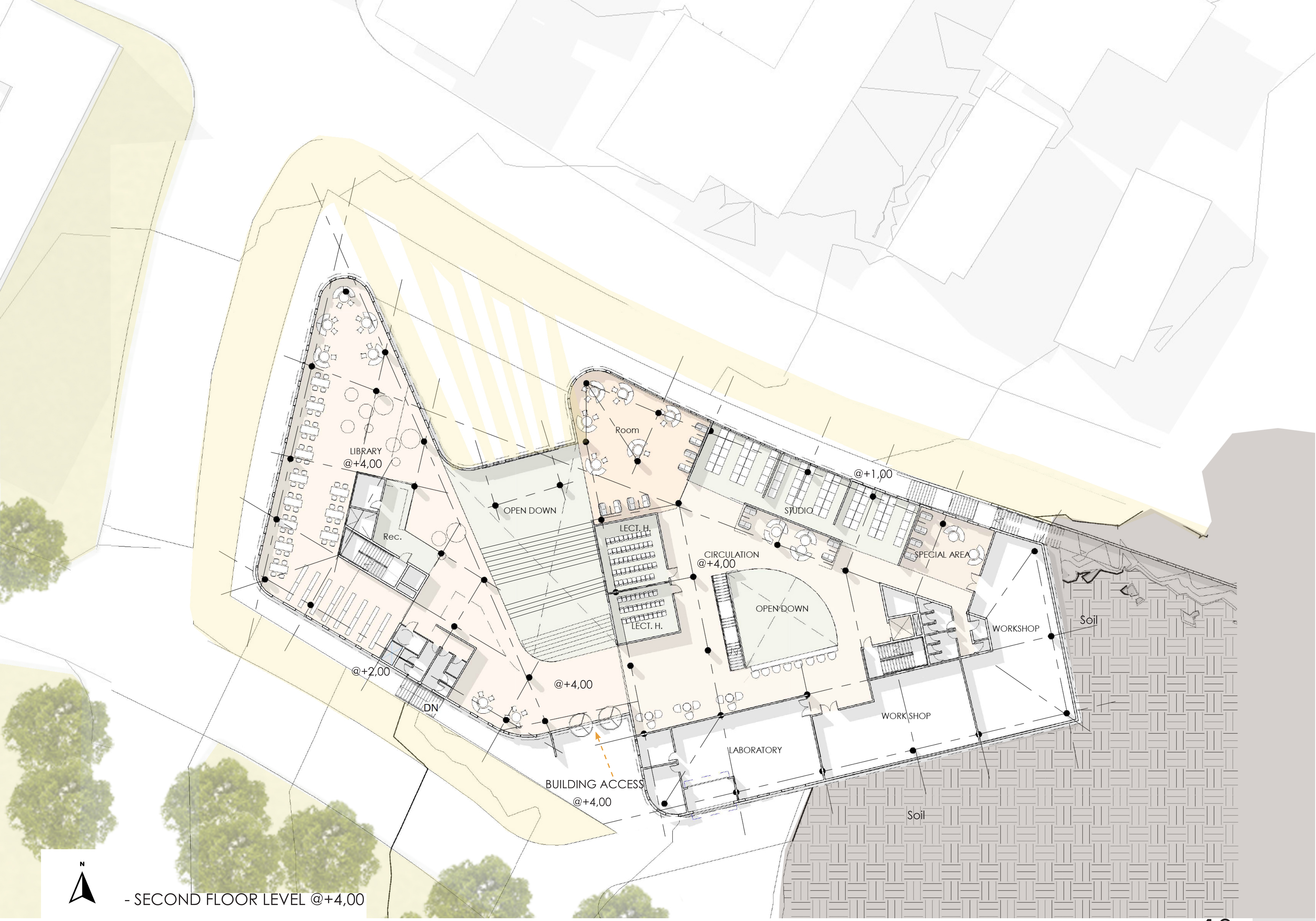
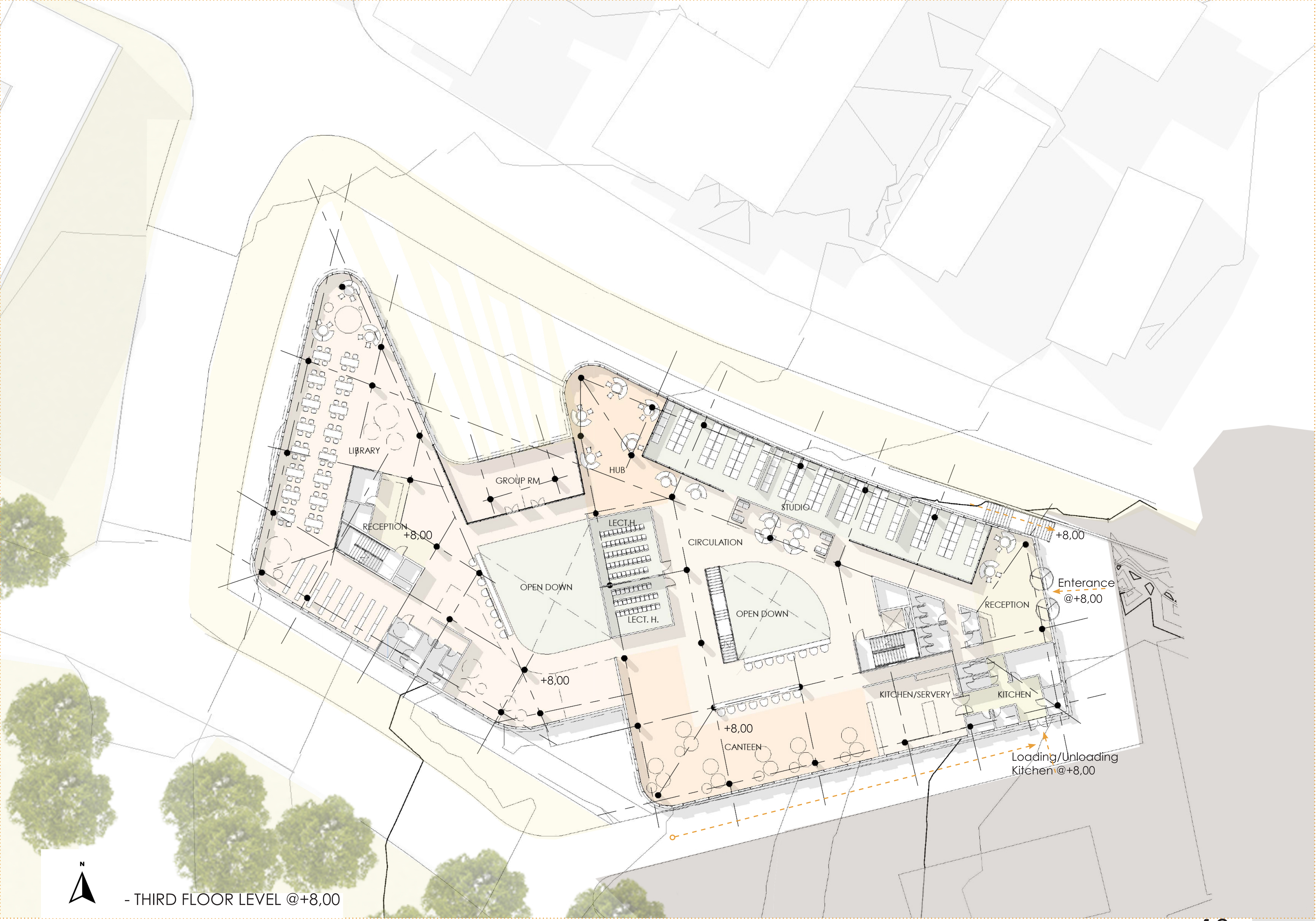


Illustration - Vertical Zoning


Main Road with public Bus route
Road
Road
@-0,40
BUILDING MAIN ACCESS
LIBRARY HUB
READING AREA
CIRCULATION
ENTRANCE
@0,00
SITTING AREA
SIT CAFE
OFFICE
LABORATORY
RECEPTION
OFFICE
STORE
OPEN GALLERY
@-0,60
LABORATORY
OFFICE
TECHNICAL ROOM
WORKSHOP
Soil
Soil
Soil
N
- FIRST FLOOR LEVEL @0,00

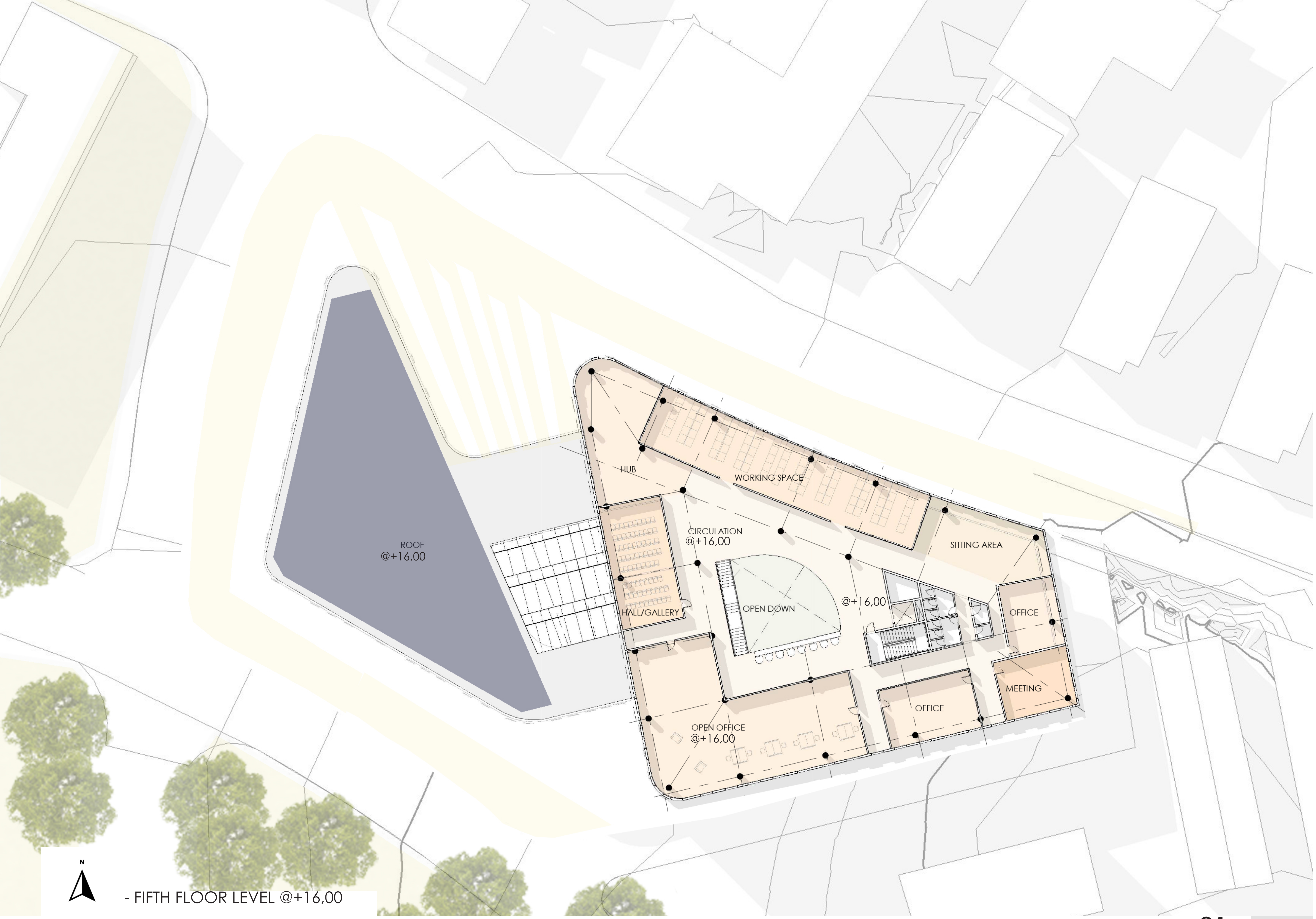


- SECOND FLOOR LEVEL @+4,00

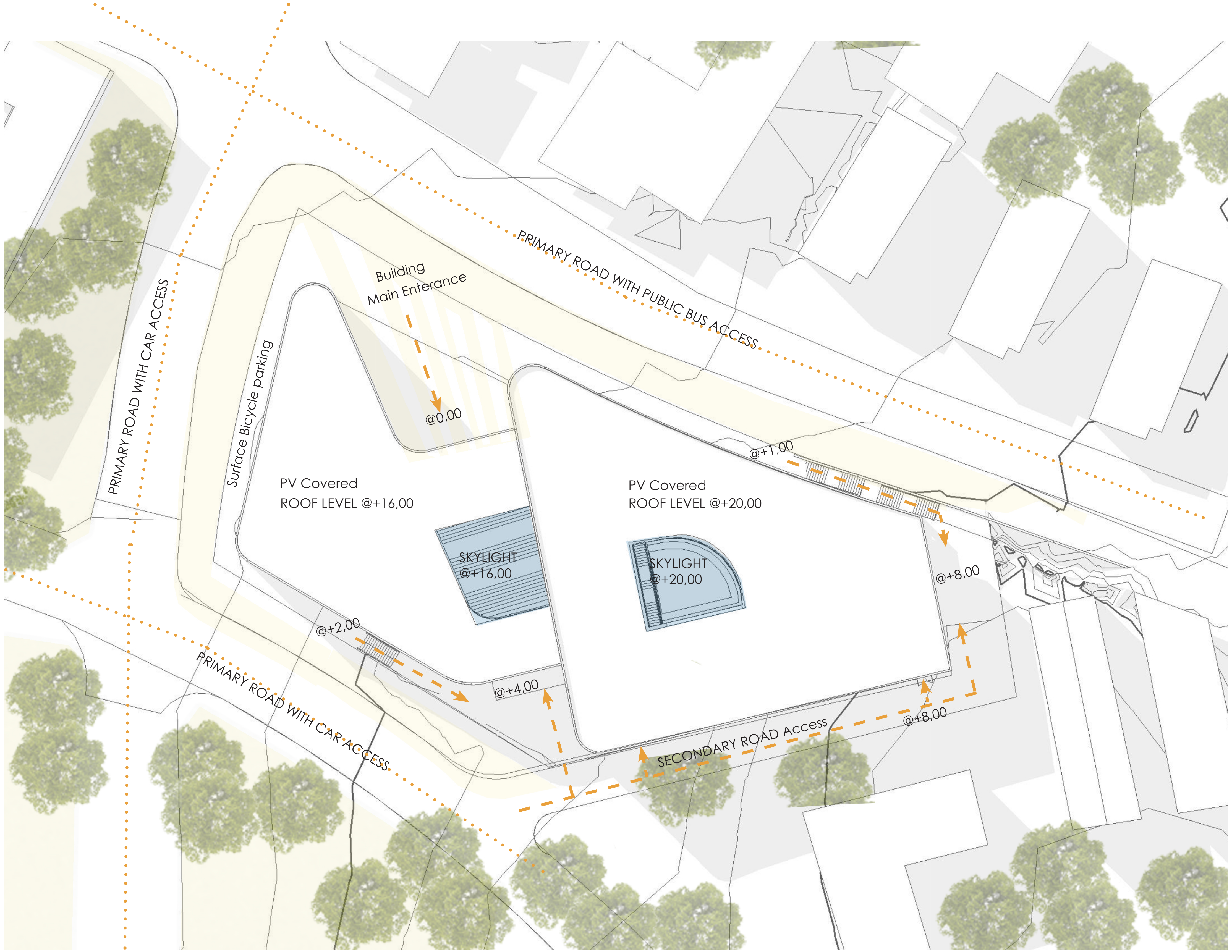


- THIRD FLOOR LEVEL @+8,00

- FOURTH FLOOR LEVEL @+12,00



- FIFTH FLOOR LEVEL @+16,00



- ROOF LEVEL @+20,00

ENERGY EFFICIENCY

BUILDING EFFICIENCY MEASURES

A series of passive design studies and strategies have undertaken in the previous sections to optimize the buildings efficiency. In this section further optimization will be carried out in the building's envelope and energy sys-tem to minimize its energy need. The target was set based on TEK 17 min-imum standard for university/college building. As low as 125kwh/m2 heated gross internal area per year should be idealized to achieve pas-sive house standard for a university/campus building.

BUILDING ENVELOPE

Building envelope act as a thermal insulation, protect internal spaces from the weather and gives the building's character "face", improving its appearance and clearly define the element of design. A Careful consid-eration must be given to the thermal properties of choosing these build-ing materials. In the meantime, reducing the use of carbon-intensive ma-terials should also be in line as its overall effect result in designing energy efficient building. Though, a complete building life cycle assessment of the building construction materials is out of this thesis scope. a careful consideration was taken in to account to reduce the embodied emission from materials. This is done by research and referring environmental product declaration (EPD) document of materials and analyzing their embod-ied emissions.

Envelope materials like concrete, brick and others could give better thermal storage in this climate. However, takes up a lot of energy to heat up and substantially increase overheating periods due to the maximum solar gain in the summertime. Therefore, besides having low embodied emission the primary energy need for heating is also considered while choosing the envelope. For this reason, A preliminary assessment was done for the structure of outer wall component. One component having steel studs as structural element and the other having wood studs having functional unit of 1m2. As seen in Fig-12 The global warming potential of the production of 1m2 steel stud accounts 161kg co2 eq/m2 while the global warming potential of production of 1m2 wood stud is -55kg co2 eq/m2 (Fig-13). And the emission arising during use of the building (through heating) are indicated by the upward curve on both tables. From this it was decided that the wooden studs will be used in the project.

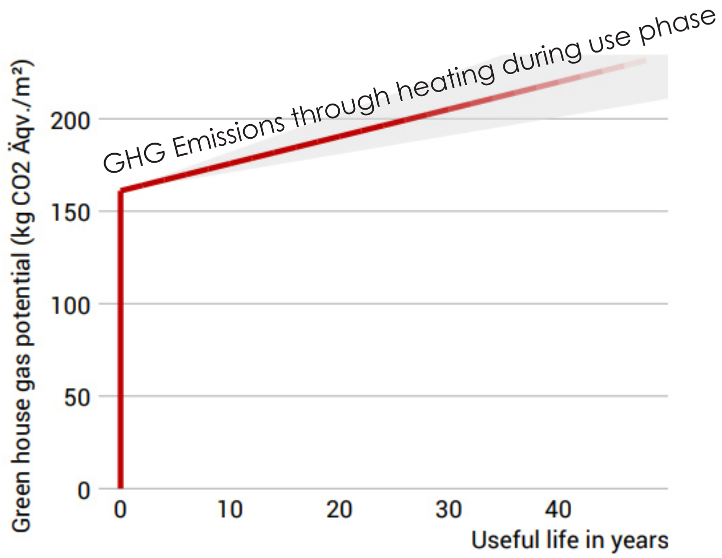


Fig-12- Emission from 1m² steel stud

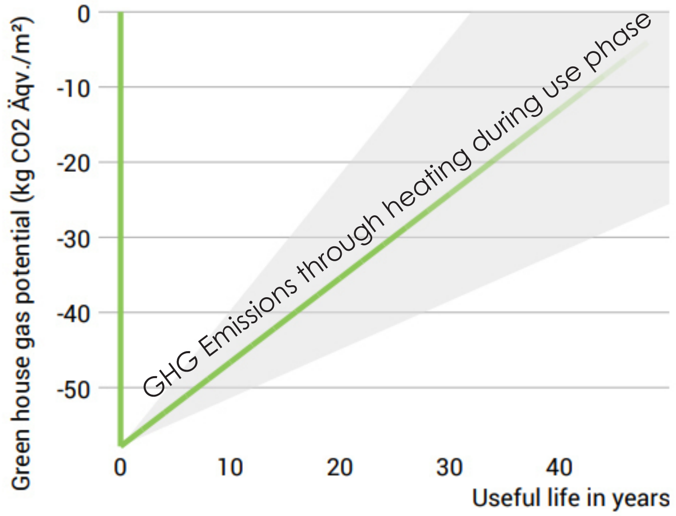


Fig-13- Emission from 1m² wood stud

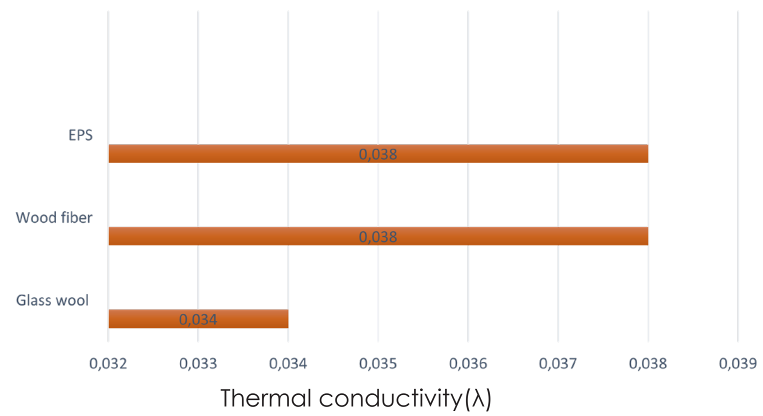


Fig-14- Thermal property of Insulation material (W/m.k)

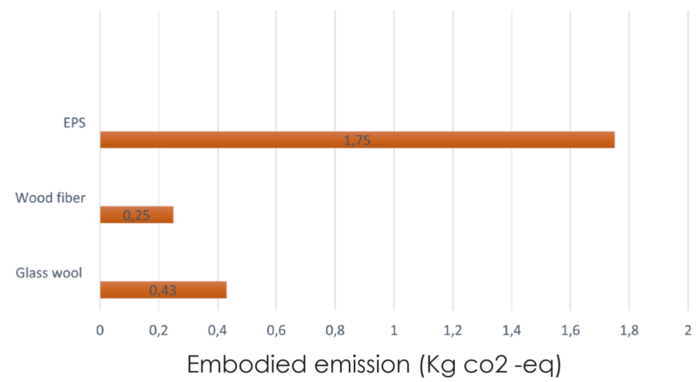


Fig-15- Embodied emission of insulation material

The other most component in the envelope making is the insulation mate-rial. It plays a significant role in making the envelop and obtain the proper U-value. Thus, understanding the thermal property and the materials em-bodied emission is equally imperative. Fig-14 illustrates the different insulation materials put to evaluation in their thermal property and their global warming potential in Fig-15 respectively.

Later to better understand the overall thermal properties of the wall component with wooden stud and insulation, the online software "ubakus.com" was used. A wall component with a U-value of 0.1W/m²k was realized having a wall thickness of 41.7cm and an overall wall thickness of 32cm resulted a U - value of 0.14w/m²k. While choosing between these two, one should consider the envelope that has extremely low U-values might result over heating during summertime and increase cooling de-mand at the end. And also, the amount of material that goes to this wall component has extra 10cm thickness, which would result in high embod-ied emissions, furthermore the internal usable area will also be compromised. Therefore, while determining the final thermal property of the wall multiple simulations have been performed using Simien and the energy saving was not considered as significant compared to the afro-mentioned motives. Hence for this project a U-value of 0.14w/m²k was set to calculate the final energy demand.

Besides this, the window to wall ratio was carefully decided as it is important to minimize heat loss through the façade whilst achieve ambient daylight inside the building. Windows with insulated frames, multiple glazing, low e-coatings and other technologies can significantly reduce heat loss. Hence, the U-value for windows and doors is taken as 0,7W/m²k considering there is better technology with high performance today in the market. The value set here for calculating the performance is lower than the required standard that is in NS 3701 which is 0,8W/m²k.

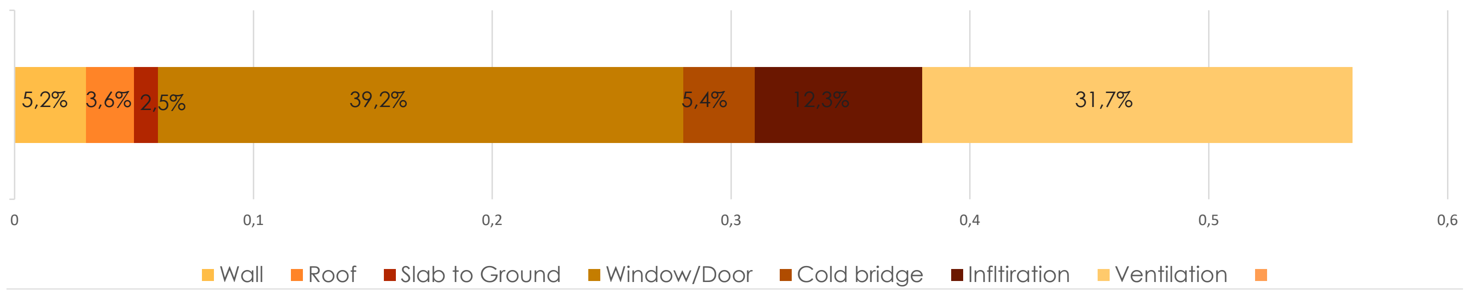


Fig-16 Heat loss Budget (W/m²k) - Result from Simien

According to the heat loss numbers resulted from the Simien calculation shown in Fig-16 the wall component shares only 5,2% of the total heat loss budget. The heat loss from the ventilation accounts the second largest contribution of 31.7%. The efficiency for the heat recovery was set 83% which is higher than the given standard 80%. This means a much higher heat loss would have resulted if it was set as 80%. The main contributor in the heat loss budget is the window/door taking up 39.2% of the share. As a better U-value of 0,7W/m2k was set for calculation this might indicate the glazing to wall ratio could be higher.

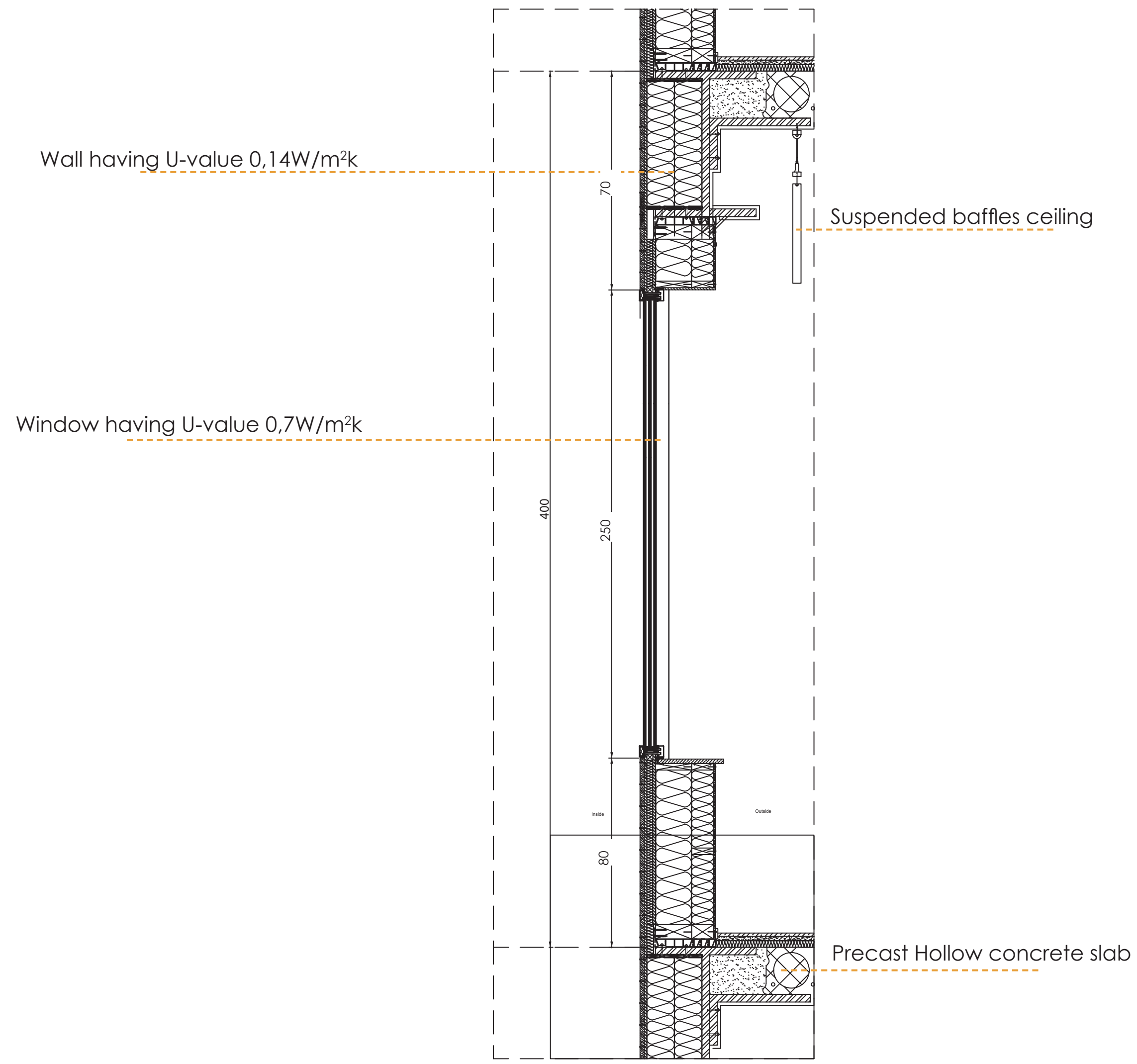
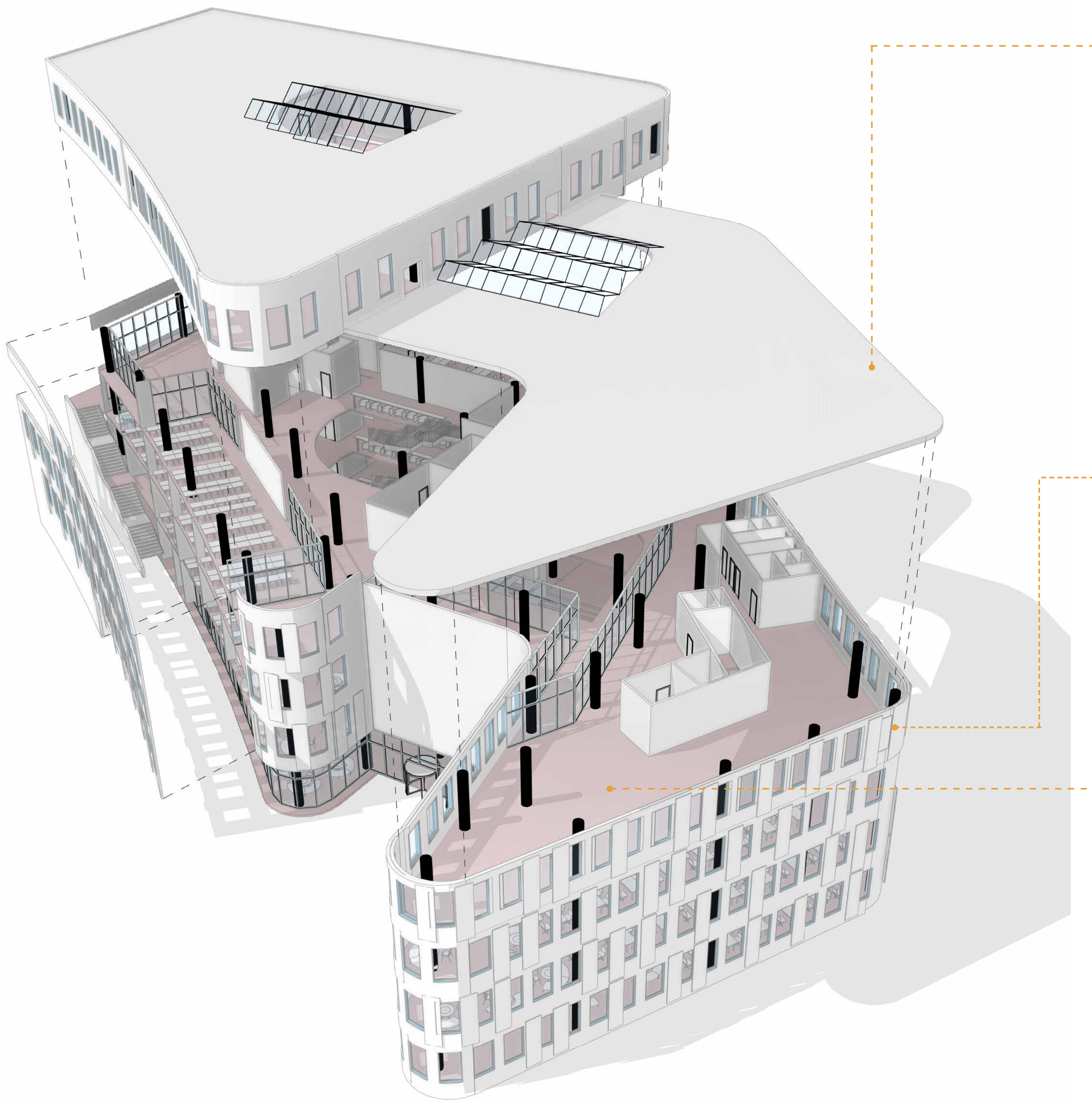


Fig - 17 Wall Section sc1:50



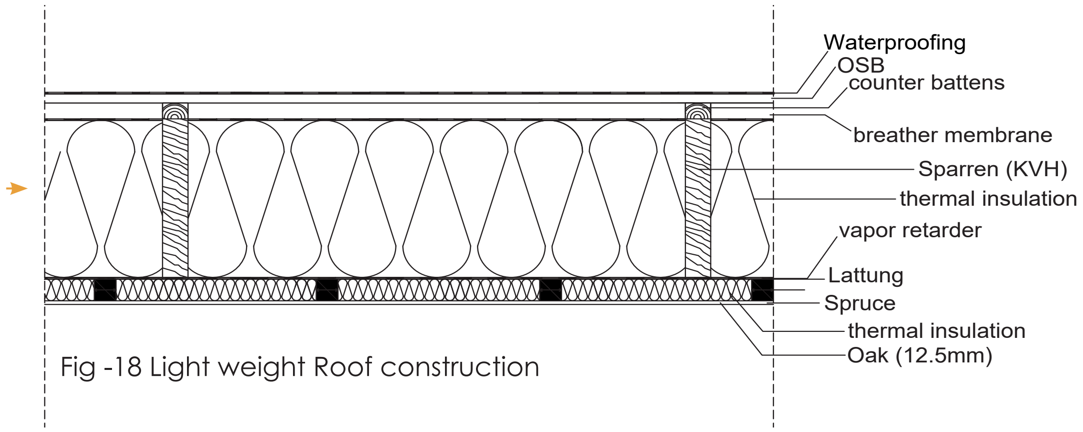


Fig -18 Light weight Roof construction

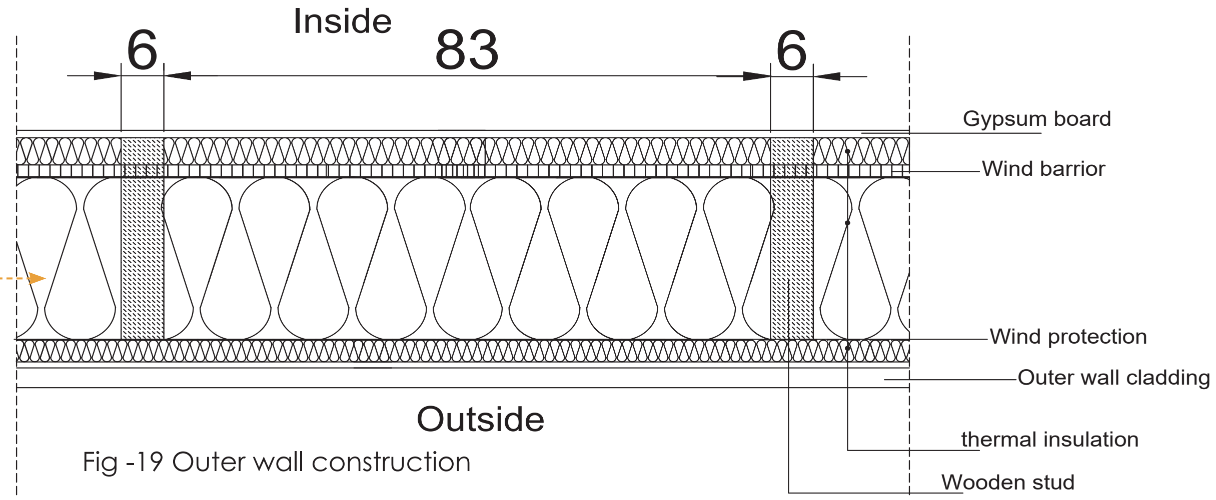


Fig -19 Outer wall construction

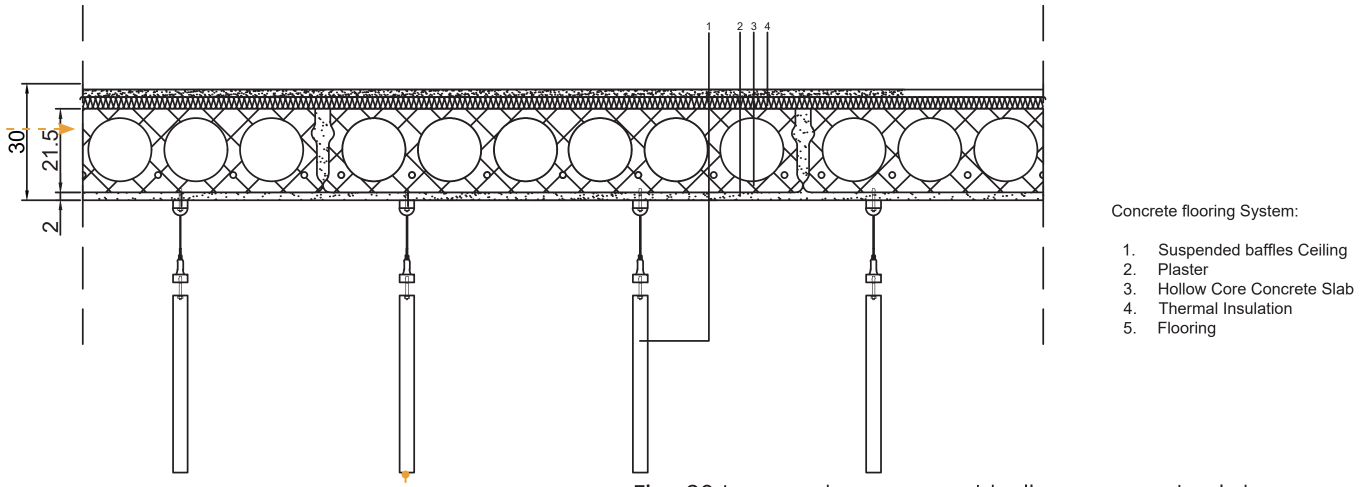
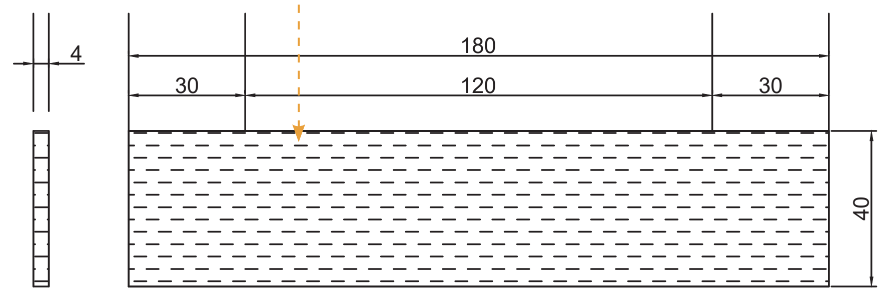


Fig -20 Low carbon precast hollow concrete slab



Vertically installed baffles ceiling Module with 120 x 40 cm

VENTILATION

The design of heating, ventilation and air conditioning (HVAC) systems has a significant impact on comfort and energy efficiency. A proper design and choice in efficiency measure could have substantial effect on it.

Displacement ventilation system is proposed for the school building as its meth-odology of providing conditioned air require less energy to operate. The system utilizes constant air volume (CAV) with less supply air flow. The rotary heat ex-changer heat recovery sys-tem is set to have 83% of efficiency. The air distribution is integrated close to the floor level from the supply shafts at every floor with a very low rate. Then heated air is extracted by the extraction duct out from the ceiling level then collected back through multiple stair shafts. Having multiple extraction shafts help to achieve good air flow and avoid high trapped air inside the building. The specific fan power value is set to 1,5KW/m³/s ac-cord-ing to passive house standards.

It has a decentralized systems where smaller ventilation zones are supplied from the main air handling unit (AHU). This is designed for good airflow control and optimization of the two different zones. The units are integrated for combined heating and cooling coil. Even though cooling demand is not that significant and the school is barely used during sum-mer time, a natural ventilation is also opted to be used during the overheating periods. For this reason, two atriums are designed to act as a main exhaust during this time in the building.

Type	CAV
Ventilation rate during/outside operation	7m³/hm² and 1m³/hm²
Operation period	6AM – 6PM
Ventilation control	CO2-control, 1000ppm
Heat recovery efficiency	83%
Supply air temprature	19⁰C
Specific fan power	1,5KW/m³/s

Fig 21 Ventilation System Input

Fig -22 Ventilation strategy

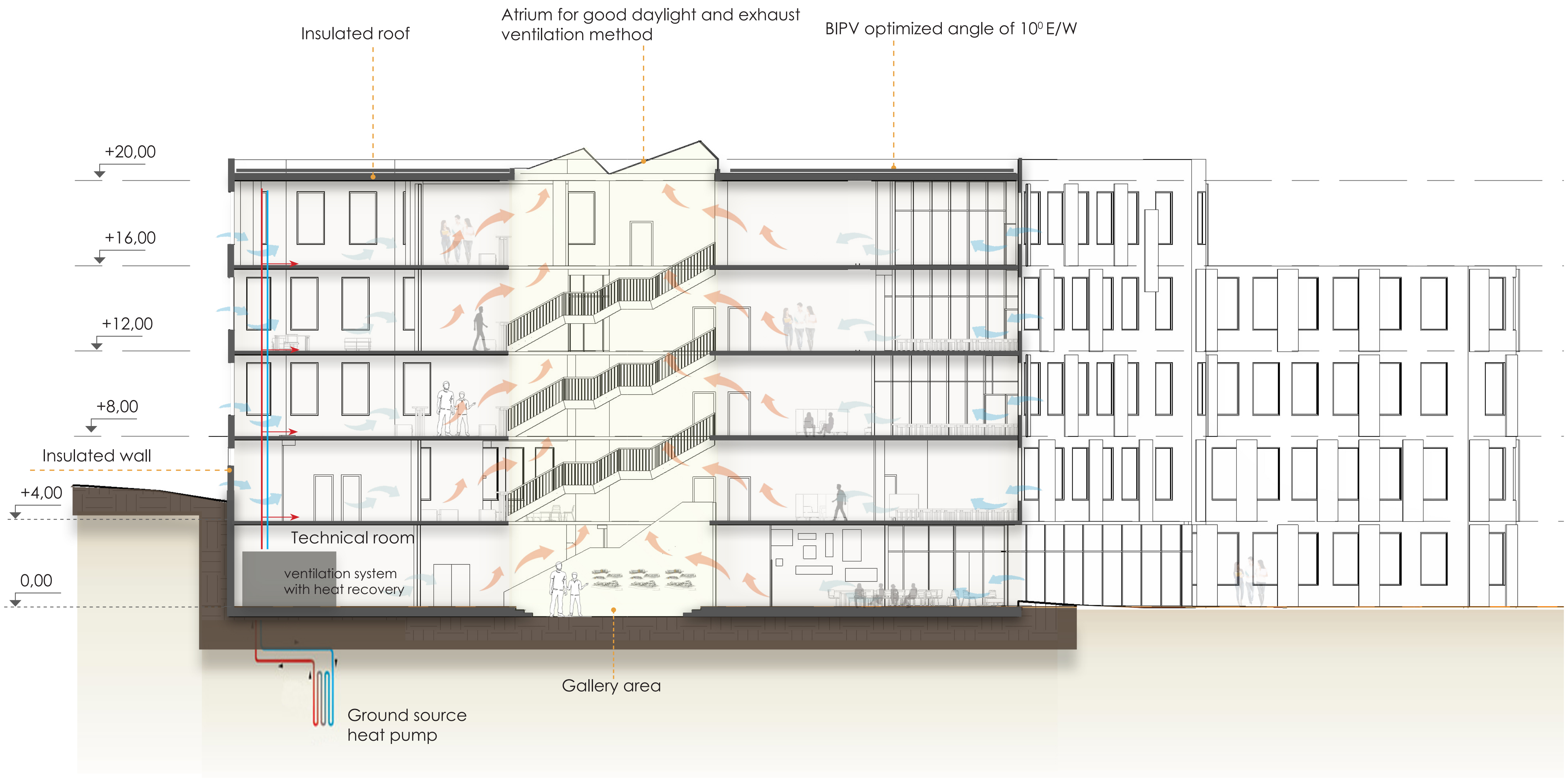


Fig -23 Section Drawing Sc. 1:200

Section Key plan

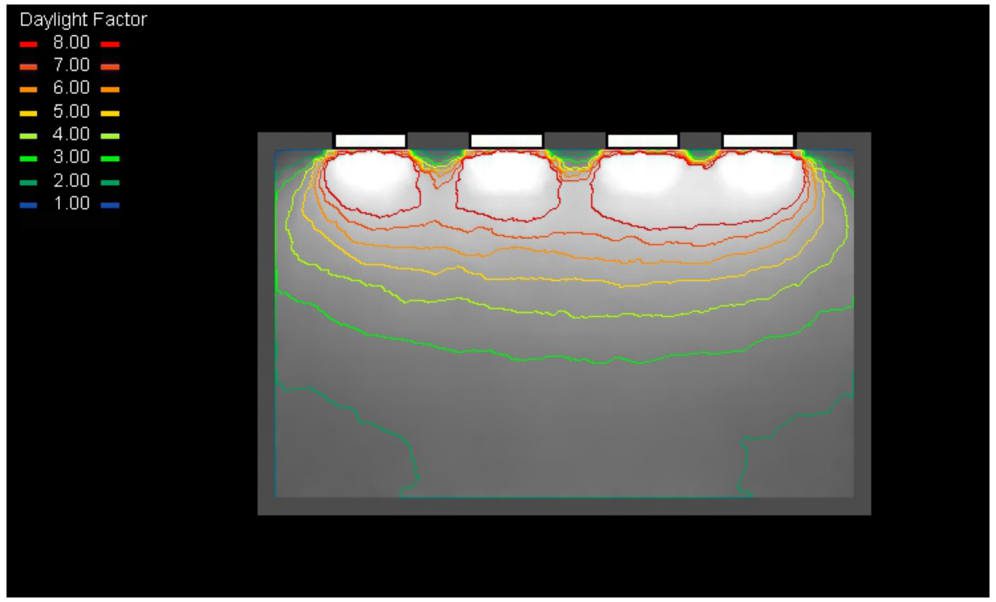
DAYLIGHT

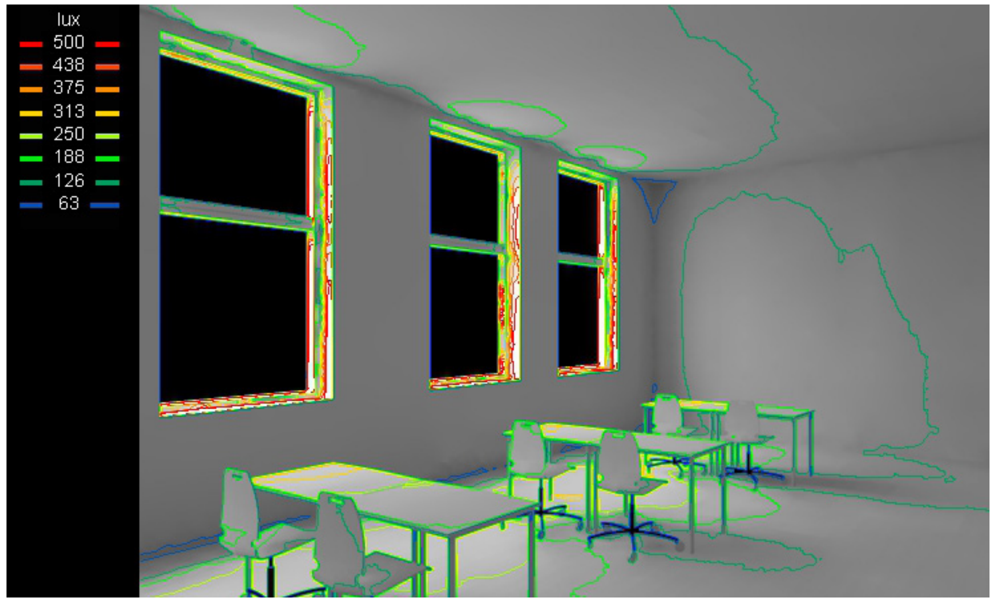
Better daylight provision is having adequate illuminance inside the building and is highly associated with the wellbeing of occupants. Moreover, achieving better daylight conditions added with supplementary electric lighting can lead to substantial energy savings in buildings. Therefore, special consideration should be given to better integrate openings into the façade to achieve better daylight condition, have better inside-outside view, avoid glare and overheating. A mean value of 2% daylight factor is required and 500lux is considered a good illuminance for a school building according to TEK-10 standard.

Three design options in a studio sized 6m x 9m were considered to evaluate and see how the opening distribution affects the daylight inside the building. Option 1 shows better daylight coverage with average daylight factor value of 3. It has an overall glazed area of 24% of the floor area. Having this typology minimized the risk of glare than option three and has better day-light penetration than option 2. With Partially automated shading control during the risk of glare it satisfies the need for the design requirements.

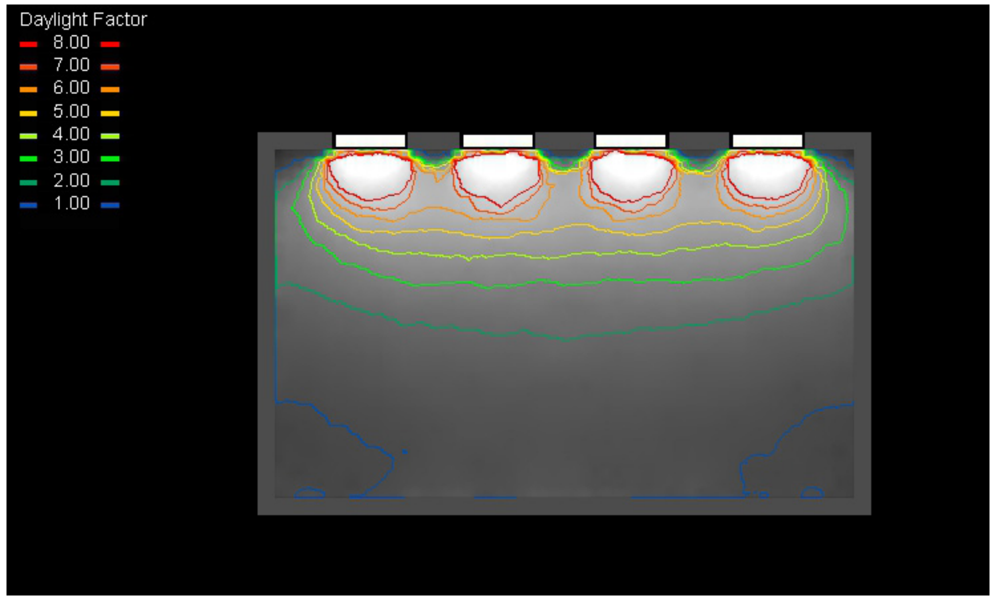
INPUT VALUES FOR OPTION - 1

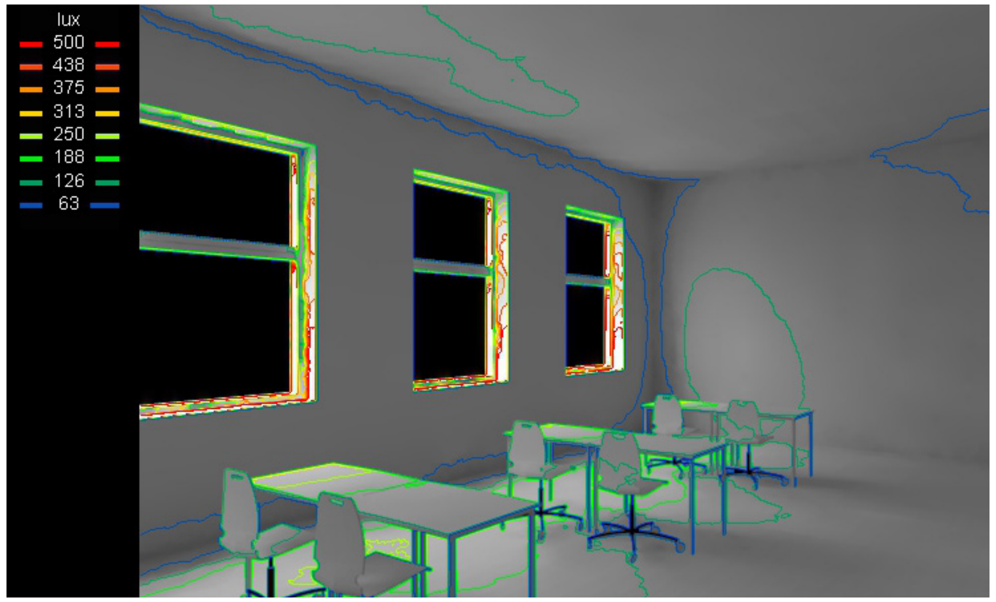
Sky condition - Overcast sky
Room size - 6 x 9m
Visual transmittance - 0,7
Window depth - 0,3m
Window size - 2,5 x 1,3m



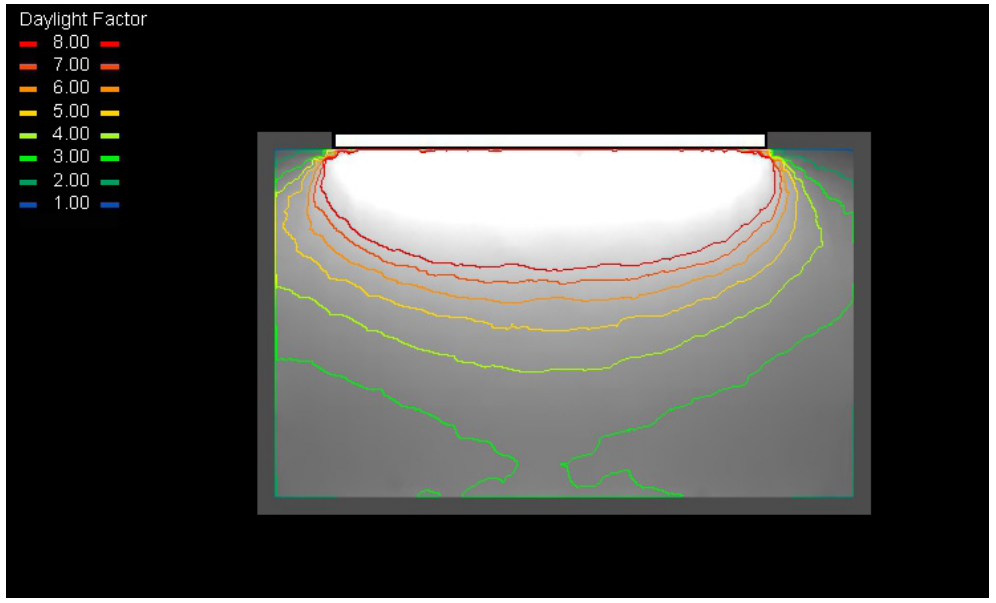


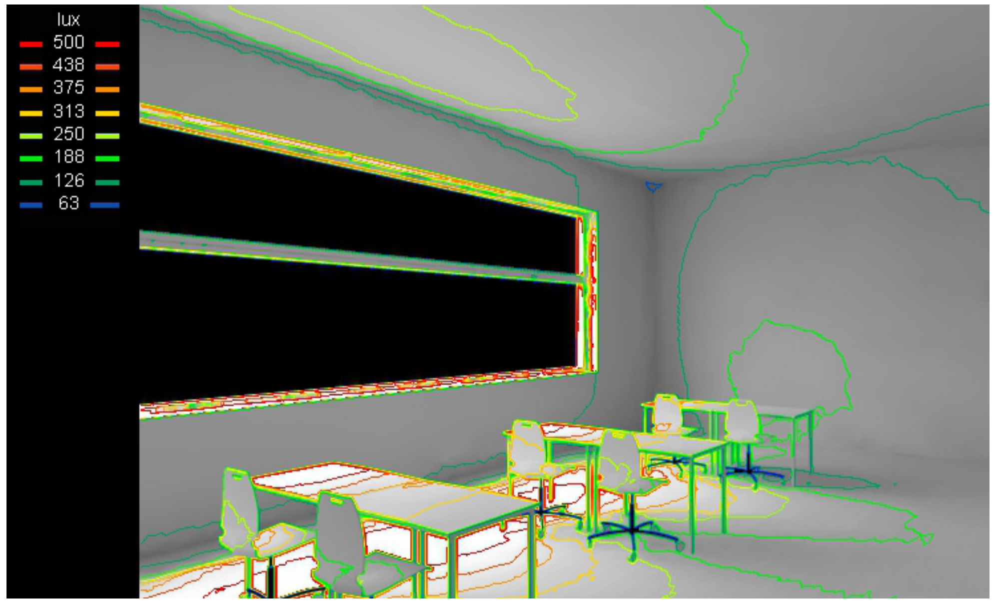
Option - one





Option - Two





Option - Three

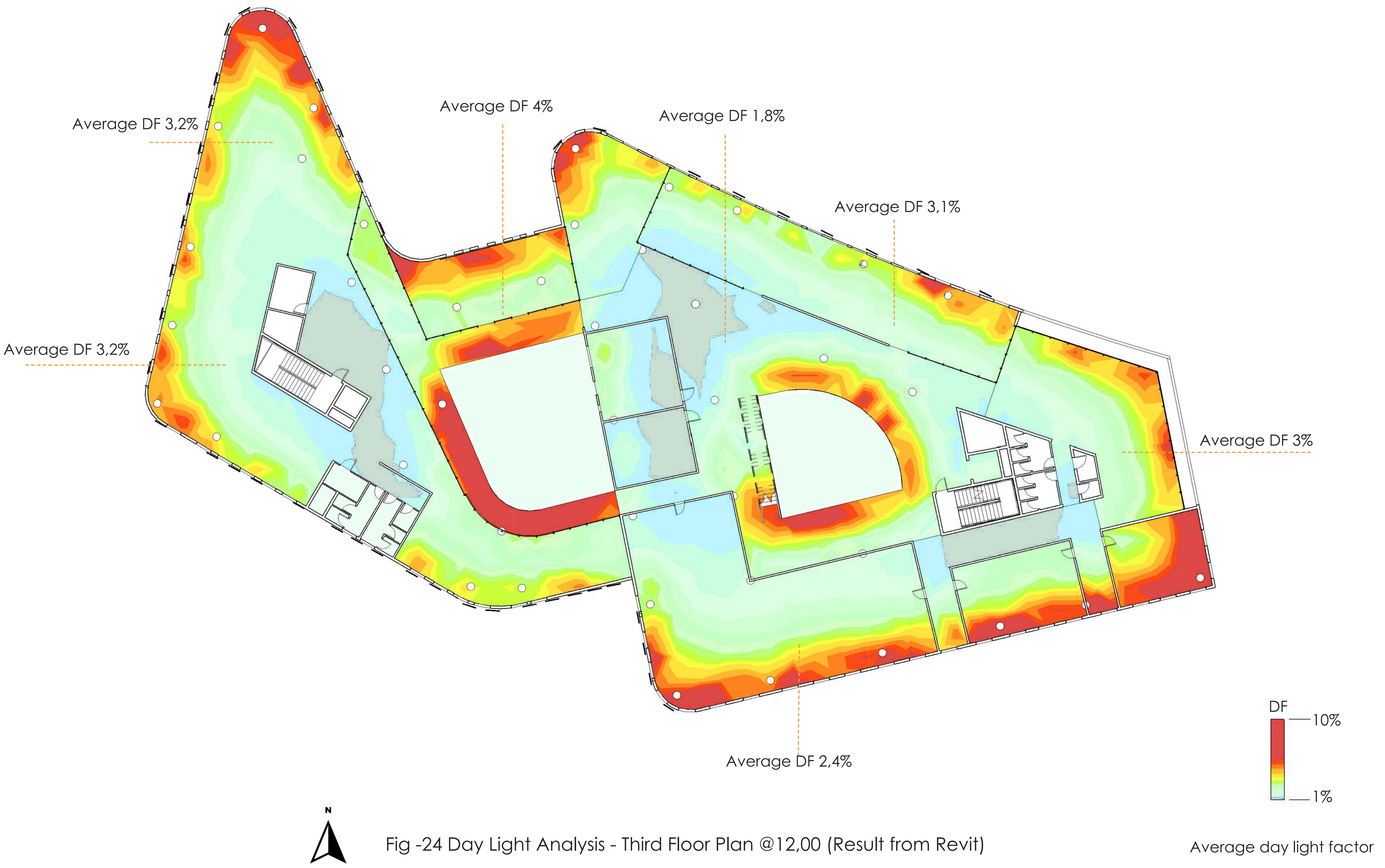


Fig -24 Day Light Analysis - Third Floor Plan @12,00 (Result from Revit)

ENERGY SUPPLY SYSTEM - HEAT PUMP

Local renewable energy sources have been introduced to reduce emissions from power systems. Geothermal heat pumps and photovoltaics were selected as the renewable electric source for this project. Properly installed geothermal heat pumps are a good source of heat for a low carbon heating system, it is economical and can be 300-400% efficient in terms of its use of electricity. This means that 3-4 units of heat are captured and transferred for each unit of electricity provided by the heat pump. The heat generated by the geothermal heat pump is sized to cover 90% of the energy required for heating, ventilation heating, and hot water production, and the remaining load and peak period is covered by the power imported from the grid. In the chart below, the balance for building's heating is shown. There is not much heating required during the summer months and the solar gain is relatively high in this time.

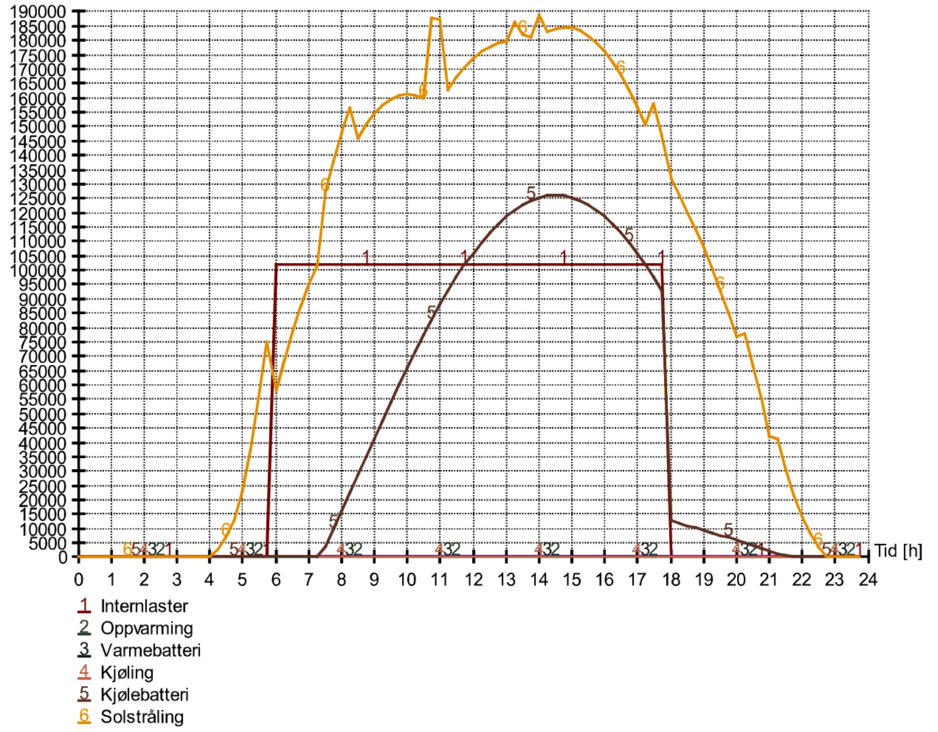


Fig -26 Room Heating and Cooling Chart - Summer(W)

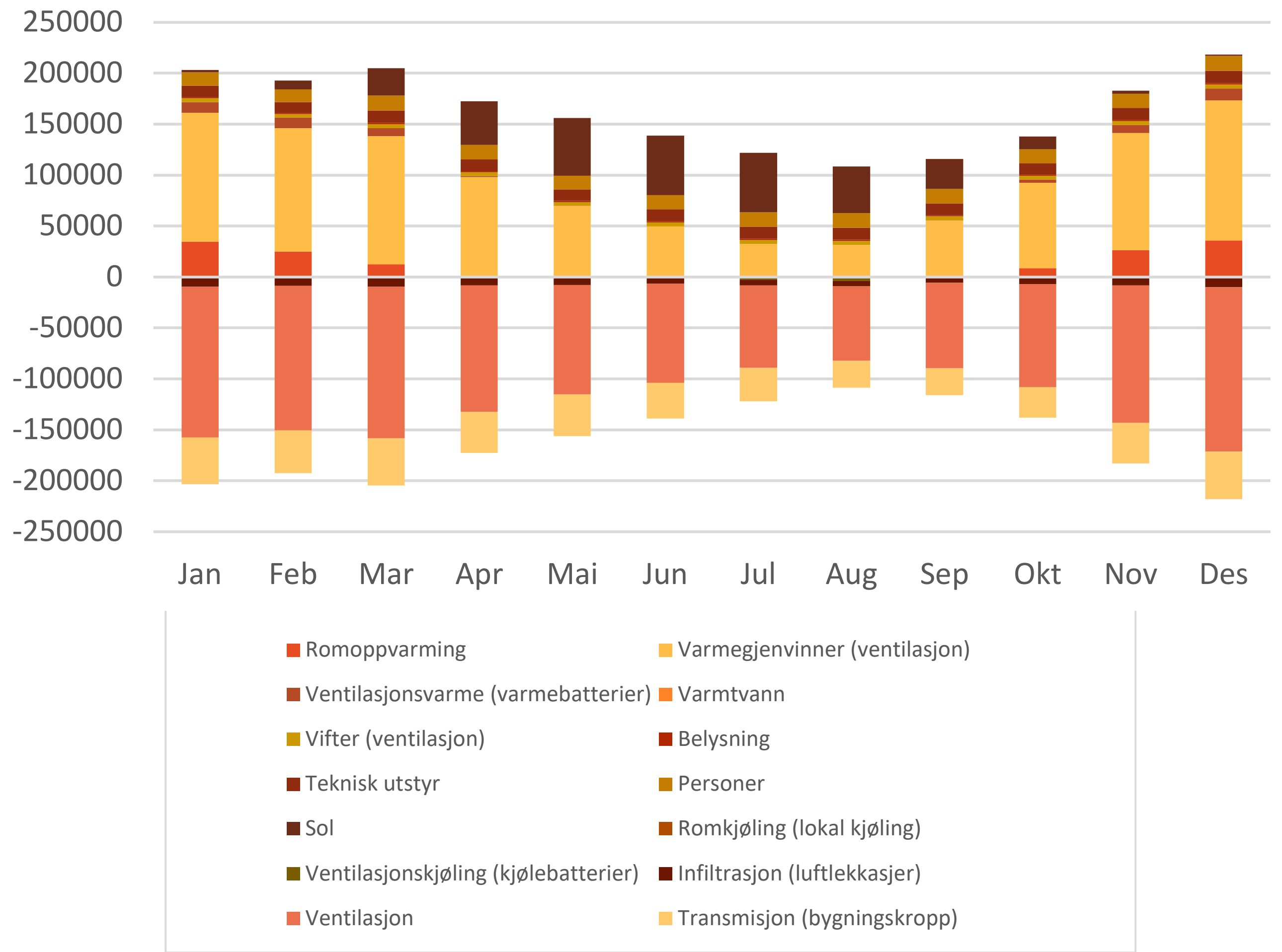


Fig -25 Monthly Heat Blance Chart - Result from Simien

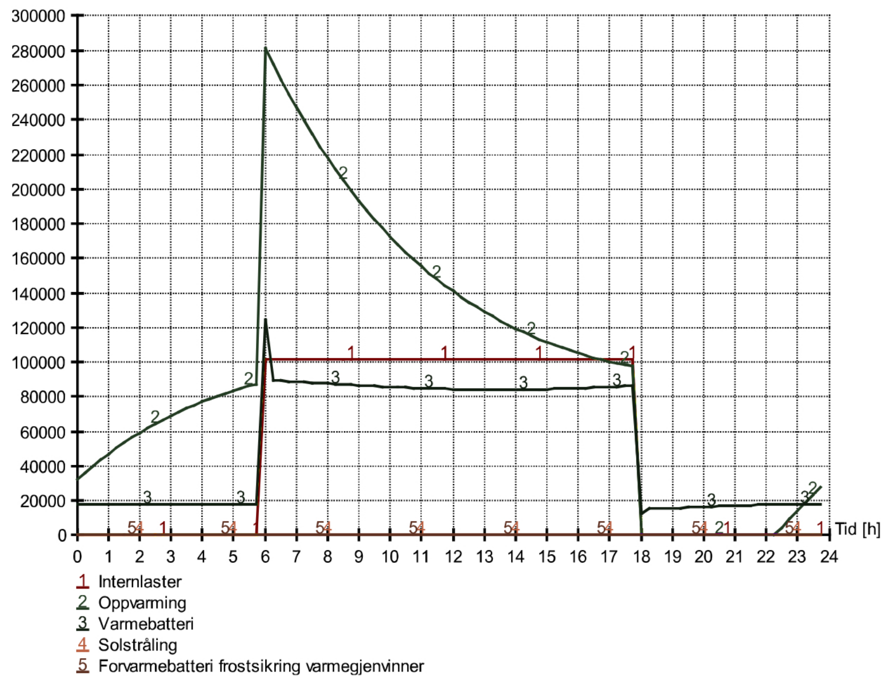
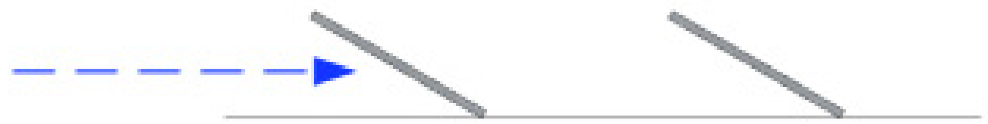


Fig -27 Room Heating and Cooling Chart - Winter(W)

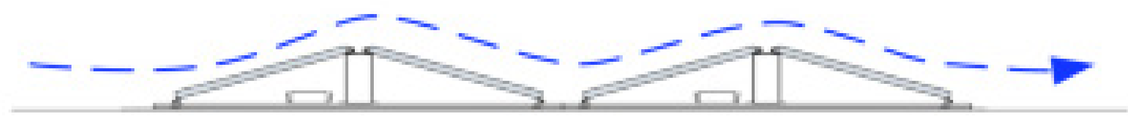
PHOTOVOLTAICS

Having sufficient onsite energy production is highly important for the annual energy compensation strategy, for this reason optimizing the performance of photovoltaic panels on the building is vital. As solar radiation on the building study resulted possible useful roof facade areas can be utilized for energy production. However, When designing a PV system on a flat surface determining the tilt and appropriate spacing between each panel is important to optimize the energy production.

To optimize the use of the panels on the roof different tilt options were evaluated. A study was performed with the possible roof area having 10⁰, 15⁰ and 20⁰ of PV tilt angle. Fig… shows the evaluation between these options as a result the PV orientation towards south with 20⁰ angle gives the highest production. However, it was realized that having a panel tilt angle of 20⁰ will result shading between the panels and require a maximum distance to fix the problem which in result a significant surface area will be lost. Therefore, multiple facing PV panels were again put to evaluation. Amongst all he East west facing panels found to be the appropriate installation with max-imum potential energy production.



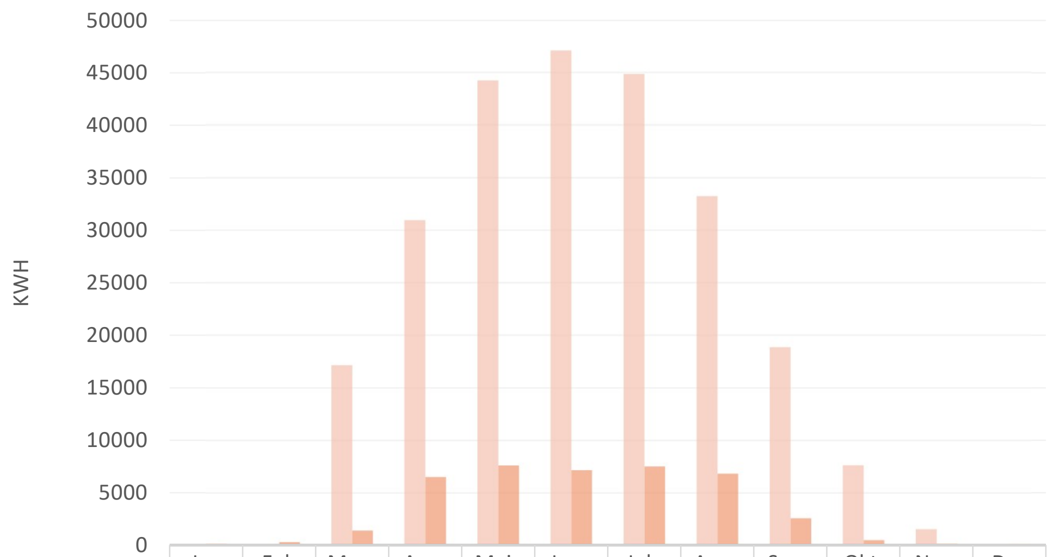
One sided solar racking



Two sided solar racking

	South facing (180⁰) production	Southeast facing (135⁰) production	Southwest facing (225⁰) production	East west facing production
10⁰angle	31.4 kwh/m2/yr.	30.9 kwh/m2/yr.	30.8 kwh/m2/yr.	29.4 kwh/m2/yr.
15⁰angle	32 kwh/m2/yr.	31.2 kwh/m2/yr.	31.1 kwh/m2/yr.	28.9kwh/m2/yr.
20⁰angle	32.4 kwh/m2/yr.	31.4 kwh/m2/yr.	31.2 kwh/m2/yr.	28.5kwh/m2/yr.

Fig -28 Optimization on pv panel angle



	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des	Total
PV's Roof	0	0	17139	30957	44265	47102	44852	33247	18850	7632	1539	0	245585
PV's Facade	106	311	1409	6500	7618	7163	7503	6842	2562	506	144	52	40715

Fig -29 Annual solar Energy production result from Simien

Building integrated photovoltaics are increasingly being incorporated into the construction of new buildings as a renewable source of power. The technology is growing and start coming in different colors with normalized production between 110Wp/m2 to 190Wp/m2. Besides being energy generator solar façade panels can also act as additional thermal property and noise reduction mechanism.

As a potential of BIPV for the building's multiple façades was apprehended different integration methods were evaluated. Fig…shows the seeming less integration with the façade elements that chosen for this building. Multiple PV panels mounted on a (4 x 1) m board size will be distributed along the facades where the possible production occur.

Panel property

Life span:
20 years

Efficiency:
22%

Nominal power:
190Wp/m2
&
430Wp/m2

Panel weight
18,6Kg

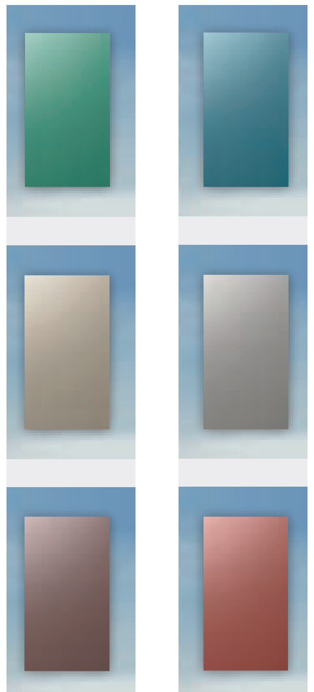


Fig -29 Color Photovoltaic integrated facads

* The facade cladding and pv panels colors was inspired by the existing neighbourhood color scheme

With the final distribution of the PV panels on the roof and possible facades an area coverage of 2100m2 is realized. The roof coverage takes up the largest share both in area coverage and energy production. The PV's put to simulation considered to have 22% efficiency with high-performance monocrystalline cells and with 25 years of lifetime.

In Fig-… it is shown the Energy demand from electricity and the energy production from the PV panels. In the month of April to September the building exports a large amount of electrical energy to the grid while support its own energy demand. Mean while in the winter times the building mostly relies on the electricity imported from the grid.

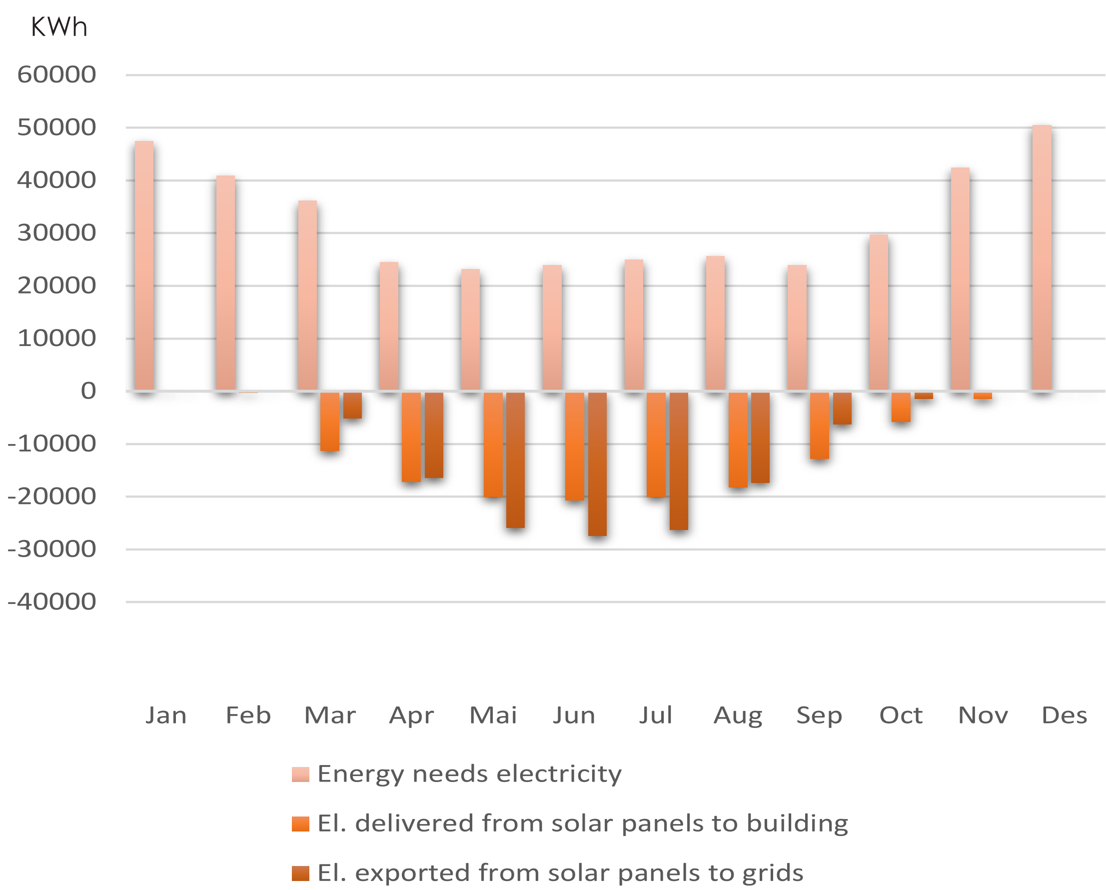


Fig -30 Annual energy need Electricity vs Energy production solar panels

ENERGY DEMAND AND SUPPLY

Energy demand is the electrical and thermal energy need for indoor climate control, heating water, operation of equipment, and lighting. Calculations for the building's energy demand with a heated floor area of 8900m2 was calculated in the dynamic building simulation tool SIMIEN using Trondheim's weather data. The building is modeled as a whole building and no zones were assigned. According to NS 3031:2014 the Energy demand represent buildings net energy need without including the efficiency of the energy production and distribution system.

The energy performance was conducted and compared using the minimum requirement for passive house standard of non-residential building NS 3701: 2012 and materials that was proposed in previous sections. Optimization was done through different parameters of active design strategies. Heating and cooling energy systems, set constant supply air temperature of 19^0c, operating strategy of heating with waterborne distribution system was used with 45^0c for the supply and 35^0c returned temperature, and a specific pump power for the distribution system is 0.5kw/(l/s). Further input data's for the energy demand used in the Simien calculation are shown below.

The energy demand calculated gives a total of 57.3Kwh/m^2/year (Fig-). The highest demand is for room heating followed by technical equipment. The maximum allowable energy need to reach the passive standard is 24.3Kwh/m2/yr meanwhile the building's energy need is 16.7Kwh/m2/yr which is wel under and satisfies the requirment.

	NS 3701	Building (8900m2 BRA)
U-value exterior walls [W / m²K]	0,10 - 0,12	0,14
U-value Roof [W / m²K]	0,08 – 0,09	0,08
U-value floor [W / m²K]	0,08	0,08
U-value windows and exterior doors [W / m²K]	0,8	0,7
Normalized cold bridge value [W / m²K]:	0,03	0,03
Air leakage rate (n50) [1 / h]:	0,6	0,6
Average air volume during operating and outside operating hours	(0.7 and 0.1)	(0.7 and 0.1)
Annual average heat supplement from equipment and people respectively (w/m2)	5 and 6	5 and 6
SFP – factor ventilation system (kw/(m3/s)	1.5	1.5
Annual heat efficiency recovery	80%	83%
Total heat loss, W/(m2/k)		0,37

Fig- 31 Input data for the energy demand calculation

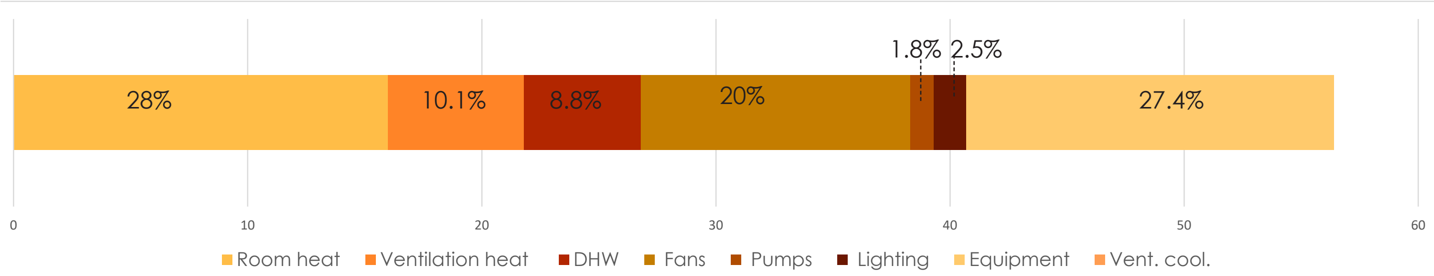


Fig -32 1Annual Specific Energy demand by catagory in kwh/m² a year - Result from Simien

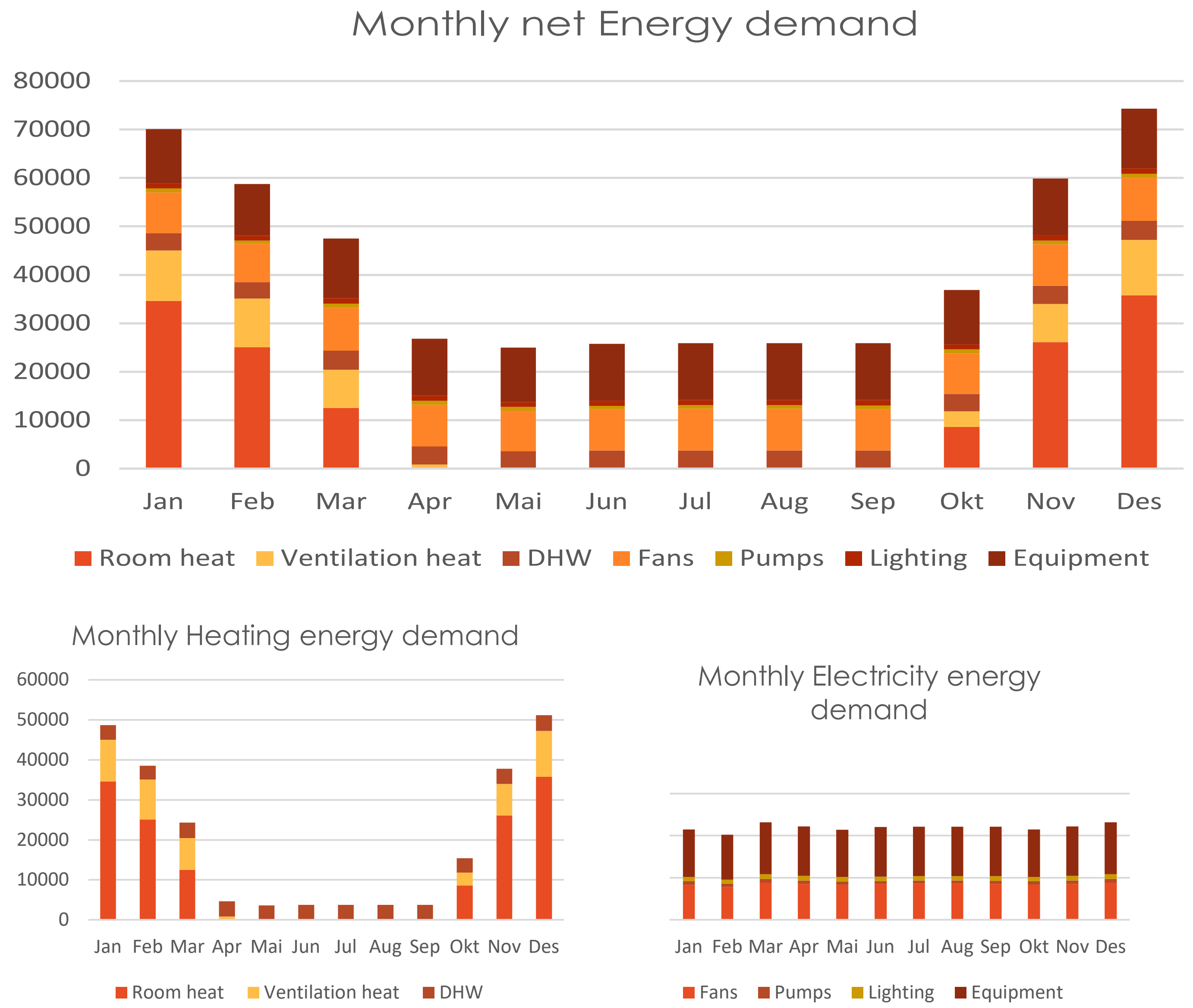


Fig - 33 Monthly energy demand - Result from Simien

Fig-33 Shows the monthly energy demand shares. The heating demand changes over the year in a seasonal matter. It increases in the winter times and decreases in the summer while the electricity remains seemingly constant through out the year.

The winter simulation in Fig - shows the operative temperature during the winter time is close to the set point 19⁰c in the nighttime and rise to 21⁰c during the day. Meanwhile there happen to be an overheating period during the summer time with a temperature rise of average maximum of 27⁰c during the day. This could be due to the heavy insulation and the maximum solar gain in summer. Fig- 35 shows with operable window the temperature could be reduced to an average of 25⁰c and becomes in the standard however, it is recognized that a significant demand in energy was registered during this time.

A reduction in U-values of the glazing reduces heating energy consump-tion but increases cooling energy consumption. Therefore, the influence of the shading system is relatively high. Even though shading devises have not been put in to a thorough study, t it could be one strategy to signifi-cantly reduce the excess solar heat gain through the window. Exterior shading devises can be effective in this case as it is said to block up to 95% of the sun’s heat.

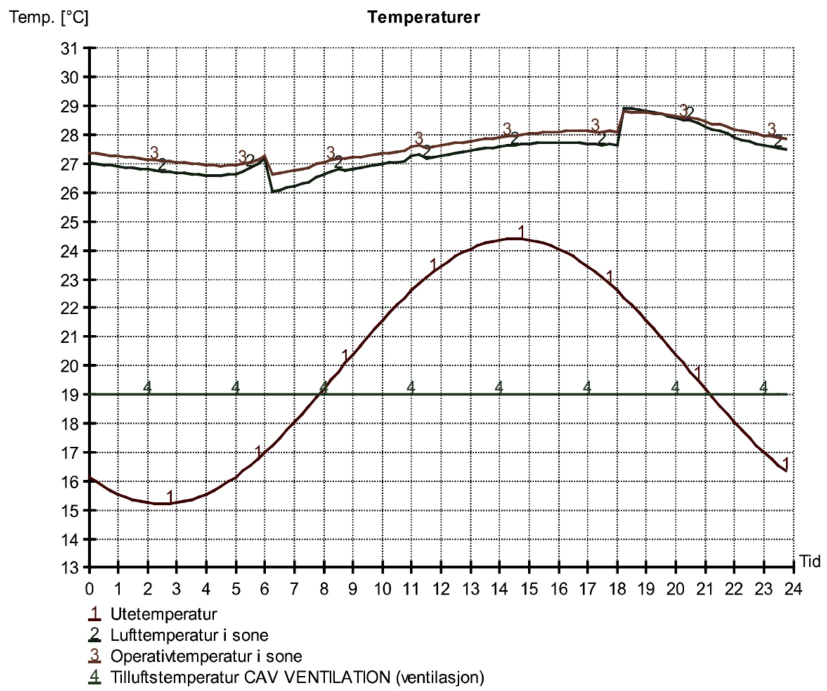


Fig - 35 Temperature - Summer

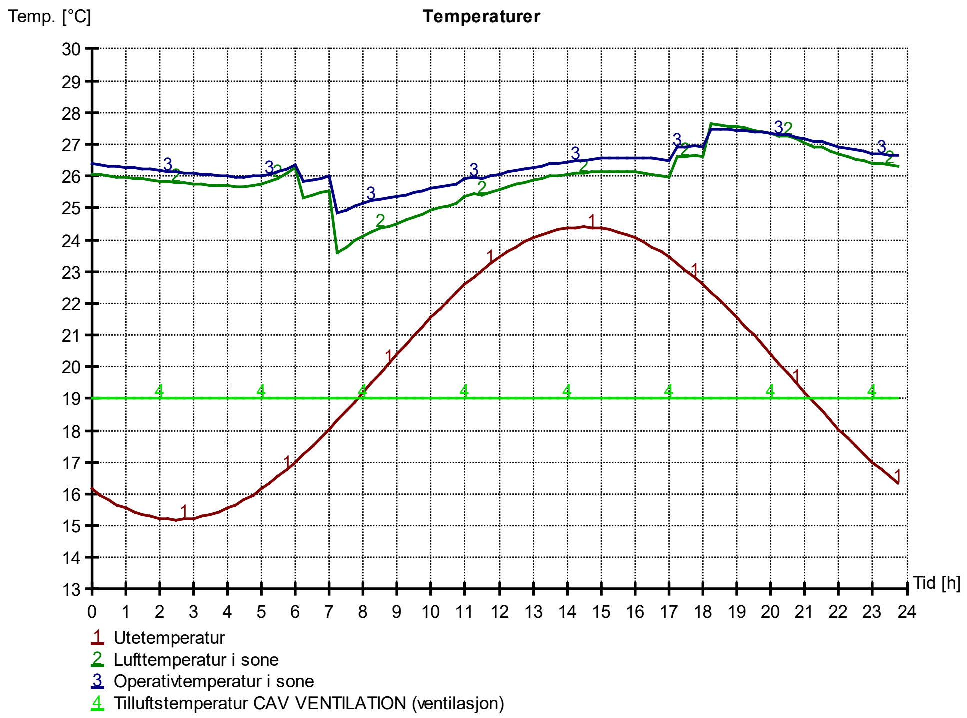


Fig -34 Temperature - Summer with window opening

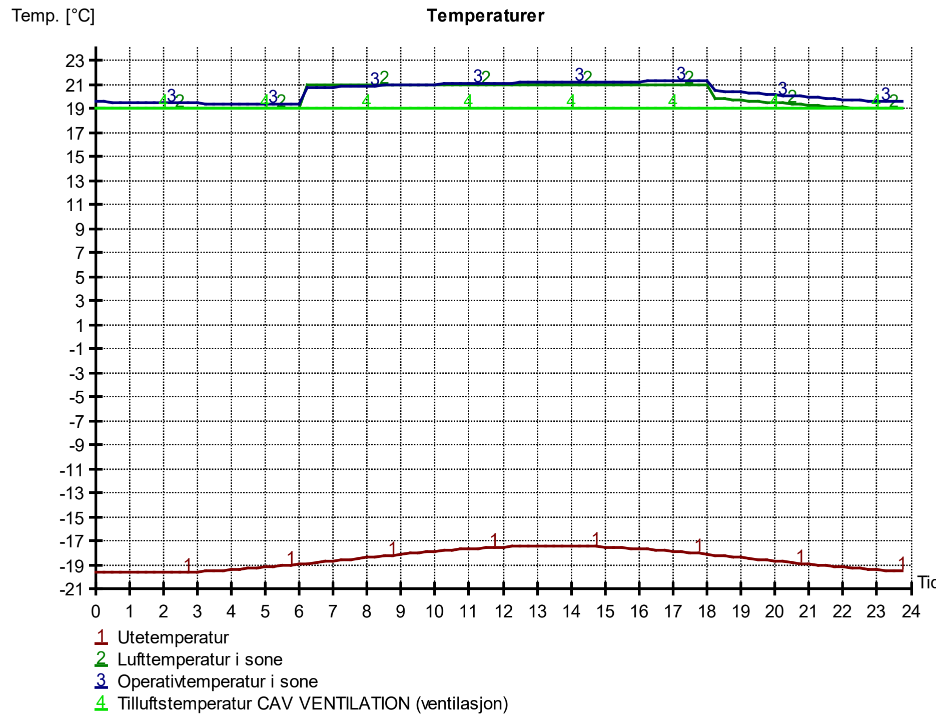


Fig - 36 Temperature - Winter

Discussion

In this project, several important design strategies were applied to achieve an energy-efficient building. Requirements were set first to reach the passive house standard and later optimize to achieve the ZEB – O ambition where on-site renewable energy production has to compensate for all the building's operational energy use. With this regard optimization strategies from early on design stage were undertaken, such as incorporating passive strategies, design of a well-insulated envelop, material choice and reduction to reduce embodied emissions, and daylight optimization. The importance of optimizing technical systems in a holistic approach throughout the design was also highlighted. The choice of energy systems, sizing, distribution, and optimizing their efficiency has led to changes in the building's delivered energy demand. The process of supplying on-site renewable energy production then realizes the net delivered and lastly weighs the building according to the CO2 equivalence of operational emissions in the building.

The project had ambitioned to reach ZEB - O balance meaning all emissions from the operational energy should be compensated from the on-site renewable energy production. However, the ZEB-O balance for all the greenhouse gas emissions associated with the building's operation energy could not be reached and falls short to fulfill the requirement Fig-38. The CO2 emission factor for the electricity from the grid is set as 0,132 KgCO2/kWh in the Simien calculations. The building's total CO2 emission per year is therefore 48550 kg-co2 eq. Electricity generated from PV in a roof area of 1600m2 and facade area of 500m2 offsets only -37219 Kg-CO2 eq emissions where 11331 Kg CO2eq emission is left uncompensated Fig -37. Further optimization of the glazing ratio and heat recovery efficiency could get the building closer to its target. Meanwhile, another scenario is as the building is situated in a Zero emission neighborhood, the performance of the neighborhood is evaluated as a whole, whereas borrowing the excess energy in the area or exporting it to the neighborhood is a possibility in a ZEN context. Therefore, the compensation for the building's greenhouse gas emissions could be realized on a neighborhood scale.

As this remains true it was finally set the building to see if it can achieve the lowest Zeb balance which is ZEB - O / EQ meaning Emissions related to all the energy use in operation except energy use for equipment shall be compensated with on-site renewable energy generation. As can be seen in Fig-39 the building can have a Zeb balance of ZEB - O / EQ compensating for attributed co2 emission of 3,9KgCO2eq/m2.

Energy supply	Emission (Kg-co2eq)	Emission (Kgco2eq/m2)
Electricity from Grid	37159	4,2
Heat pump	11391	1,3
Total	48550	5,5
PV production Total	-37219	-4,2
Net Balance	11331	1,3

Fig- 37 CO2 Emission balance in kgco2-eq

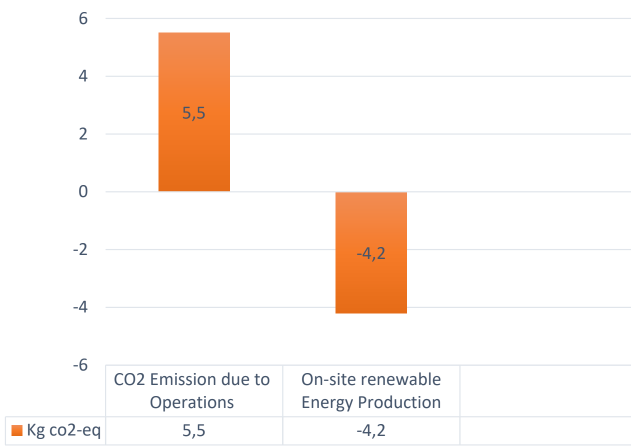


Fig- 38 Emission Balance for ZEB - O (Kgco2-eq)

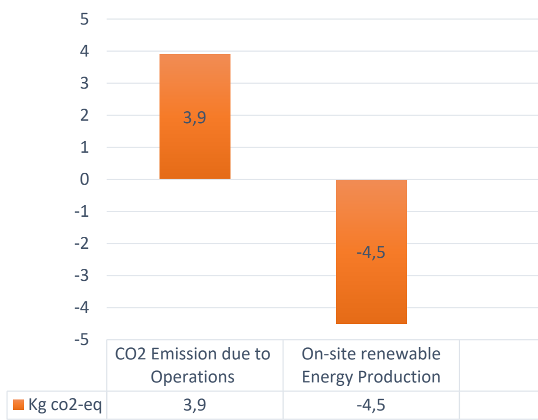


Fig- 39 Emission Balance for ZEB- O - EQ (Kgco2-eq)

Fig -40 North Elevation   Sc:1:200

Fig -41 West Elevation   Sc:1:200

Fig -42 South Elevation   Sc:1:200

Fig -43 East Elevation   Sc:1:200

3D View of the building from the main road.

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Appendix:

Output from Simien analysis with Technical Equipment

Energibudsjett

Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	142756 kWh	16,0 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	51723 kWh	5,8 kWh/m²
2 Varmtvann (tappevann)	44600 kWh	5,0 kWh/m²
3a Vifter	102177 kWh	11,5 kWh/m²
3b Pumper	9309 kWh	1,0 kWh/m²
4 Belysning	12542 kWh	1,4 kWh/m²
5 Teknisk utstyr	139385 kWh	15,7 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	7131 kWh	0,8 kWh/m²
Totalt netto energibehov, sum 1-6	509623 kWh	57,3 kWh/m²

Levert energi til bygningen (beregnet)

Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	285838 kWh	32,1 kWh/m²
1b El. til varmepumpesystem	87624 kWh	9,8 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	-134383 kWh	-15,1 kWh/m²
Totalt levert energi, sum 1-7	239079 kWh	26,9 kWh/m²
Solstrøm til eksport	-151916 kWh	-17,1 kWh/m²
Netto levert energi	87163 kWh	9,8 kWh/m²

Årlige utslipp av CO2

Energivare	Utslipp	Spesifikt utslipp
1a Direkte el.	37159 kg	4,2 kg/m²
1b El. til varmepumpesystem	11391 kg	1,3 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	-17470 kg	-2,0 kg/m²
Totalt utslipp, sum 1-7	31080 kg	3,5 kg/m²
Solstrøm til eksport	-19749 kg	-2,2 kg/m²
Netto CO2-utslipp	11331 kg	1,3 kg/m²

Output from Simien analysis with out Technical Equipment

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	208271 kWh	23,4 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	54089 kWh	6,1 kWh/m²
2 Varmtvann (tappevann)	44600 kWh	5,0 kWh/m²
3a Vifter	102177 kWh	11,5 kWh/m²
3b Pumper	10885 kWh	1,2 kWh/m²
4 Belysning	12542 kWh	1,4 kWh/m²
5 Teknisk utstyr	0 kWh	0,0 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	7131 kWh	0,8 kWh/m²
Totalt netto energibehov, sum 1-6	439695 kWh	49,4 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	149646 kWh	16,8 kWh/m²
1b El. til varmepumpesystem	114717 kWh	12,9 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	-79902 kWh	-9,0 kWh/m²
Totalt levert energi, sum 1-7	184461 kWh	20,7 kWh/m²
Solstrøm til eksport	-206398 kWh	-23,2 kWh/m²
Netto levert energi	-21937 kWh	-2,5 kWh/m²

Årlige utslipp av CO2		
Energivare	Utslipp	Spesifikt utslipp
1a Direkte el.	19454 kg	2,2 kg/m²
1b El. til varmepumpesystem	14913 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	-10387 kg	-1,2 kg/m²
Totalt utslipp, sum 1-7	23980 kg	2,7 kg/m²
Solstrøm til eksport	-26832 kg	-3,0 kg/m²
Netto CO2-utslipp	-2852 kg	-0,3 kg/m²

- U - Value result for the wall component and roof