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Modification of ZEB Lab (NTNU) building design – prioritizing passive climate control & comparison with existing

Master's thesis in Sustainable Architecture
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Master's thesis

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Acknowledgement

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I would like to thank my supervisor Neil Alperstein and co-supervisor Matteo Tagnocchetti for all the guidance, feedback and help during whole work process. All the discussions we had were helping me to move further investigating the new boundaries of the project. Also would like to thank my groupmate Soumenh Leng, as we had same end goal in similar topic, but different approaches, we were having discussions with teachers together. Thus, we had twice more feedback and information about the project, which also made the whole process very exciting. Additionally, I would like to thank Erlend Andenæs and Tore Kvande for providing us all possible information about ZEB Laboratory, and guided tours inside the building with all the answers for our questions. With all that support, the process of making this thesis was not only very interesting, but also much fun. Finally, I would like to thank my family for the encouraging words, ideas and support.

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Department of Architecture and Technology, NTNU, Trondheim, May 19th, 2022

Abstract

Sustainability is one of the fast-developing trends in every aspect of our lives, each year demand and goals for making less pollution of the environment is increasing. Thus, buildings as one of the highest pollutants must be not only, reconsidered as a way of construction materials and energy consumption, but also kept up with the stricter sustainable standards which appears each year, to reach the highest ZEB (Zero Emission Building) goals.

Study will include redesign of existing ZEB building, which is located in NTNU Gløshaugen campus in Trondheim. A ZEB Laboratory is an experimental facility, it plays role as a testing place of new technologies on a larger scale. The ambitions of that building is to achieve ZEB–COM level in 60 years perspective.

This thesis aims to unveil new possibilities of passive strategies together with finding better combinations with active ones to decrease building's energy consumption, with keeping or improving indoor comfort. Main goal is to reach the ZEB-COM level with using same amount of material or less, with the same area of the building, and implementation of new or improving existing passive strategies. There will be simulations of different possible modifications of form of ZEB Laboratory, with their pros and cons in comparison with existing one, to find the best possible shape in terms of energy consumption and PV production.

In the end there will be two proposed shapes in comparison with existing one. First form is called "Big North" will have lesser energy consumption and similar PV production as the existing one, with the ZEB Balance calculation of (-0,22) in comparison with existing (-0,17), both reached ZEB-COM level. Then the second form "Small North" will have even lower energy consumption due to the shape, however much smaller PV production, which will lead to not reaching ZEB-COM (0,66).

At the level of a ZEB-COM building it is difficult to introduce changes which would make a significant difference. As one can see from the results, the improvements are small in relation to the existing ZEB lab, but it is possible to make improvements with replanning of windows placements, reducing of material usage and modifying passive strategies. My research shows that one can achieve some improvements by prioritizing passive strategies in the context of finding a balance between passive and active strategies.

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1 INTRODUCTION

1.1 Background

One of the most profitable measures to reduce greenhouse gas emissions is transition to energy-efficient buildings, as zero-emission building shall not contribute to greenhouse gas emissions by generating more energy than it uses through its lifetime.

ZEB “Flexible” Laboratory is a zero-emission building, of a ZEB-**COM** category, which means that building generates more energy than it uses (**O**peration) also compensates energy that was needed in production of materials for the building (**M**aterials) and their construction on site (**C**onstruction).

ZEB Lab is located in Trondheim, Norway at the NTNU Gløshaugen campus, it is an office and educational building with focus on research of the innovative materials and solutions that can be investigated, developed, tested and demonstrated.

The shape of the building has been inspired by the form of the silicon crystals and with respect to surrounding area [1]. Roof has an angle of 30^{O} with integrated PV panels of 21,5% efficiency, also South, West and East facades has BIPV panels with 16% efficiency [2].

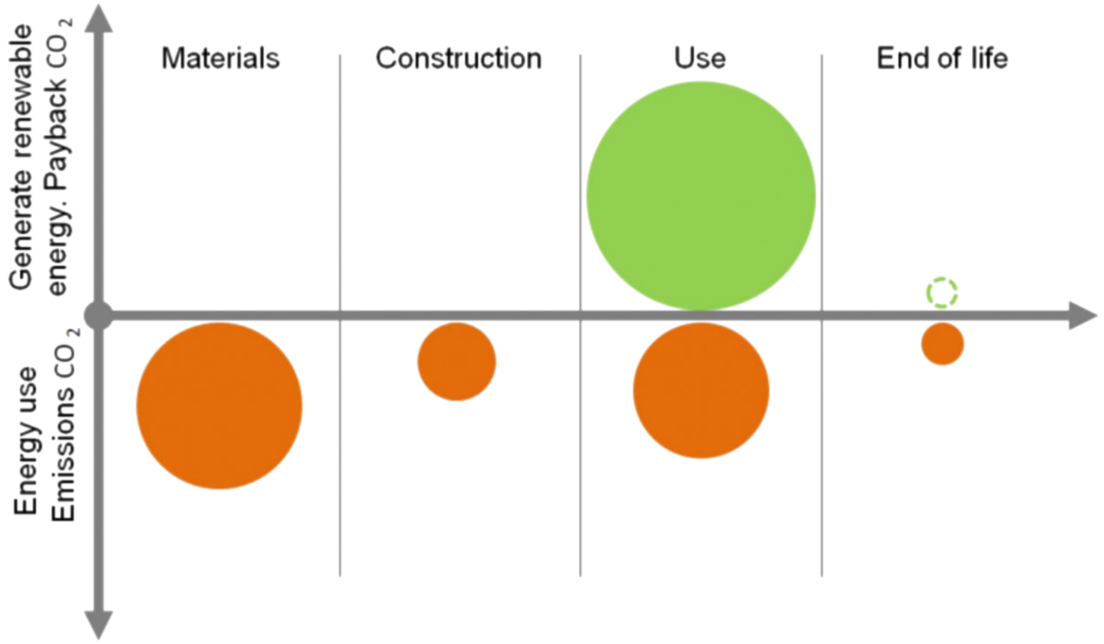


Figure 1: Correlation between CO2 emissions and renewable energy for ZEB

- 2000 sq. m gross total area

- Located in Trondheim at the NTNU Gløshaugen campus

- ZEB-COM

- The first floor is 440 m2 (due to two inclined walls)

- The second and the third floor is 448 and 453 m2

- The fourth floor is 414 m2

Figure 2: General plan of ZEB Lab

Figure 3: 3D visualization of existing ZEB Laboratory

1.2 Objective and aim

The objective of this thesis is to analyze the design that has been made in ZEB Laboratory, understand how and why those decisions affect energy production of the building, as well as inner environment for the workers. Find passive strategies that were implemented in the design of the building and try out new strategies with comparison results to existing building.

Focus on the passive climate control inside of the building by changing the shape and position, keeping the same amount of materials or even lowering their amount. Increasing solar heat gain with reducing surface areas that can be a source of heat loss, especially on the north part of the building. The main goal is to reach the same level of ZEB-COM (to have more energy production than was used during Construction, Operation and Material production in a 60 year lifetime of the building), by reducing consumption of energy of the building.

First of all, prioritize the passive strategies, excluding changing materials or improving efficiency of BIPV (Building Integrated Photovoltaic), keeping the same footprint and overall gross total area, in order to make fair comparison to existing building. The amount of material should be kept same or reduced, to have same LCA (Life Cycle Assessment) in the end calculation of ZEB balance.

The aim is to explore and test other solution that might improve or worsen the energy consumption and energy production of ZEB Laboratory, not only pushing boundaries of passive strategies to the maximum, but also gathering the data for future exploration in case of another construction of similar ZEB-COM building.

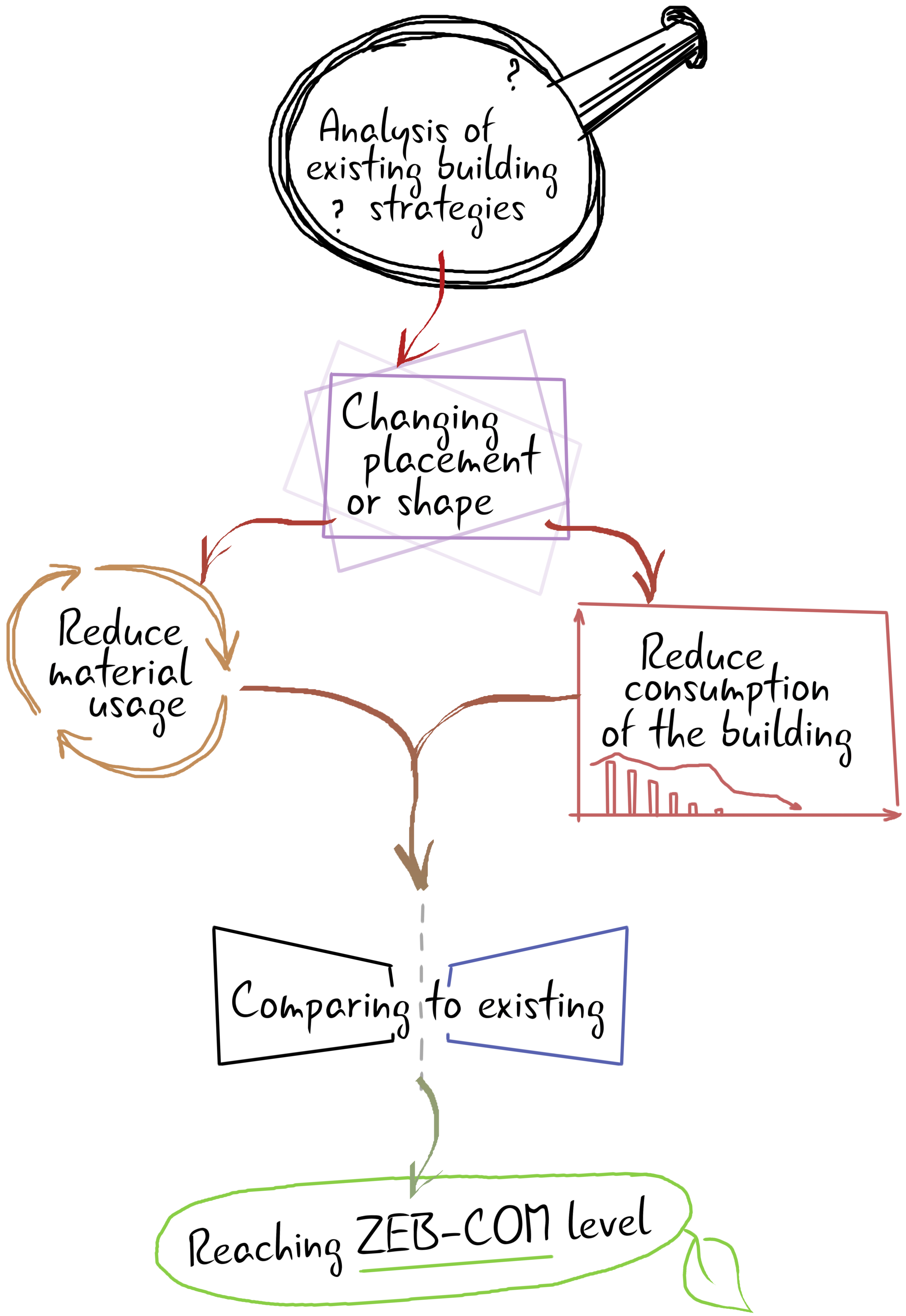


Figure 4: Simplified version of roadtrip to the goal

1.3 Methodology

This thesis will start first from collecting data of existing building, for example, what material has been used, drawings of existing ZEB Lab from architecture companies who were responsible for that building, all possible calculations that were made (especially Simien, as that is one of the main software in Norway for calculation ZEB building's consumption, production etc.). Several visits on site with help of PhD workers from the building, which can help to get an answer for certain questions from professionals and people who participate in ZEB Lab research.

The project is going in parallel with the other groupmate that had the similar topic about ZEB Laboratory, but in his case the building is fully rebuilt, whereas in my case the shape is modified. All gathered information and simulation results are shared between us, to improve efficiency and reduce workload for each other.

That information helps to develop a simulation model of ZEB Laboratory in different software for example:

1. Revit (Drawings and PV analysis)
2. Rhino, Grasshopper (Solar radiation, Energy simulation and Daylight analysis)
3. Simien (Energy calculations, PV production, ZEB balance)

First step in analysis of the existing building is understanding what and why it was made the way it is, then trying different positions (rotation of the building by it's axis towards west and east with energy simulations to see the fluctuations in results). After finding optimal position try different shapes of the building, also with comparison to existing one in energy consumption. Then, excluding all forms that are not beneficial in terms of energy consumption and comparing their PV production. In order to reach ZEB-COM level amount of energy given to the grid should outweigh energy used for construction, operation and materials of the building, thus if it possible I will try to reduce the amount of material used in the building without harming environment inside the building. For that, Daylight simulations will be given, to show that conditions inside of the building didn't change in a bad way in comparison with existing.

After getting the results compare and find best possible shape of the building, with it's pros and cons, also calculate the ZEB balance similar way that existing building made their calculations, to prove that the shape or shapes reached ZEB-COM level.

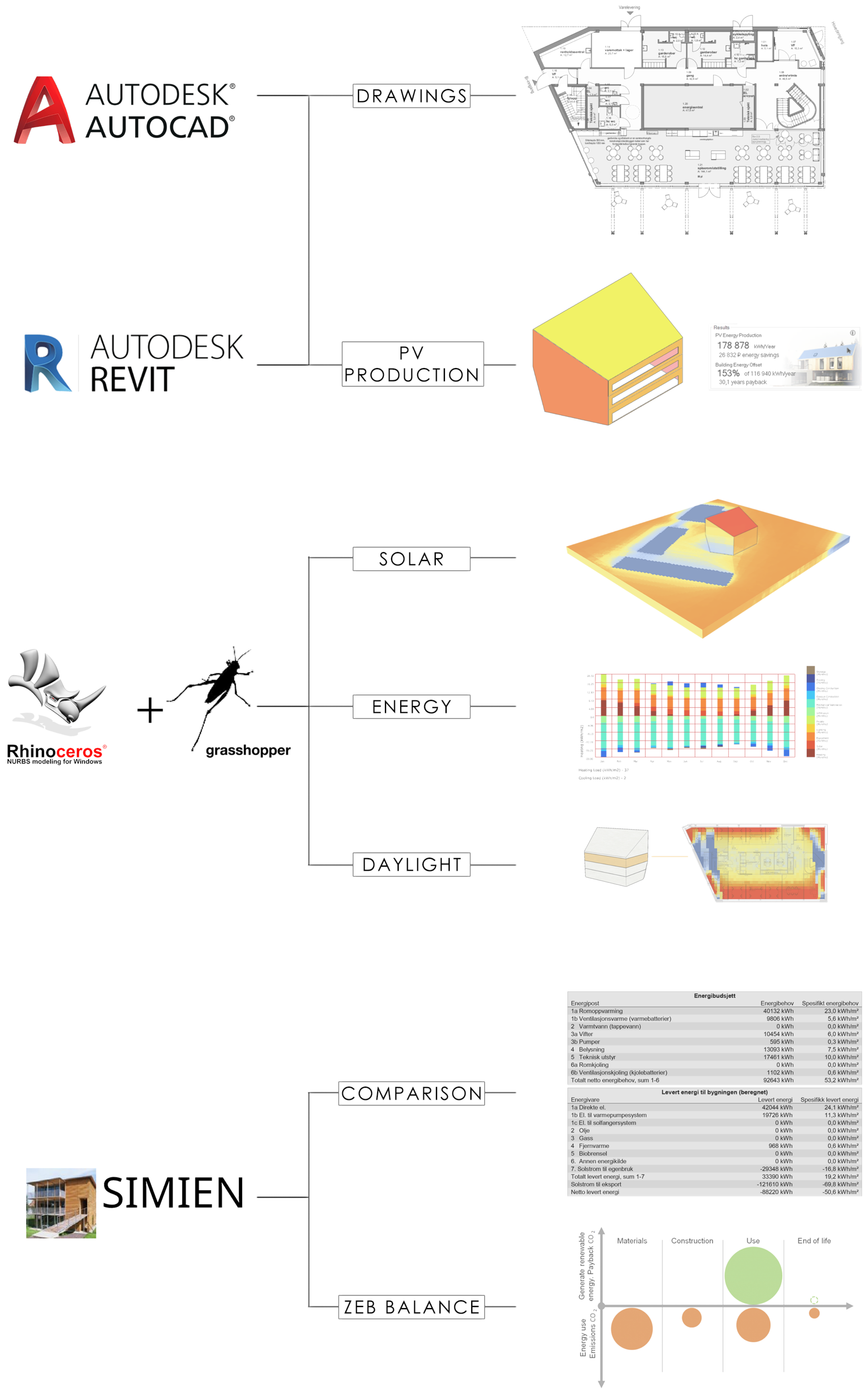


Figure 5: Types of software used in thesis

1.4 Limitations and framing of the project

ZEB "Flexible" Laboratory - is called flexible for a reason that it can be modified, anytime during operational time, for example facades should not have difficult forms as it will be changed during tests. Even the form of the windows will play a role for study purposes, as the building is meant to be as a testing, teaching and working laboratory at different times during whole lifetime. Even inside areas should be easily changeable for different needs.

"Twin rooms" the two identical rooms on the second floor, that made for testing comparable conditions should be placed next to each other on the South part of the building, having same amount of glazing and area, as they have separated AHU (Air Handling Unit) from the building, just for themselves, in order to have flexible schedule of testing from the rest of the rooms [15].

Solar PV panels - in order to have fair comparison of new shapes in thesis, roof PV panels have 21% efficiency, whereas the facade PV panels have 16% completely the same as in existing ZEB Lab [3].

Total area of the building should not exceed 2000 sq.m., also the amount of materials used should either be the same or less. Preserve all the special technical rooms, also preserve passive strategies that already implemented into the building such as staircases that work as an extract shafts [4].

Ventilation systems on each floor of the ZEB Laboratory is different, in order to test all possible types, thus ventilation types should stay the same as in existing one to keep modified ZEB Lab as a research building.

Height of the building should not be taller than the existing one, recommended to have same amount of storeys.

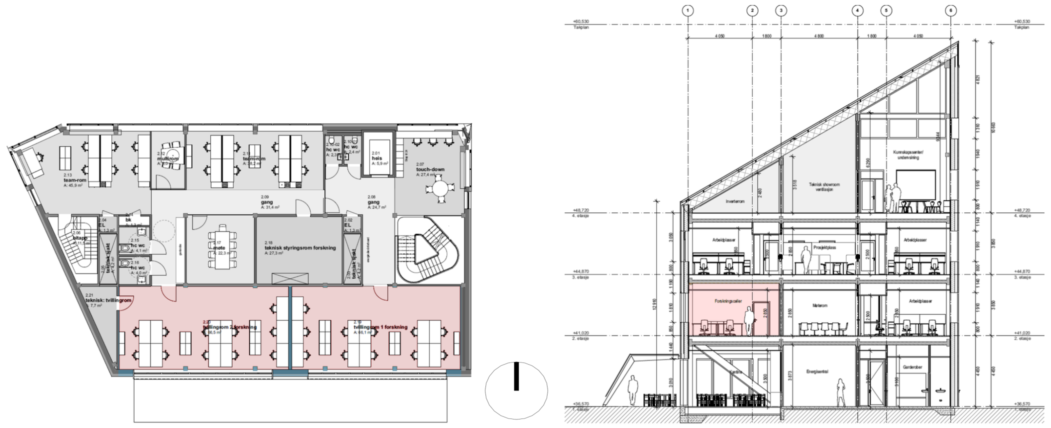


Figure 6: Twin rooms on plan of the second floor, and section

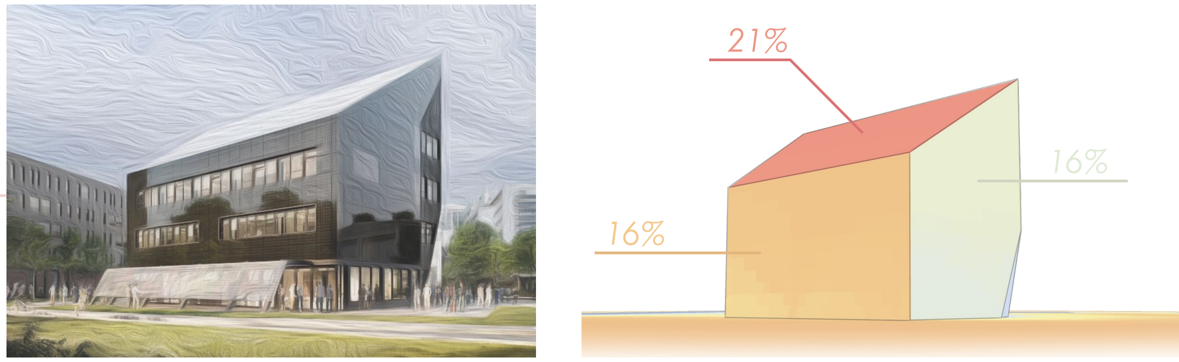


Figure 7: Building integrated photovoltaics with different efficiency

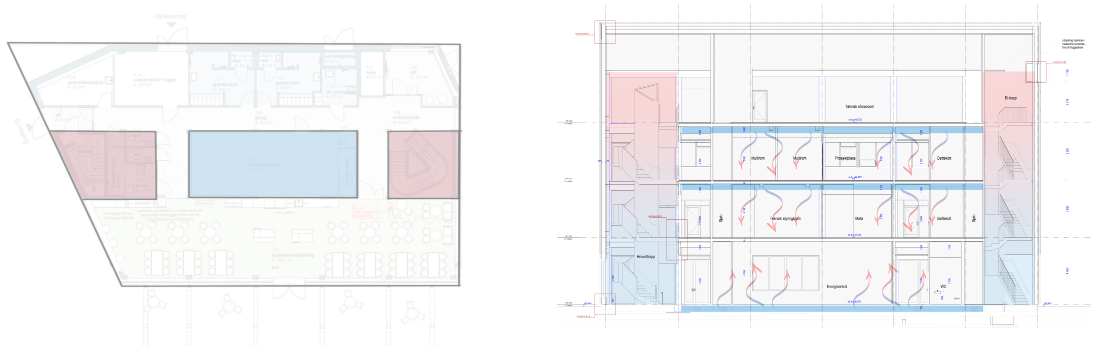


Figure 8: Staircases and technical rooms on the left, Stack effect and different types of ventilation on the right

2 ARCHITECTURAL ANALYSIS OF THE EXISTING BUILDING

2.1 Form development

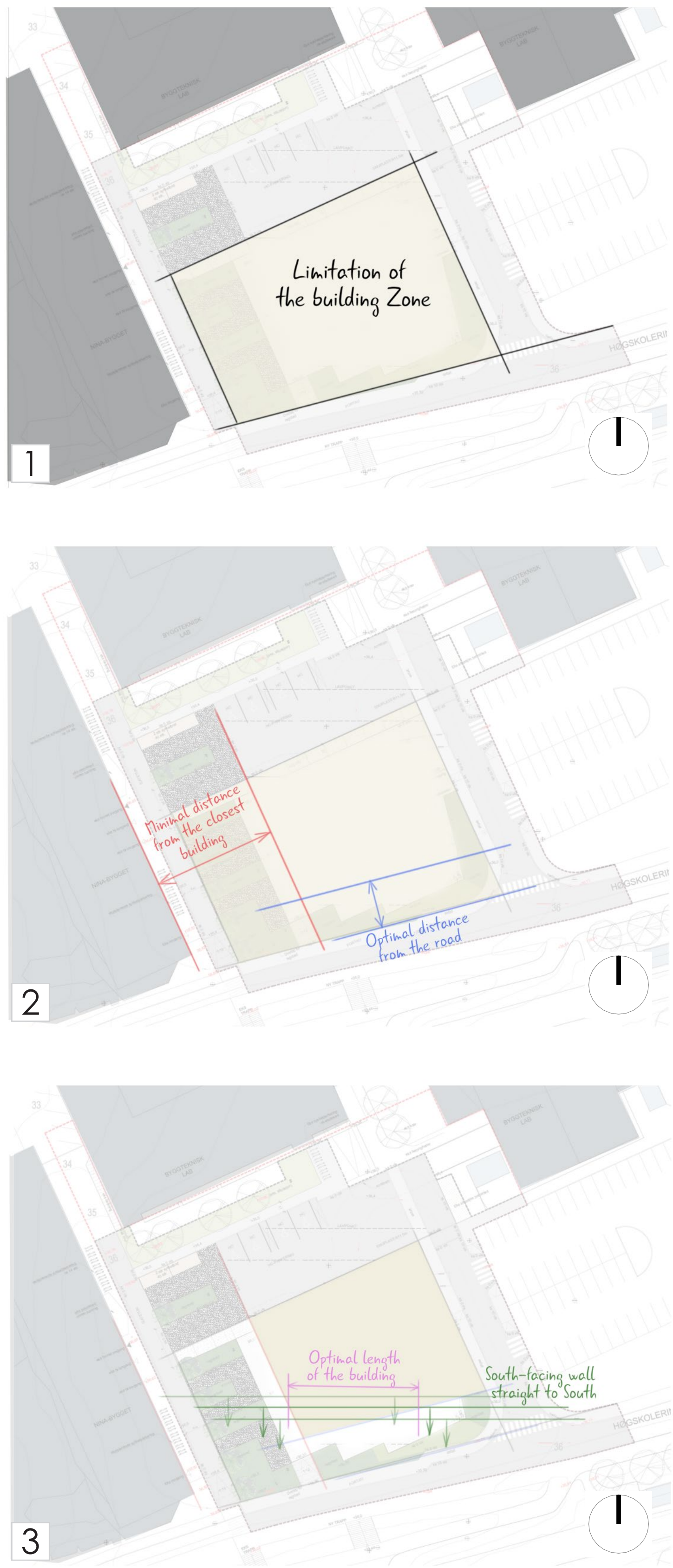


Figure 9: First three steps of form development

The architectural analysis of ZEB Laboratory, which reflects my assumptions and thoughts of how the building was made, after collecting all the data for the existing building, also with interviewing workers and after having presentation from Erlend Andenæs. Simplified version of form development is illustrated in six steps how the shape of the building appeared as it is now.

At the first step (1) defining limitations of building zone in all directions, basically finding frames of construction area with respect of surroundings.

The second step (2) is to take into consideration neighboring buildings, for instance, optimal distance between existing buildings and proposed one (ZEB Lab) [7]. Thinking about, not only to not block the view for neighboring buildings or possible view of ZEB Lab [9], but also not to build a new one in the shade of the existing ones [8]. Thus, optimal distance from west neighboring building was chosen in parallel to it. Some distance from south-east was cut further from the road area [10], probably to place greenery in order to reduce noise, and create division space from road area [11].

Next step (3), after cutting away all previous areas, they ended up with this form. Now thinking about "twin-rooms" that were planned to be in the ZEB Lab [3], they need to have a south facade looking straight to the south with approximately from 20 to 30 meters length of the facade.

Moving forward (4), after getting the cut on south, they measured the distance of the light getting through the windows inside of the building, in range of 4 to 6 meters [12]. In their case they chose 5.6-5.8 meters with planning that the middle part will have all the technical rooms, staircases and meeting rooms that won't require daylight [13].

After knowing site limitations on west, south and north parts (5), the cut on east side was made approximately to make the size of the building smaller. The perpendicular cut presumably was made to test different angle of PV panels on the facade. As the building had a sharp edges on pedestrian level on north-west and north-east sides, cuts were made to facilitate passage from the adjacent building to the west to the parking lot to the east.

The cuts, as it is seen in step six (6), are not going until the roof, as the roof area was enlarged back for the increase of area for PV panels on the roof.

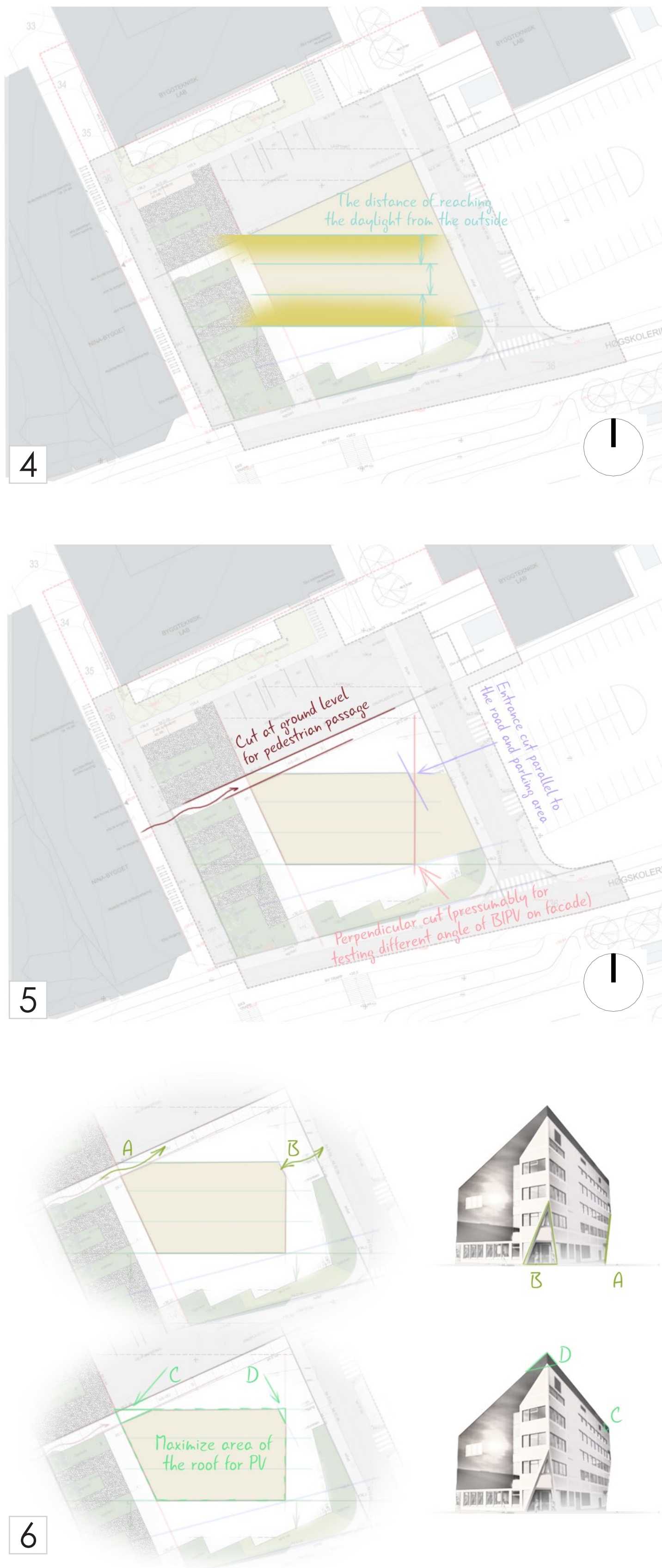


Figure 10: Last three steps of form development

2.2 Passive strategies

The major passive strategy of the ZEB Laboratory is using staircases, that are located on west and east parts of the building, as a ventilation shafts (Figure 11) [14].

The principle is called "stack effect" - it occurs due to the warm air being less dense, thus it has tendency to rise [4]. When cooler air is supplied at the bottom of the building, after contacting with heat sources (people, heating, equipment, solar gain), the air warms and goes up due to buoyancy [5]. Buoyancy is an upward force exerted by a fluid, and the air is made of air particles that are loosely held together in a gas form, which makes it some sort of fluid, thus by extracting exhaust warm air next to the staircases at the top floor, they created that stack ventilation.

Each floor has different type of supplying air in research purposes. The best one, by the interviewing worker's experience during work inside the building, is the one on the first floor, which was made by creating an empty cavity between floor and false floor, to pump fresh cool air inside that cavity. Due to pressure the air rises through the ventilation valves on the floor, after warming moves to the staircases and up.

On the other floors instead of making cavity between floor and false floor, they have done those cavities between ceiling and false ceiling. Each floor has different types and placement of ventilation valves in a different zones (places), also it is flexible to change, in order to have variety of tests.

Air handling unit (AHU) is located at the top floor with a heat exchanger, that allows to transfer heat from warm exhaust air to fresh cool air, which helps in energy savings for heating.

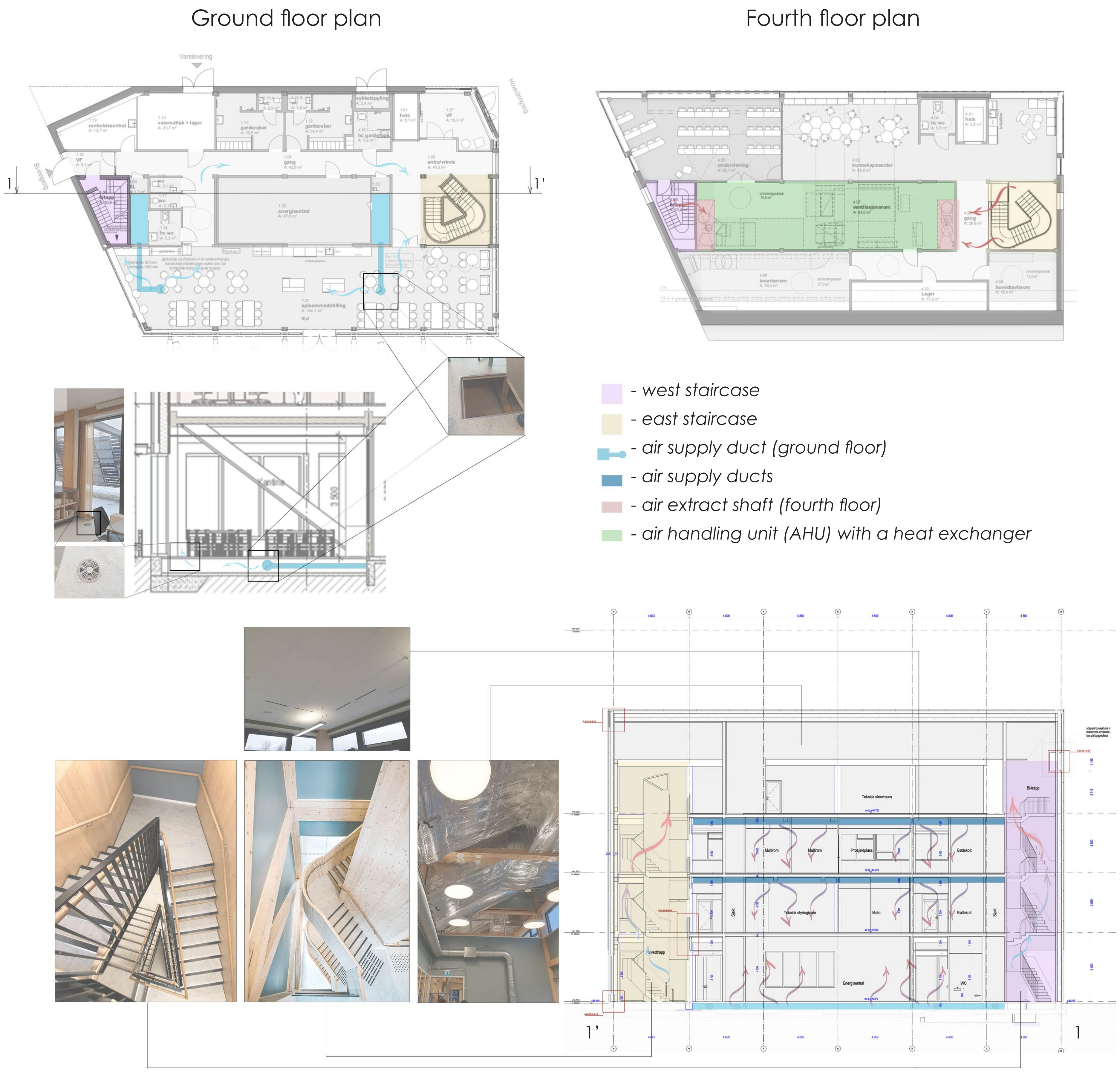


Figure 11: Ventilation strategies

3 GATHERED DATA FOR EXISTING BUILDING

3.1 Data for simulations

The main data for Simien was taken from Tore Kvande (professor of building materials) with help of Erlend Andenæs (PhD student), most of the numbers and settings were taken from the Energy concept report [19]. However, because I had only PDF with some input data and final results in there, thus I made a simien simulation of existing ZEB Laboratory building, using those data from report.

According to all data of simien I had, I got these results (Figure 12), which closely represents original results from PDF, that is why next comparisons of modified forms of ZEB Lab in thesis will be done to my simulation of existing ZEB Lab. Because, in order to have fair comparison of new modifications, all the settings inside the software should be similar, then changes in results will be more precise.

With the data from simulation I compared the results in ZEB Balance from Erlend Andenæs's presentation, in which we can see how ZEB Laboratory reached the ZEB-COM level. To reach that level building should import more energy, how it is seen in (Figure 12), than energy was used during material production (5,32), construction (1,20) and operation time (4,73). In my simulation materials and construction stays the same as it is the same existing building, however use and PV production is a little bit different. I assume, the difference in those numbers appeared because in my simulation I used full area of the facade (excluding windows) as a PV panel's area, which is not possible in realistic way, as there will be spaces where PV panels won't fit or the gaps between them. Thus, in my future modifications of the ZEB Lab building I will use same strategy of using whole area of facade (excluding windows) as a PV panel area.

EXISTING BUILDING (PDF)

Energy budget from PDF

Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	54355 kWh	31,2 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	7504 kWh	4,3 kWh/m²
2 Varmtvann (tappevann)	1745 kWh	1,0 kWh/m²
3a Vifter	10676 kWh	6,1 kWh/m²
3b Pumper	675 kWh	0,4 kWh/m²
4 Belysning	13093 kWh	7,5 kWh/m²
5 Teknisk utstyr	17461 kWh	10,0 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	0 kWh	0,0 kWh/m²
Totalt netto energibehov, sum 1-6	105510 kWh	60,6 kWh/m²

Energy supplied to the building without PV panels

Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42516 kWh	24.4 kWh / m²
1b El. for heat pump system 1c	20541 kWh	11.8 kWh / m²
El. for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	1221 kWh	0.7 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 0 kWh	- 0.0 kWh / m²
delivered energy, total 1-7 Solar	64278 kWh	36.9 kWh / m²
power for export	- 0 kWh	- 0.0 kWh / m²
Net delivered energy	64278 kWh	36.9 kWh / m²

Energy supplied to the building with PV panels

Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42516 kWh	24.4 kWh / m²
1b El. for heat pump system 1c	20541 kWh	11.8 kWh / m²
El. for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	1221 kWh	0.7 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 28317 kWh	- 16.3 kWh / m²
delivered energy, total 1-7 Solar	35961 kWh	20.6 kWh / m²
power for export	- 118197 kWh	- 67.9 kWh / m²
Net delivered energy	- 82236 kWh	- 47.2 kWh / m²

EXISTING BUILDING (MY SIMULATION)

Energy budget from my simulation

Energy post	Energy needs	Specific energy needs
1st Room heating	40407 kWh	23.2 kWh / m²
1b Ventilation heating (heating	9814 kWh	5.6 kWh / m²
batteries) 2 Hot water (tap water)	0 kWh	0.0 kWh / m²
3a Fans	10454 kWh	6.0 kWh / m²
3b Pumps	595 kWh	0.3 kWh / m²
4 Lighting	13093 kWh	7.5 kWh / m²
5 Technical equipment	17461 kWh	10.0 kWh / m²
6a Room cooling	0 kWh	0.0 kWh / m²
6b Ventilation cooling (dress batteries)	1102 kWh	0.6 kWh / m²
Total net energy requirement, sum 1-6	92926 kWh	53.3 kWh / m²

Energy supplied to the building without PV panels

Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42044 kWh	24.1 kWh / m²
1b El. for heat pump system 1c El.	19838 kWh	11.4 kWh / m²
for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	975 kWh	0.6 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 0 kWh	- 0.0 kWh / m²
energy delivered, total 1-7 Solar	62857 kWh	36.1 kWh / m²
power for export	- 0 kWh	- 0.0 kWh / m²
Net delivered energy	62857 kWh	36.1 kWh / m²

Energy supplied to the building with PV panels

Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42044 kWh	24.1 kWh / m²
1b El. for heat pump system 1c El.	19838 kWh	11.4 kWh / m²
for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	975 kWh	0.6 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 29368 kWh	- 16.9 kWh / m²
energy delivered, total 1-7 Solar	33489 kWh	19.2 kWh / m²
power for export	- 121590 kWh	- 69.8 kWh / m²
Net delivered energy	- 88101 kWh	- 50.6 kWh / m²

Figure 12: Simien simulation results of existing ZEB Laboratory in PDF from Tore K., and my simulation

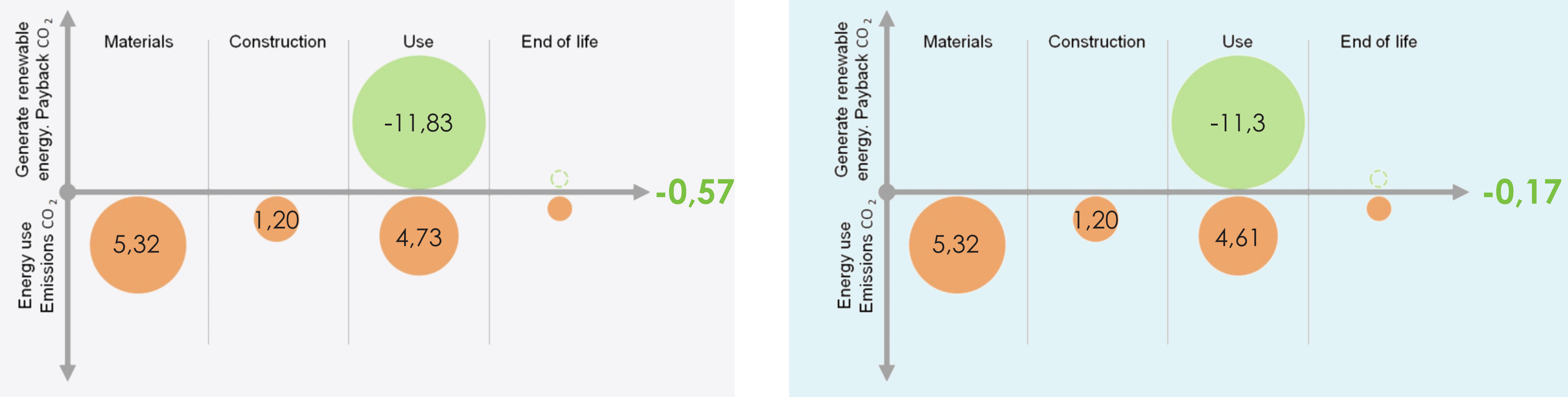


Figure 13: Comparison of ZEB balance calculation to reach ZEB-COM level in PDF from Tore K., and my simulation

3.2 Materials and other specifications

Component	Lifetime (years)	U-value ($W/m^2 K$)	Documentation
Roof	60	0.09	Insulated barrier roof of I-profiles, t_{iso}= 450 mm, t_{beam}= 48 mm, λ_{iso}= 0.036 W / mK
Exterior walls	60	0.15	Insulated truss, t_{iso}= 300 mm, t_{stands}= 48 mm, λ_{iso}= 0.033 W / mK Insulated truss, t_{iso}= 225 mm, t_{stands}= 48 mm, λ_{iso}= 0.033 W / mK
Windows fixed/openable wood	40	0.77	According to environmental product declarations (EPDs), windows and doors without/with aluminium cladding have an expected lifetime of 40/60 years
Windows fixed/openable wood+aluminium	60	0.77	
Ground floor	60	0.10	Floor on ground, t_{iso}= 250 mm, λ_{iso}= 0.038 W / mK

Figure 14: Materials with their lifetime and U-value

All these data was gathered from different sources, for instance the energy concept report with simien calculations from Tore K. [19], and report on nZEB cost calculation [6].

Figure 14, shows the main U-values for the simulation input, for both Simien and Rhino (Grasshopper) software.

Figure 15, illustrates the values that was implemented in Simien simulation, more specifications will be added in appendix, here are only main values. For example, temperature efficiency for heat recovery or with other words efficiency of heat exchanger, was written as an 85/88 (%), however in the energy concept report that we got from Tore K. [19], they reduced it in the final simulation to 84% (more realistic value), which can be seen in (Figure 12). Thus, in all modifications efficiency of heat recovery is also set to 84% to compare buildings in more realistic way.

Component	Input	Documentation
Normalized cold bridge value (Ψ) [W / m2K]	0.04	Given in 418722-RIBfy-NOT-002
Normalized heat capacity (c '') [Wh / m2K]	81	Solid wood constructions. Molded core and sole.
Temperature efficiency (ηT) for heat recovery [%]	85/88	Concept value. Good heat recovery, for TEK calculations. Unit runs for NS 3701 air volumes. Measurements on existing ventilation units have shown that this value can be on the unsafe side when driving the unit on partial load. In real calculation, a value corresponding to the concept value has been entered.
Specific fan power (SFP) related to air volumes during operating time [kW / m3/ s]	1.0/0.9	Estimated value based on unit driving for TEK for balanced system. For passive houses, SFP is documented in NOT-RIV-01 ZEB flexible lab - documentation of calculated specific fan effect
Specific fan power (SFP) related to air volumes outside operating time [kW / m3/ s]	0.5	For balanced system
Total sun factor (g_t) for window and sun protection	0.31	Windows, whole built: - Three-layer window with low-emission coating (g_{tot}= 0.45) South-facing windows behind transparent solar cells - Three-layer window with low-emission coating (g_{tot}= 0.35) South - Three-layer window with external sun protection (g_{tot}= 0.10) East and West - Three-layer window with low-emission coating and interior screen (g_{tot}= 0.35).

Figure 15: Major specifications for simulation

4 FINAL DESIGN PROPOSAL

This is brief introduction to the final shape proposal, which showed better results in comparison with existing ZEB Laboratory. The consumption of the building is reduced, not only by reducing the amount of window area on the north part of the building, but also with the new shape heat gains of the building increased, which reduced the energy for heating. Photovoltaic production of energy is the same as in existing building which helps in reaching the ZEB - COM level in ZEB balance calculation, and due to lower energy consumption of the building, the final result in ZEB balance is better than in existing building.

The form has most of the strategies passive and active that was used in existing ZEB Lab, with addition of extra solar heat gain due to the shape. It was a long way to find the most optimal shape with having all the limitations of the project, which you can see in "limitations and framing of the project" section.

At the beginning, this form (Figure 16) has shown the worst results in reducing energy consumption, as the simulations were made in comparison with existing building with having the same amount of window area. However, with implementation of more passive strategies such as heat gain on the south part of the building, and reduction of the glazing area on the north part of the building, also with careful replanning inside spaces with respect to existing room areas, the shape became the best one in reaching ZEB balance.

The final ZEB balance calculation was made with having same amount of materials (5,32), which in further work can be recalculated to more accurate values with Life Cycle Assessment, as the windows will have more CO2 footprint than the wood walls with insulation, thus the amount of material in this calculation should be lower (Figure 17), which will make the final result even better.

My main goal was to make more optimal shape for existing building, with increasing passive strategies while preserving most of the decisions of the existing one. The report from my groupmate Soumenh L. will show the other case, if the building was redesigned completely from scratch.

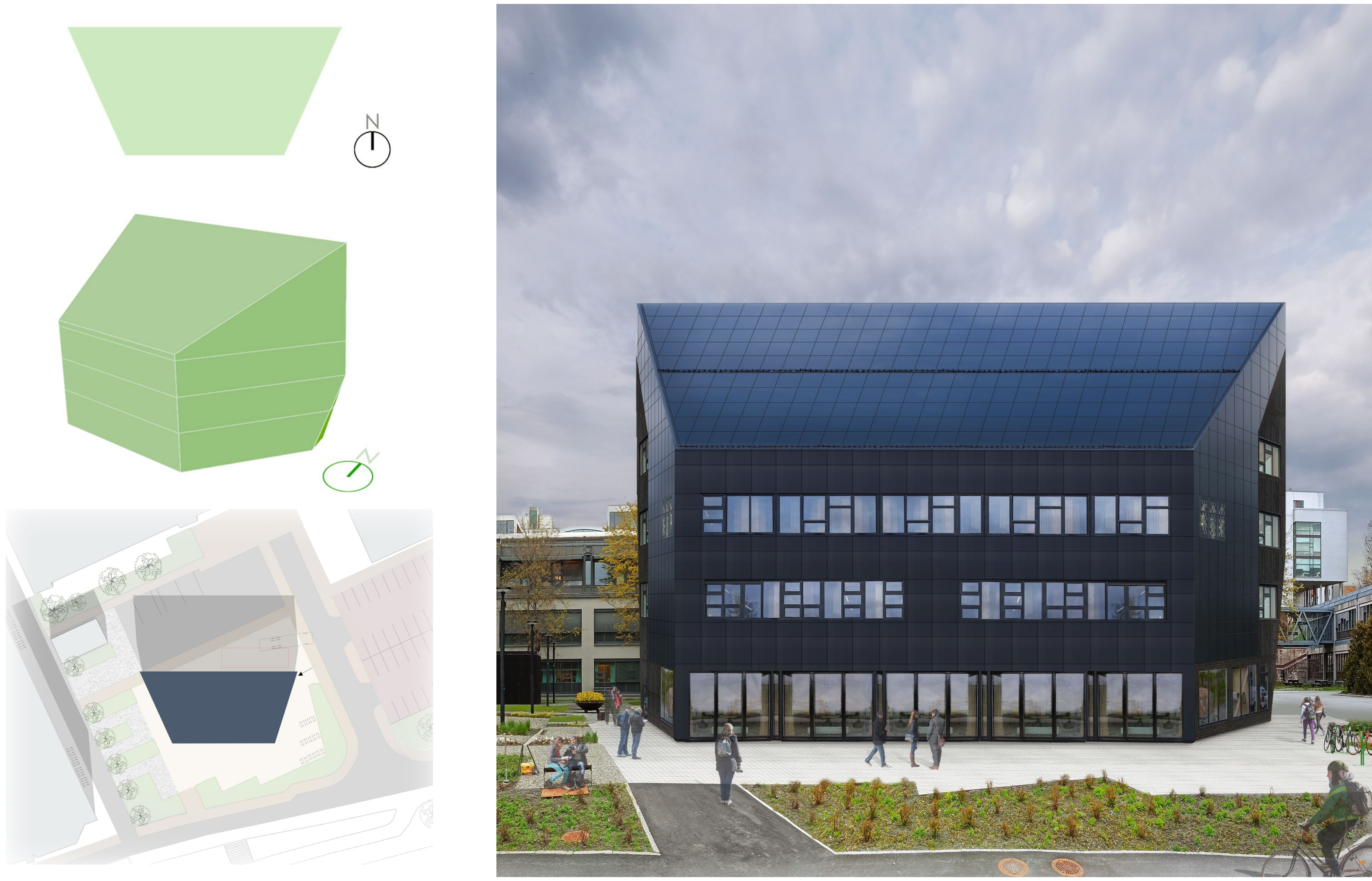


Figure 16: Graphic illustrations of the shape, general plan and 3D visualization

Energy post	Energy needs	Specific energy needs
1st Room heating	38958 kWh	22.4 kWh / m²
1b Ventilation heating (heating	9716 kWh	5.6 kWh / m²
batteries) 2 Hot water (tap water)	0 kWh	0.0 kWh / m²
3a Fans	10454 kWh	6.0 kWh / m²
3b Pumps	595 kWh	0.3 kWh / m²
4 Lighting	13093 kWh	7.5 kWh / m²
5 Technical equipment	17461 kWh	10.0 kWh / m²
6a Room cooling	0 kWh	0.0 kWh / m²
6b Ventilation cooling (dress batteries)	1102 kWh	0.6 kWh / m²
Total net energy requirement, sum 1-6	91378 kWh	52.5 kWh / m²

Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42044 kWh	24.1 kWh / m²
1b El. for heat pump system 1c El.	19222 kWh	11.0 kWh / m²
for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	940 kWh	0.5 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 0 kWh	- 0.0 kWh / m²
energy delivered, total 1-7 Solar	62205 kWh	35.7 kWh / m²
power for export	- 0 kWh	- 0.0 kWh / m²
Net delivered energy	62205 kWh	35.7 kWh / m²

Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42044 kWh	24.1 kWh / m²
1b El. for heat pump system 1c El.	19222 kWh	11.0 kWh / m²
for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	940 kWh	0.5 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 29281 kWh	- 16.8 kWh / m²
energy delivered, total 1-7 Solar	32925 kWh	18.9 kWh / m²
power for export	- 121515 kWh	- 69.8 kWh / m²
Net delivered energy	- 88590 kWh	- 50.9 kWh / m²

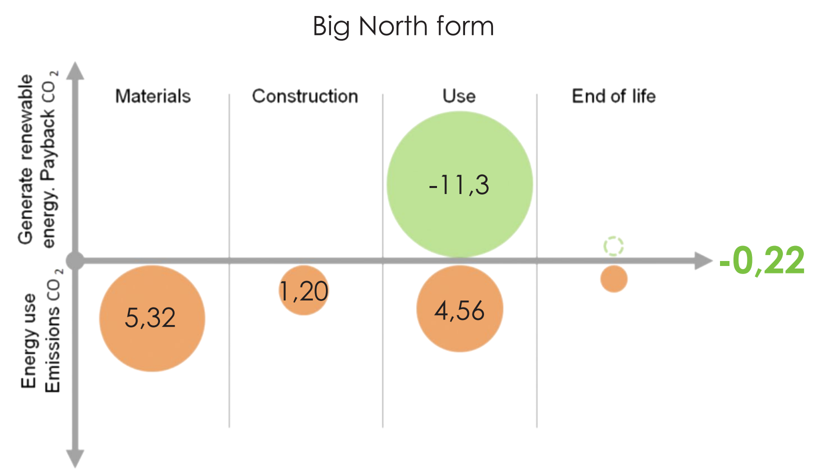


Figure 17: Final simien data results with ZEB balance calculation

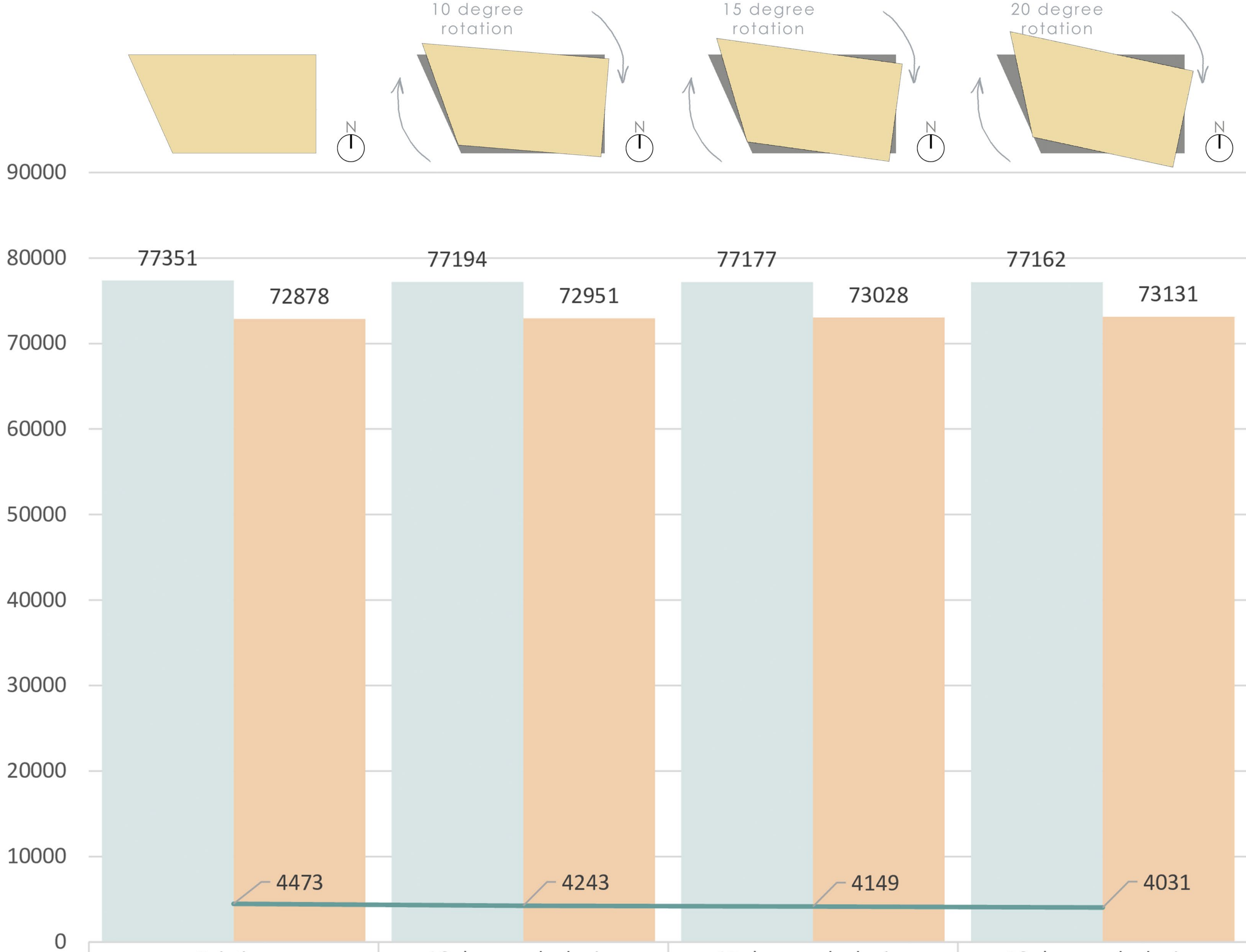
5 FORM DEVELOPMENT FROM THE BEGINNING

5.1 Experimentation with existing form

At first, I wanted to test and see what will happen with the existing form if I start turning it clockwise by 10, 15 and 20 degree, to make the south-facing facade more turned to the west. Because, after solar analysis that you can see in report [18], the orientation of the building to get the most solar heat gain is not straight to the south, but from 10 to 20 degree to the west. Thus, in (Figure 18) we can see the results of energy spent during a year for heating and cooling the building.

In all three rotations we see that the total consumption of energy is decreasing, the more we rotate south-facing facade to the west. In more detailed look we see that heating demand is increasing, whereas cooling demand is decreasing.

This happens due to having west facade now more and more perpendicular to the south, thus less area is heated during the day, which appears in reduction of cooling loads.



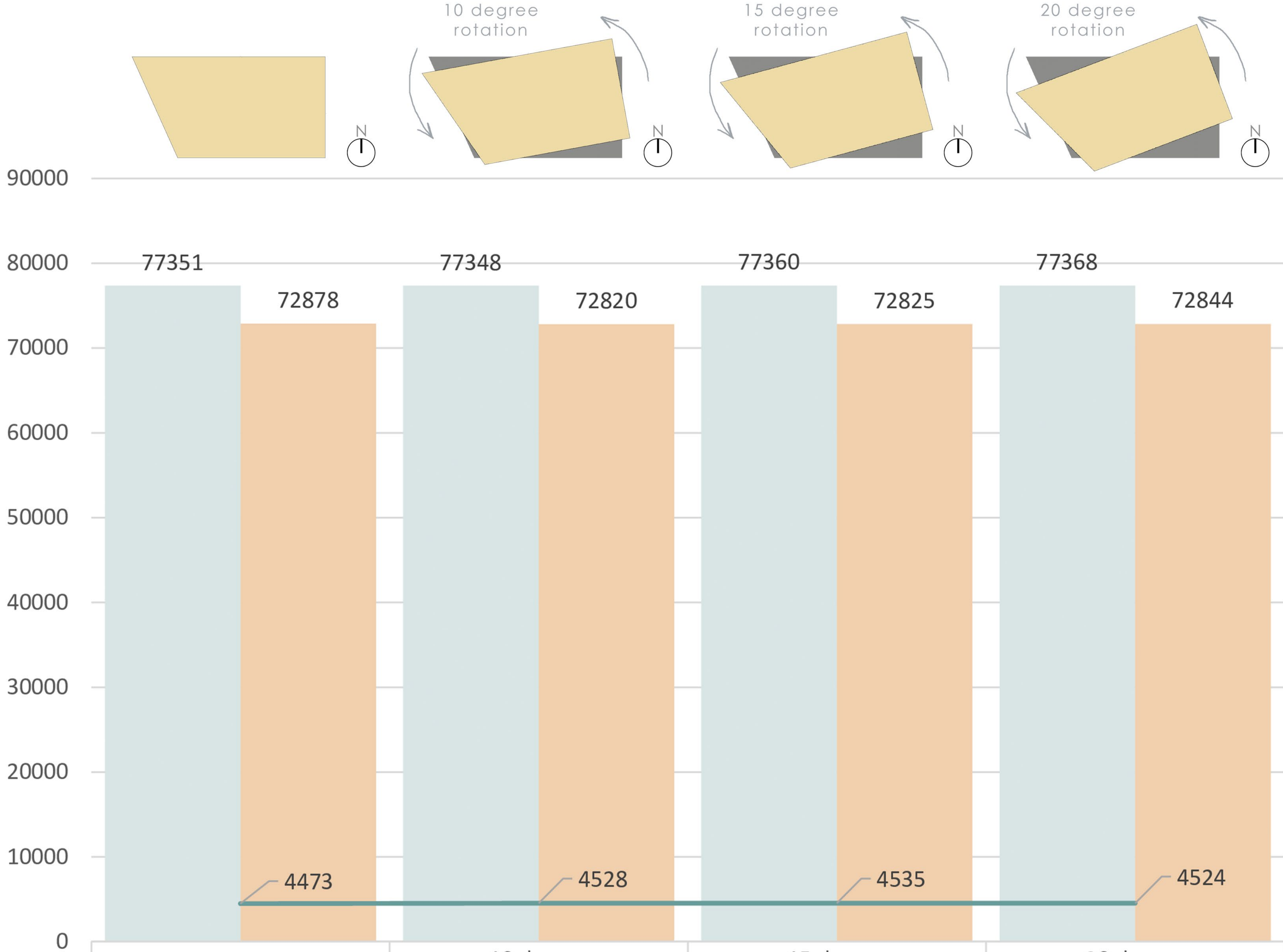
	Existing	10 degree clockwise	15 degree clockwise	20 degree clockwise
Total consumption (kWh)	77351	77194 ↓ 157	77177 ↓ 177	77162 ↓ 189
Heating load (kWh)	72878	72951 ↑ 73	73028 ↑ 150	73131 ↑ 253
Cooling load (kWh)	4473	4243 ↓ 230	4149 ↓ 324	4031 ↓ 442
Total consumption (kWh/m^2)	39,68	39,60 ↓	39,59 ↓	39,59 ↓

Figure 18: Energy consumption of existing building after turning it clockwise

Further, if we rotate the existing building counterclockwise with the same 10, 15 and 20 degrees, we will see that total consumption at first 10 degree is reduced very slightly, but then it starts rising slowly. Looking in more detailed, at first demand for heating reduces in first 10 degree, then it slowly goes back to the existing one as we rotate it further. Looking at the cooling loads, we can see that the energy needed for cooling is increased and fluctuates due to the form of the building.

These tests show, that in order to reduce energy use on heating the building we need to either rotate it towards east, or increase south facing areas of the building, as we can see in (Figure 19). And similarly, if we rotate the building towards the west (Figure 18), then we reduce cooling demand of the building. As the V. Olgyay's book [16] suggests having a 12-degree rotation to the east for cold climates as an optimal solution to not have overheating and underheating, these tests show that it is the optimal way in existing case too, however we do not need to forget about the PV production, that has a substantial role in reaching ZEB-COM level, which we will see further in this thesis.

All these simulations were made in rhino with tool (grasshopper), as the software gives relatively quick and simple simulations that are flexible to changes, and can define the beginning of the project.



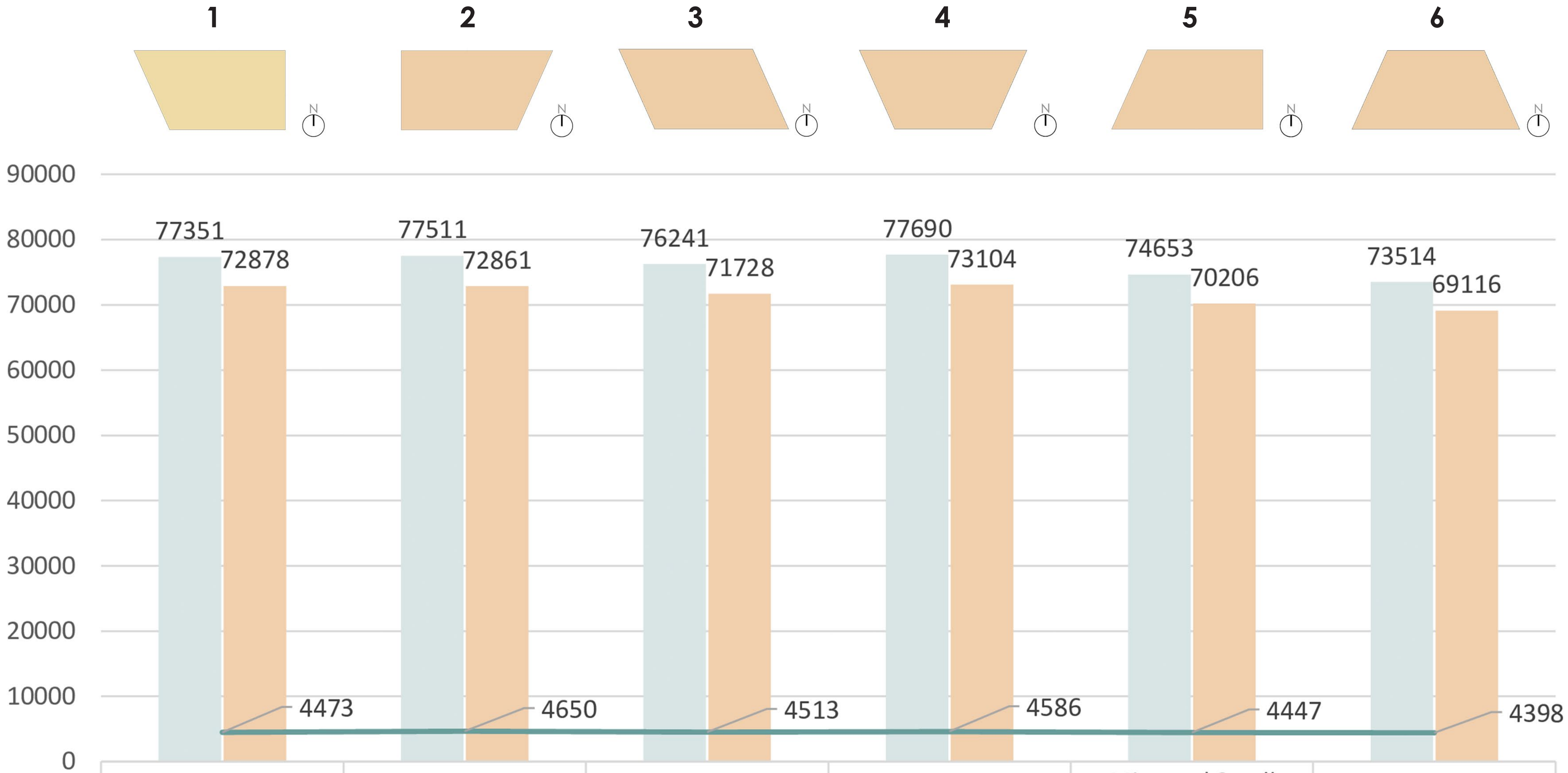
	Existing	10 degree counterclockwise	15 degree counterclockwise	20 degree counterclockwise
Total consumption (kWh)	77351	77348 ↓ 3	77360 ↑ 9	77368 ↑ 17
Heating load (kWh)	72878	72820 ↓ 58	72825 ↓ 53	72844 ↓ 34
Cooling load (kWh)	4473	4528 ↑ 55	4535 ↑ 62	4524 ↑ 51
Total consumption (kWh/m^2)	39,68	39,68 ↓	39,69 ↑	39,69 ↑

Figure 19: Energy consumption of existing building after turning it counterclockwise

5.2 Simulation of different shapes

After understanding of the changes in heating and cooling demand due to shape, these shapes (Figure 20) were developed to test each option of increasing east facade instead of west (2) or decreasing east facade (3), increasing north (4), mirroring existing building (5), or decreasing north by increasing south facade (6).

All these shapes have the same amount of glazing area, which will play significant role in further thesis development. With the same area of glazing, we can see that the best form strategy is reducing the north part of the building with increasing the south facing side, which will reduce total consumption of the building in heating and cooling, and the worst is opposite, increasing the north part of the building with decreasing the south. We also need to keep in mind that all this happens also because of the steep roof of 30°, because with the flat roof the results could be very different.

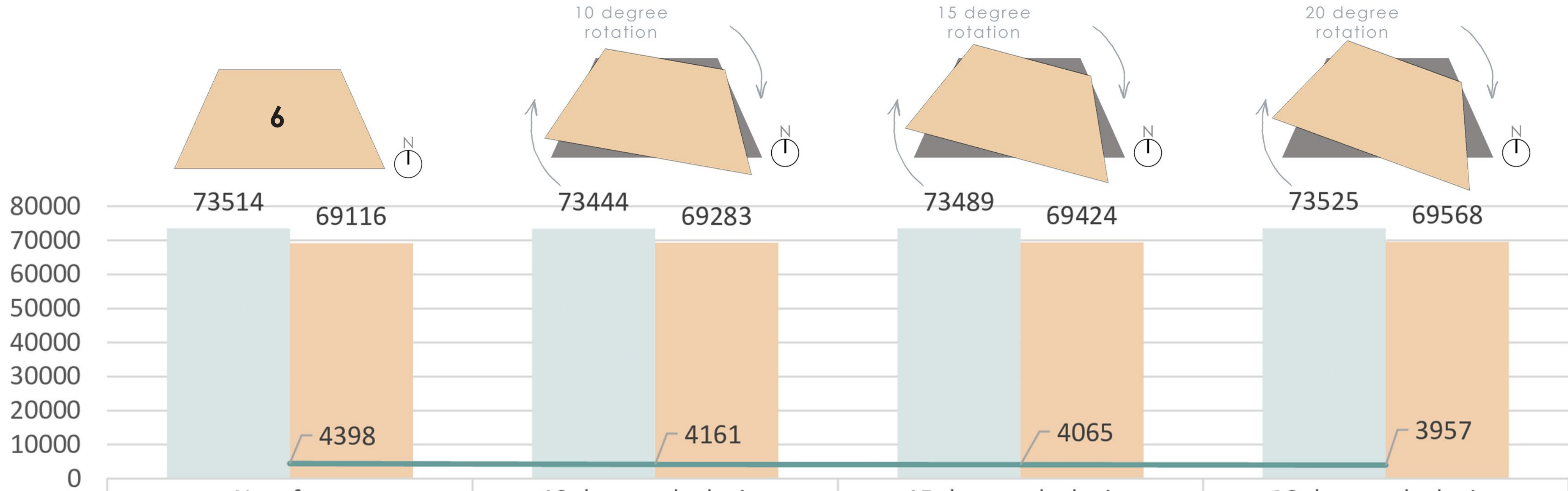


	Existing	Mirrored	Combined	Big North	Mirrored Small North	Small North
Total consumption (kWh)	77351	77511 ↑ 160	76241 ↓ 1110	77690 ↑ 339	74653 ↓ 2698	73514 ↓ 3837
Heating load (kWh)	72878	72861 ↓ 17	71728 ↓ 1150	73104 ↑ 226	70206 ↓ 2672	69116 ↓ 3762
Cooling load (kWh)	4473	4650 ↑ 177	4513 ↑ 55	4586 ↑ 113	4447 ↓ 26	4398 ↓ 75
Total consumption (kWh/m^2)	39,68	39,76 ↑	39,11 ↓	39,86 ↑	38,30 ↓	37,71 ↓

Figure 20: Energy consumption of existing building in comparison with all modified shapes

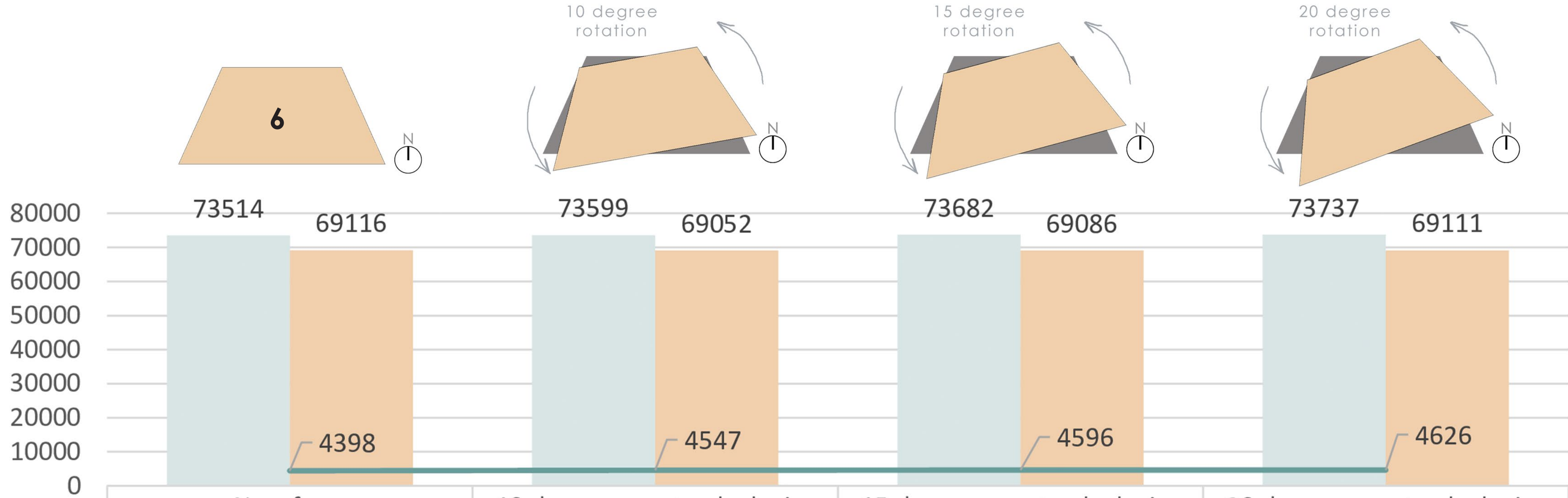
5.3 Experimentation with the most efficient form

The most efficient form is with the small north one, thus I do the same rotation test on it to see the differences. In clockwise rotation we can see, that heating demand of the building is increasing the same as in existing shape, in (Figure 18), the more we rotate south-facing facade to west, and cooling demand is decreasing. However, at some point cooling demand is not overweighting the heating and the total consumption of the building is becoming worse than initial shape



	New form	10 degree clockwise	15 degree clockwise	20 degree clockwise
Total consumption (kWh)	73514	73444 ↓ 70	73489 ↓ 25	73525 ↑ 11
Heating load (kWh)	69116	69283 ↑ 167	69424 ↑ 308	69568 ↑ 452
Cooling load (kWh)	4398	4161 ↓ 237	4065 ↓ 333	3957 ↓ 441
Total consumption (kWh/m^2)	37,71	37,68 ↓	37,70 ↓	37,72 ↑

With counterclockwise rotation the optimal position for this shape is straight to the south with south-facing facade, as when we start rotating the building, the heating load decreases at first then starts getting back to the same value. However, the more we rotate the more energy for cooling the building is needed. Thus, in this shape leaving it straight to the south is the best option.



	New form	10 degree counterclockwise	15 degree counterclockwise	20 degree counterclockwise
Total consumption (kWh)	73514	73599 ↑ 85	73682 ↑ 168	73737 ↑ 223
Heating load (kWh)	69116	69052 ↓ 64	69086 ↓ 30	69111 ↓ 5
Cooling load (kWh)	4398	4547 ↑ 149	4596 ↑ 198	4626 ↑ 228
Total consumption (kWh/m^2)	37,71	37,76 ↑	37,80 ↑	37,83 ↑

Figure 21: Energy consumption of the most efficient form in different rotated situations

5.4 Comparison of PV panel production (Revit)

Further to test the forms in PV energy production I kept all forms that got better results than existing one, and also added the form that was the worst in energy savings, as the form was looking more promising than others in PV production. Looking at the (Figure 22), it can be seen that the best in energy consumption form "Small North form" is actually the worst in PV production, as the area of panels is the largest with the least energy produced during a year.

On the other hand, the worst form in energy consumption, making the best results with having the least area of panels.

Simulations were made in Revit software in PV analysis, roof, west and east surfaces were fully accounted as PV panel areas, on the south part there were windows as in existing building, and the rest area of south facade was PV panels.

At first, I was not considering the "Big North form" as it was shown the worst result in energy consumption. However, only after finalizing the best form "Small North form" and making ZEB balance calculation of that shape, I found out that the best form in energy consumption is not reaching ZEB-COM level as the production of PV panels is not enough to cover materials and construction. Especially when I started putting precisely the number of windows that the form needed in order to have good daylight conditions inside. Mainly, because the west and east facades had very little production of energy as they were turned more to north-west and north-east respectively. Thus, I went back and reconsidered the changes and added the worst form to see how it might change with further improvements.

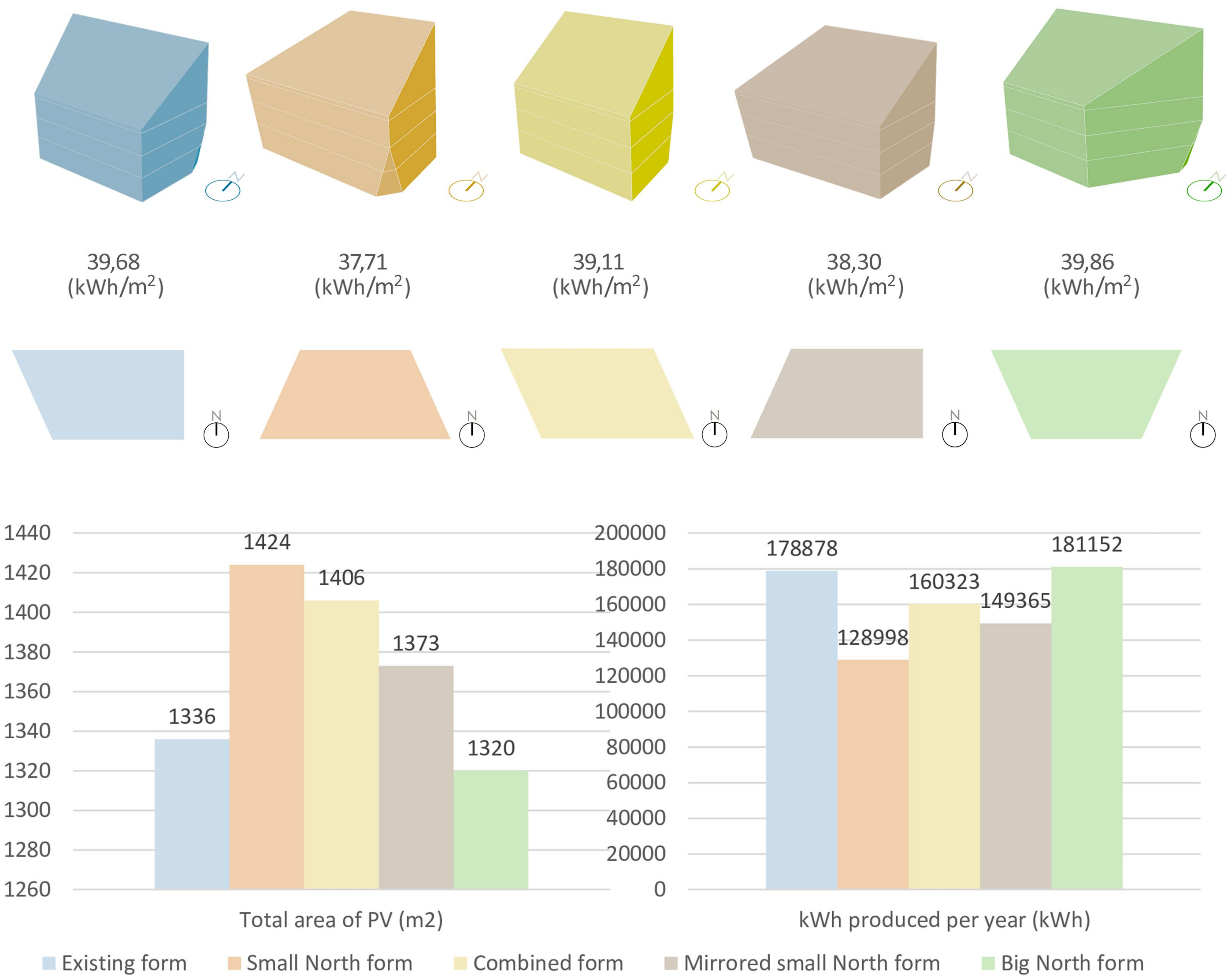
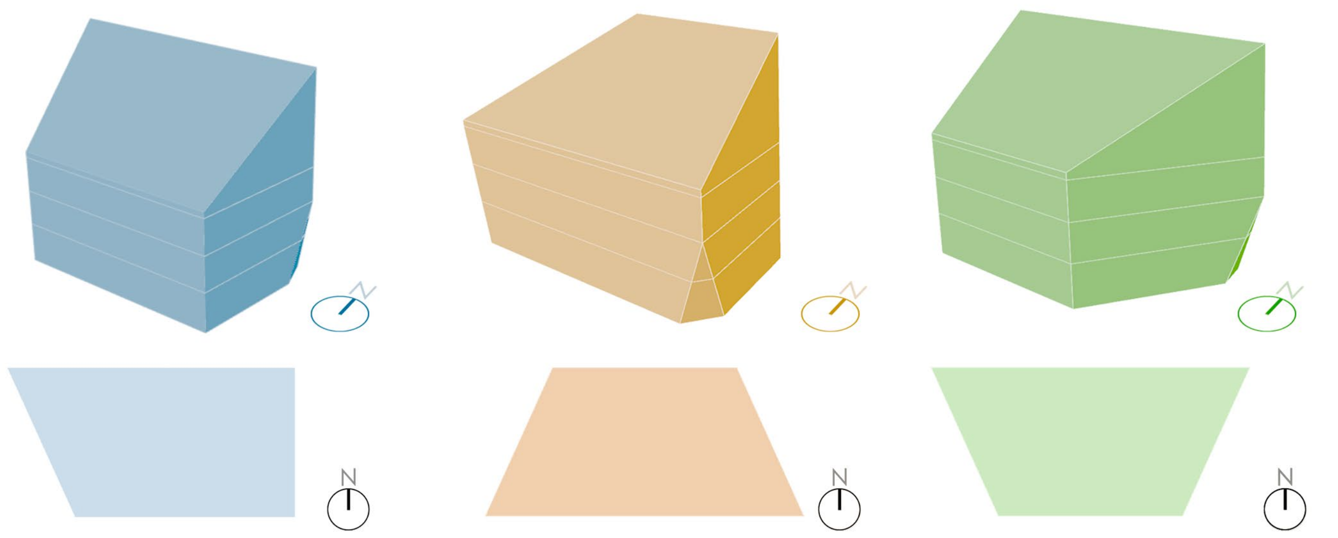


Figure 22: Comparison of the total area of PV of each shape with production

5.5 Comparison of PV panel production (Simien)

After arranging all the windows that are needed for each shape, as Simien software needs precise sizes and amount of windows, the results became more accurate. As we can see (Figure 23), the amount of total production in existing form and "Big North form" is similar, whereas the "Small North form" has the least production on west and east facades due to it's shape, even with the highest south facade production.

Also looking at the area of PV panels, we can see that the "Big North form" has the least area, which will save some material usage for production of building integrated photovoltaics.



	Existing form	Small North form	Big North form
Total produced (kWh)	150958	139515	150796
Delivered to building (kWh)	29368	29170	29281
Exported to the grid (kWh)	121590	110345	121515
Area of PV panels (m2)	1228,1	1232,7	1199,3

Figure 23: Final results about PV production per year, consumption of the building, exported energy and total area of PV panels

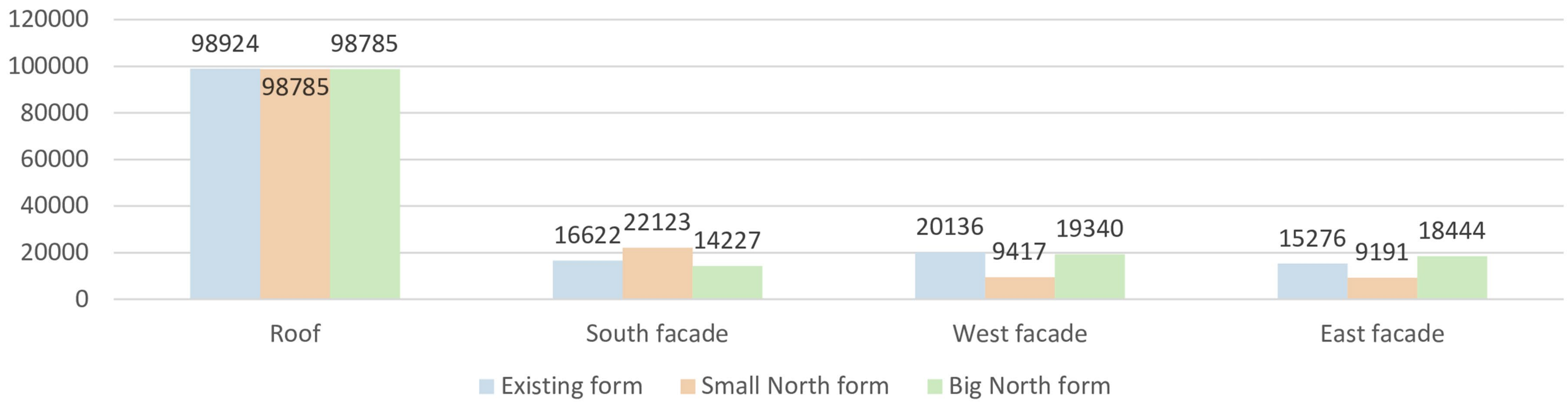
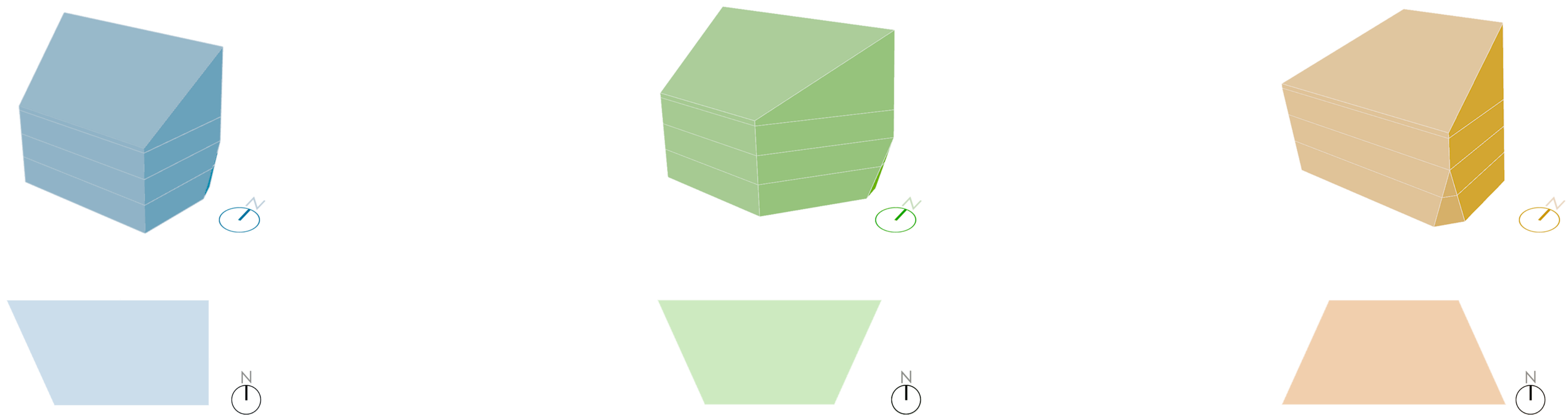


Figure 24: Precise amount of kWh produced by PV panels per year from each facade and roof

5.6 Final simulation results from Simien



Energy budget of existing form

Energy post	Energy needs	Specific energy needs
1st Room heating	40407 kWh	23.2 kWh / m^2
1b Ventilation heating (heating	9814 kWh	5.6 kWh / m^2
batteries) 2 Hot water (tap water)	0 kWh	0.0 kWh / m^2
3a Fans	10454 kWh	6.0 kWh / m^2
3b Pumps	595 kWh	0.3 kWh / m^2
4 Lighting	13093 kWh	7.5 kWh / m^2
5 Technical equipment	17461 kWh	10.0 kWh / m^2
6a Room cooling	0 kWh	0.0 kWh / m^2
6b Ventilation cooling (dress batteries)	1102 kWh	0.6 kWh / m^2
Total net energy requirement, sum 1-6	92926 kWh	53.3 kWh / m^2

Energy budget of Big North form

Energy post	Energy needs	Specific energy needs
1st Room heating	38958 kWh	22.4 kWh / m^2
1b Ventilation heating (heating	9716 kWh	5.6 kWh / m^2
batteries) 2 Hot water (tap water)	0 kWh	0.0 kWh / m^2
3a Fans	10454 kWh	6.0 kWh / m^2
3b Pumps	595 kWh	0.3 kWh / m^2
4 Lighting	13093 kWh	7.5 kWh / m^2
5 Technical equipment	17461 kWh	10.0 kWh / m^2
6a Room cooling	0 kWh	0.0 kWh / m^2
6b Ventilation cooling (dress batteries)	1102 kWh	0.6 kWh / m^2
Total net energy requirement, sum 1-6	91378 kWh	52.5 kWh / m^2

Energy budget of Small North form

Energy post	Energy needs	Specific energy needs
1st Room heating	37843 kWh	21.7 kWh / m^2
1b Ventilation heating (heating	9767 kWh	5.6 kWh / m^2
batteries) 2 Hot water (tap water)	0 kWh	0.0 kWh / m^2
3a Fans	10454 kWh	6.0 kWh / m^2
3b Pumps	610 kWh	0.4 kWh / m^2
4 Lighting	13093 kWh	7.5 kWh / m^2
5 Technical equipment	17461 kWh	10.0 kWh / m^2
6a Room cooling	0 kWh	0.0 kWh / m^2
6b Ventilation cooling (dress batteries)	1102 kWh	0.6 kWh / m^2
Total net energy requirement, sum 1-6	90330 kWh	51.9 kWh / m^2

Energy supplied to the building without PV panels

Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42044 kWh	24.1 kWh / m^2
1b El. for heat pump system 1c El.	19838 kWh	11.4 kWh / m^2
for solar collector system 2	0 kWh	0.0 kWh / m^2
Oil	0 kWh	0.0 kWh / m^2
3 Gas	0 kWh	0.0 kWh / m^2
4 District heating	975 kWh	0.6 kWh / m^2
5 Biofuels	0 kWh	0.0 kWh / m^2
6. Other energy source	0 kWh	0.0 kWh / m^2
7. Solar power for own use Total	- 0 kWh	- 0.0 kWh / m^2
energy delivered, total 1-7 Solar	62857 kWh	36.1 kWh / m^2
power for export	- 0 kWh	- 0.0 kWh / m^2
Net delivered energy	62857 kWh	36.1 kWh / m^2

Energy supplied to the building without PV panels

Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42044 kWh	24.1 kWh / m^2
1b El. for heat pump system 1c El.	19222 kWh	11.0 kWh / m^2
for solar collector system 2	0 kWh	0.0 kWh / m^2
Oil	0 kWh	0.0 kWh / m^2
3 Gas	0 kWh	0.0 kWh / m^2
4 District heating	940 kWh	0.5 kWh / m^2
5 Biofuels	0 kWh	0.0 kWh / m^2
6. Other energy source	0 kWh	0.0 kWh / m^2
7. Solar power for own use Total	- 0 kWh	- 0.0 kWh / m^2
energy delivered, total 1-7 Solar	62205 kWh	35.7 kWh / m^2
power for export	- 0 kWh	- 0.0 kWh / m^2
Net delivered energy	62205 kWh	35.7 kWh / m^2

Energy supplied to the building without PV panels

Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42059 kWh	24.1 kWh / m^2
1b El. for heat pump system 1c El.	18795 kWh	10.8 kWh / m^2
for solar collector system 2	0 kWh	0.0 kWh / m^2
Oil	0 kWh	0.0 kWh / m^2
3 Gas	0 kWh	0.0 kWh / m^2
4 District heating	913 kWh	0.5 kWh / m^2
5 Biofuels	0 kWh	0.0 kWh / m^2
6. Other energy source	0 kWh	0.0 kWh / m^2
7. Solar power for own use Total	- 0 kWh	- 0.0 kWh / m^2
energy delivered, total 1-7 Solar	61767 kWh	35.5 kWh / m^2
power for export	- 0 kWh	- 0.0 kWh / m^2
Net delivered energy	61767 kWh	35.5 kWh / m^2

Energy supplied to the building with PV panels

Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42044 kWh	24.1 kWh / m^2
1b El. for heat pump system 1c El.	19838 kWh	11.4 kWh / m^2
for solar collector system 2	0 kWh	0.0 kWh / m^2
Oil	0 kWh	0.0 kWh / m^2
3 Gas	0 kWh	0.0 kWh / m^2
4 District heating	975 kWh	0.6 kWh / m^2
5 Biofuels	0 kWh	0.0 kWh / m^2
6. Other energy source	0 kWh	0.0 kWh / m^2
7. Solar power for own use Total	- 29368 kWh	- 16.9 kWh / m^2
energy delivered, total 1-7 Solar	33489 kWh	19.2 kWh / m^2
power for export	- 121590 kWh	- 69.8 kWh / m^2
Net delivered energy	- 88101 kWh	- 50.6 kWh / m^2

Energy supplied to the building with PV panels

Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42044 kWh	24.1 kWh / m^2
1b El. for heat pump system 1c El.	19222 kWh	11.0 kWh / m^2
for solar collector system 2	0 kWh	0.0 kWh / m^2
Oil	0 kWh	0.0 kWh / m^2
3 Gas	0 kWh	0.0 kWh / m^2
4 District heating	940 kWh	0.5 kWh / m^2
5 Biofuels	0 kWh	0.0 kWh / m^2
6. Other energy source	0 kWh	0.0 kWh / m^2
7. Solar power for own use Total	- 29281 kWh	- 16.8 kWh / m^2
energy delivered, total 1-7 Solar	32925 kWh	18.9 kWh / m^2
power for export	- 121515 kWh	- 69.8 kWh / m^2
Net delivered energy	- 88590 kWh	- 50.9 kWh / m^2

Energy supplied to the building with PV panels

Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42059 kWh	24.1 kWh / m^2
1b El. for heat pump system 1c El.	18795 kWh	10.8 kWh / m^2
for solar collector system 2	0 kWh	0.0 kWh / m^2
Oil	0 kWh	0.0 kWh / m^2
3 Gas	0 kWh	0.0 kWh / m^2
4 District heating	913 kWh	0.5 kWh / m^2
5 Biofuels	0 kWh	0.0 kWh / m^2
6. Other energy source	0 kWh	0.0 kWh / m^2
7. Solar power for own use Total	- 29170 kWh	- 16.7 kWh / m^2
energy delivered, total 1-7 Solar	32597 kWh	18.7 kWh / m^2
power for export	- 110345 kWh	- 63.3 kWh / m^2
Net delivered energy	- 77748 kWh	- 44.6 kWh / m^2

Figure 25: Comparison of the final results from Simien on energy budget, consumption and production of the forms.

5.7 ZEB Balance calculation

Looking at the (Figure 25), it can be seen that the best shape if we consider only energy consumption without reaching ZEB-COM level is the "Small North Form" with 35,5 kWh/m2, however in ZEB balance calculation it reaches only 0.66, which means it did not reach the required level. Energy for material and construction were taken as in existing building, to have a comparison, but we do not need to forget about the amount of windows in all those forms. For example, existing form has **445,9 m2** of windows area, when "Big North form" and "Small North form" have **409,4 m2** and **417,6 m2** respectively. That means actual emissions of materials in ZEB calculation could be smaller, which would lead to better results.

This thesis shows, how at first, the worst form in energy consumption, because of having same glazing area as an existing building, after careful replanning of interior spaces, reducing or replacing windows especially on the north part of the building and implementing passive strategy of increasing solar heat gains on the south part, became the best optimal form and reached a little bit higher level of ZEB-COM level, than the existing ZEB Laboratory. All that mainly because of reduction of energy consumption of the building which we can see in (Figure 25). With all the changes inside of the building, now it is not the worst, as it has lower energy consumption in comparison with existing, **35,7** kWh/m2 in "Big North form" and **36,1** kWh/m2 in existing building.

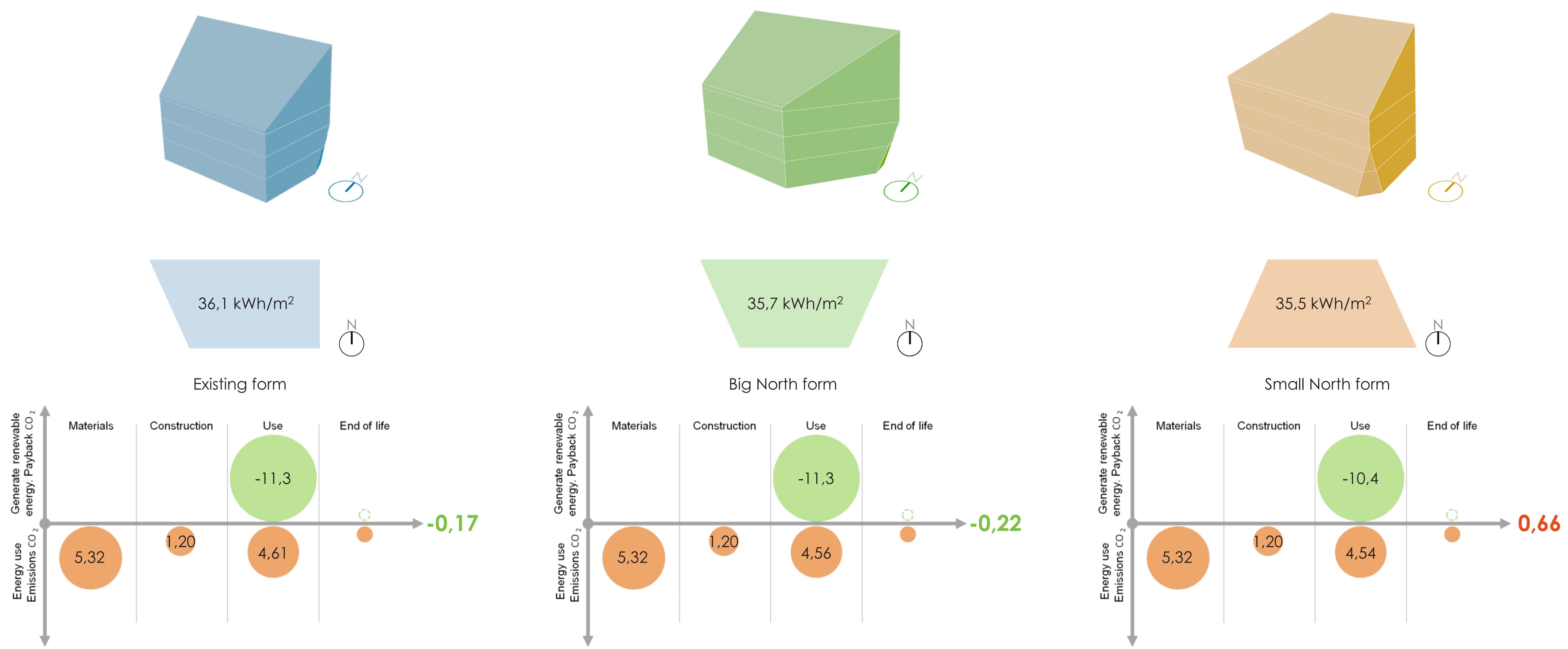
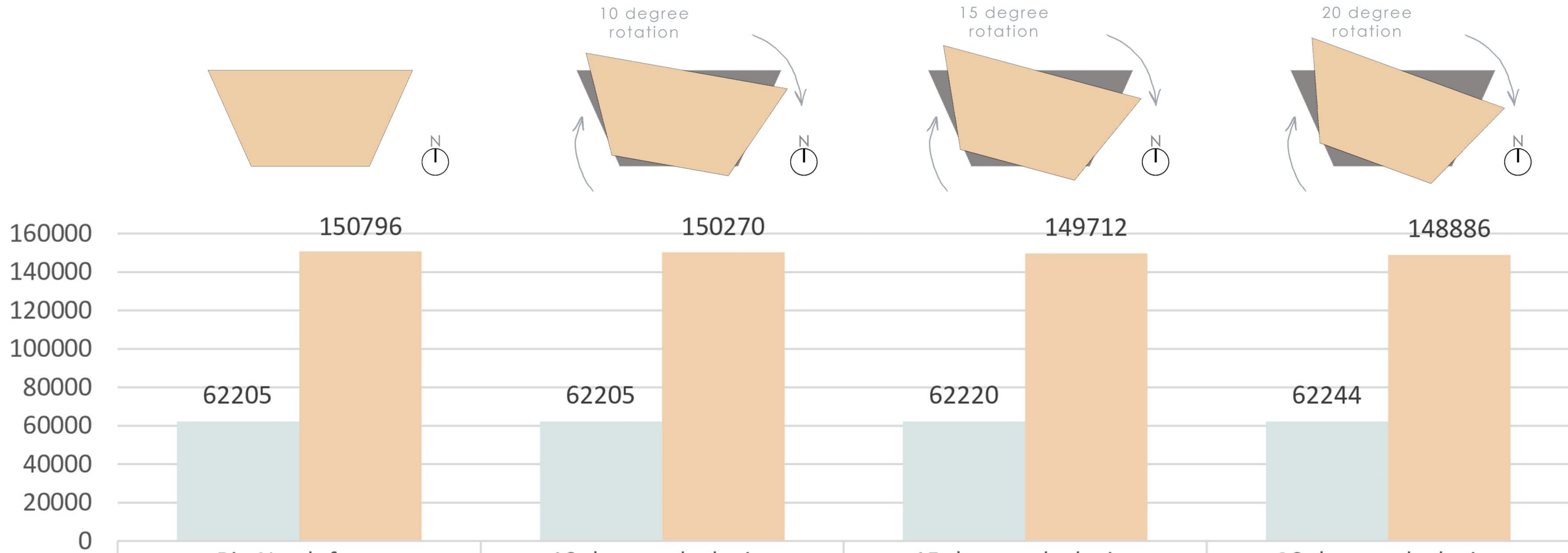


Figure 26: Comparison of ZEB balance calculation to reach ZEB-COM level in all three forms

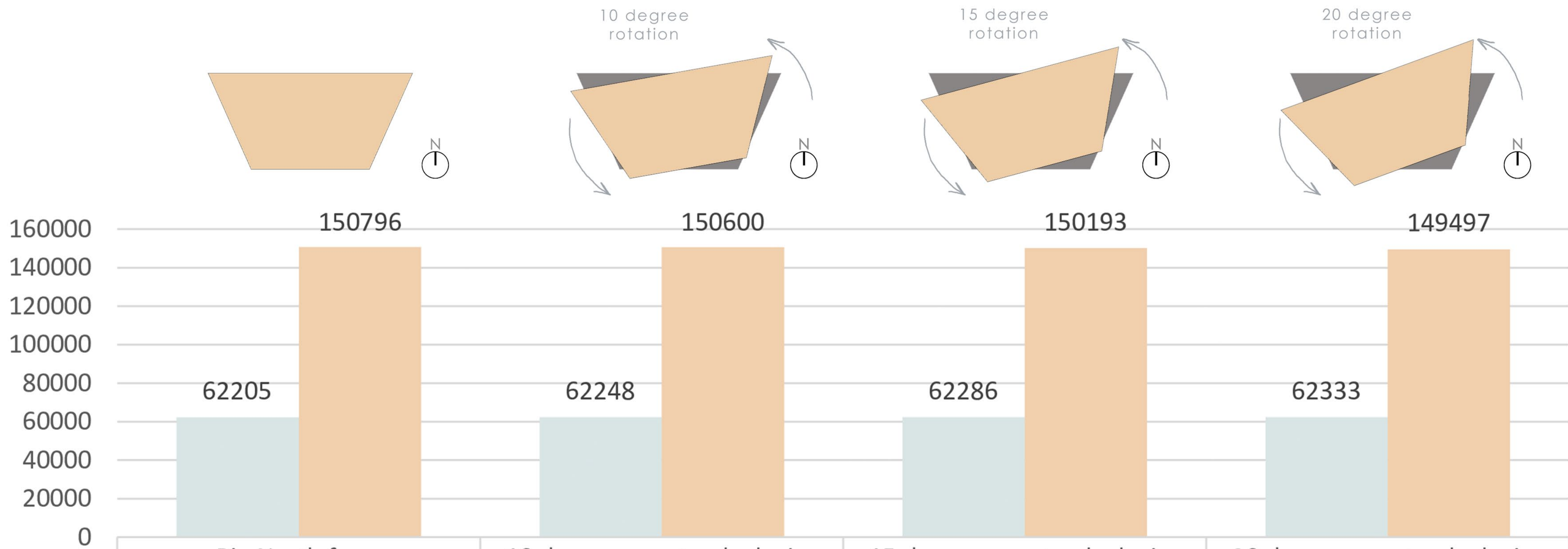
5.8 Experimentation with the final proposed form

The same rotation experiments were made on the final proposed form “Big North form”, with difference of using simien in this case to have not only changes in values of total consumption of the building, but also fluctuations in PV production as well. In clockwise rotation, we can see that, until 10 degrees the consumption of the building does not change, whereas the PV panel production reduces. Rotating more will slightly increase energy demands of the building, however the reduction of energy from PV’s drops twice each 5 degree.



	Big North form	10 degree clockwise	15 degree clockwise	20 degree clockwise
Total consumption (kWh)	62205	62205 = 0	62220 ↑ 15	62244 ↑ 39
PV production (kWh)	150796	150270 ↓ 526	149712 ↓ 1084	148886 ↓ 1910

Considering opposite way or rotation, it can be seen that, energy consumption increases slightly more each turn, than in clockwise type of rotation. However, the energy from PV panels reduces slower in comparison with previous type. All these tests show that for this final form, with that type of the roof, the most optimal position is having south-facing wall straight to the south, which gives the lowest total energy consumption of the building in combination with highest PV production.



	Big North form	10 degree counterclockwise	15 degree counterclockwise	20 degree counterclockwise
Total consumption (kWh)	62205	62248 ↑ 43	62286 ↑ 81	62333 ↑ 128
PV production (kWh)	150796	150600 ↓ 196	150193 ↓ 603	149497 ↓ 1299

Figure 26.1: Energy consumption of the final proposed form in different rotated situations with PV production (Simien)

6 ADDITIONAL SIMULATIONS

6.1 Daylight analysis

Additional tests were made to see that the daylight conditions inside of the proposed "Big North form" is reaching to required level as existing building.

Requirement for an office building is to have not less than 300 lux, best option is to have 500 lux in average [17]. On the (Figure 27), we can see that, proposed form "Big North form" is reaching the required level of 500 lux in all office areas in summer and winter. Middle area of the building has meeting rooms, technical and staircases, thus those areas are not required direct daylight.

Comparing the proposed form with existing and "Small North form" it can be seen that the difference almost not visible. For example, in existing building there was only one place at north part of the building, which were taken by the elevator and toilet without glazing, and second toilet was in the middle of the building. But, "Big North form" after replacing middle toilet to north part of the building, it has two covered places from north, which reduces glazing to the north area and improves energy consumption of the building.

Shading devices on the south part of the building are required, especially for the autumn and winter period of time.

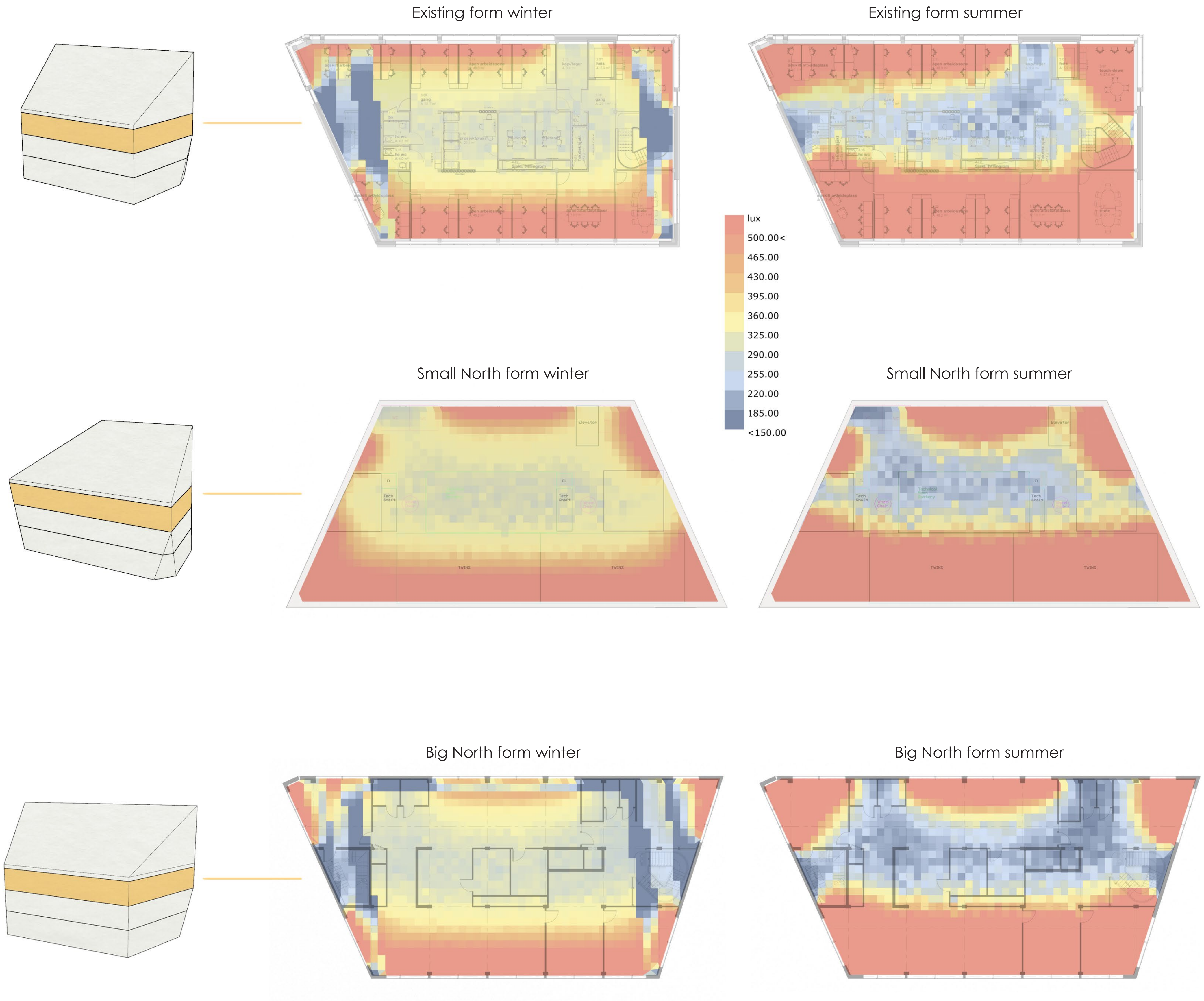


Figure 27: Daylight condition comparison in winter and summer of all three forms

6.2 Glare analysis

With analysis of the glare inside of three points of view of the office area in the south part of the building, it can be seen that, in autumn and winter there will be some problems with glare, which will require the shading options.

Existing building has black roll curtains outside of the building which is monitored by computer, in proposed form I suggest to use some other shading devices that can be placed inside between glazing in the window or inside of the building. Because, main passive strategy on proposed shape is to increase solar heat gain to the building, which we will lose if we implement shading devices outside of the building.

I suggest using controllable louvers, that can be manually controlled or by a computer, as after interviewing worker's in ZEB Laboratory, majority did not like the shading devices that were chosen for existing building. Controllable louvers can have variety options and changed for each individual, which will increase comfort level on the south part of the building.

Fiberglass water storage tubes (Trombe wall) are also an option, as the water can gain more heat than concrete, release the heat faster and environmentally friendly solution as a shading device. As the size of tubes can be designed for different purposes, as a shading or as a heat storage, so it can be developed in more detailed research in further work.

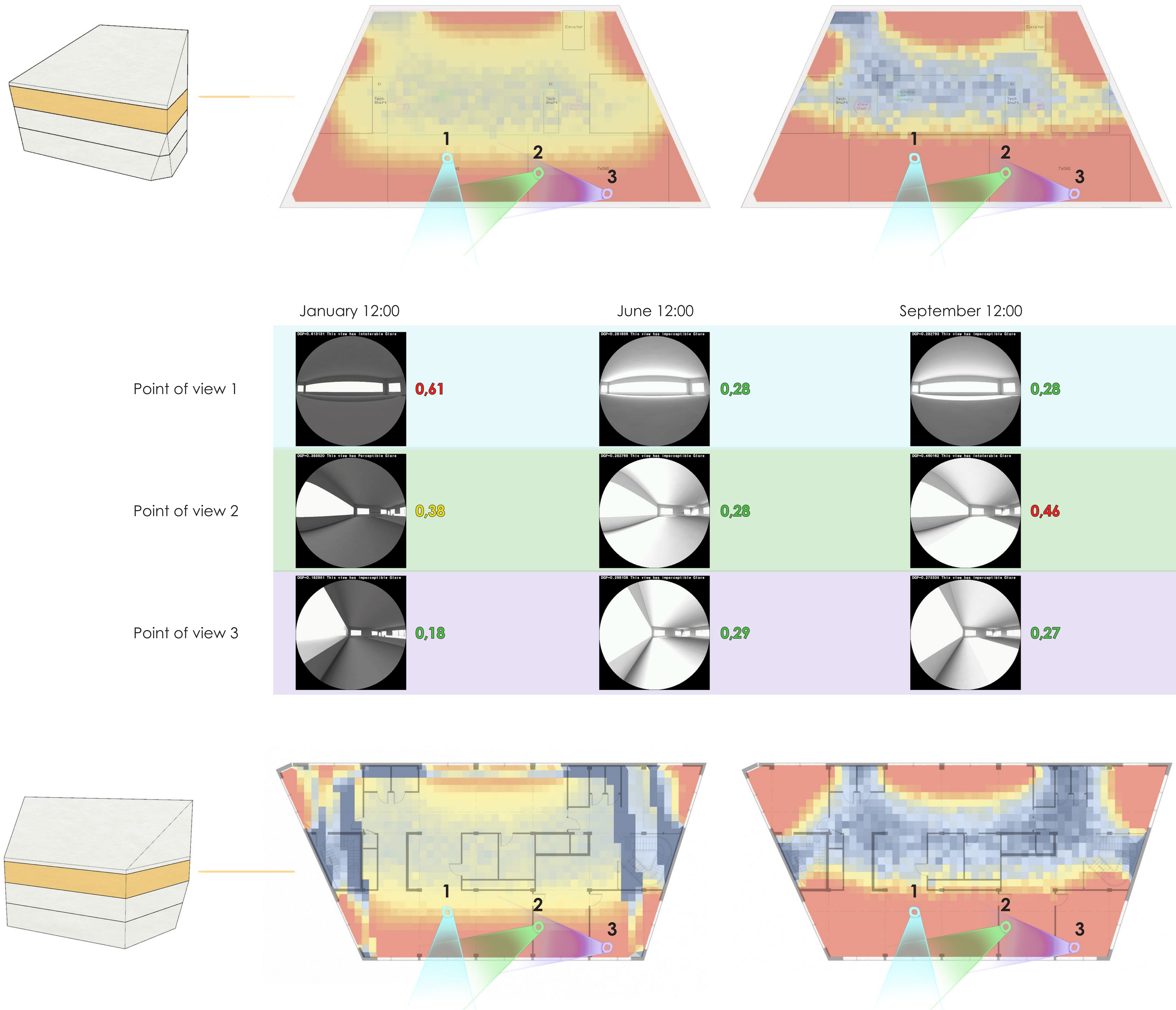


Figure 28: Amount of glare on three different points of view inside

7 ARCHITECTURAL DRAWINGS OF THE FINAL DESIGN

7.1 General plan

The main strategies of placement and cuts of the building are kept the same as in existing building, with addition of increasing an angle of east facade more to south-east. Due to limitation of having 2000 sq. meters of gross total area, as we can see in (Figure 29), in order to have same size as an existing building, the north part of the existing form and a corner on south-east part were cut and placed at the east part of the proposed form, to have more facade area closer towards south, which will help in increase of solar heat gain and will keep production of PV panels at the same level to reach ZEB-COM. Area of the cut from existing building is 106,5 m2, and area of addition in proposed form is the same 106,5 m2, which means total area is completely the same.

Angled corners on north-west and north-east parts of the building remained the same in proposed one too, as that design decision is the best in order to have a passage for pedestrians and removing sharp corners of the building at a ground level, which improves the look of the building.

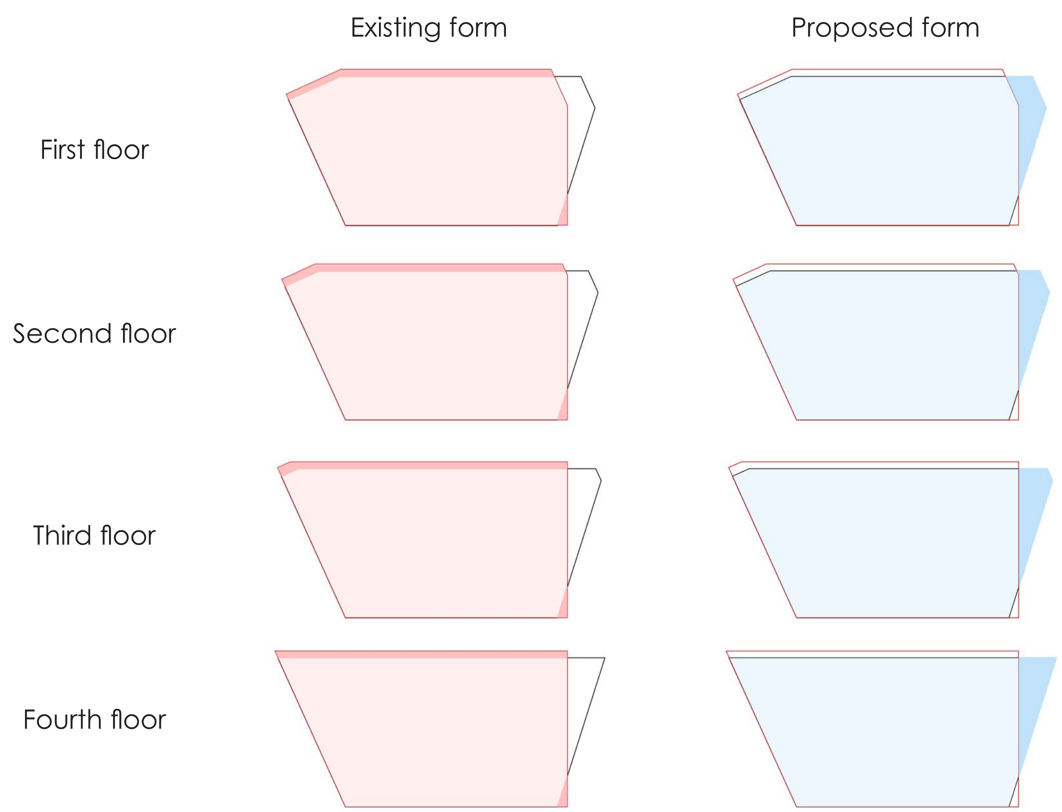


Figure 29: Comparison in size of existing building with proposed form

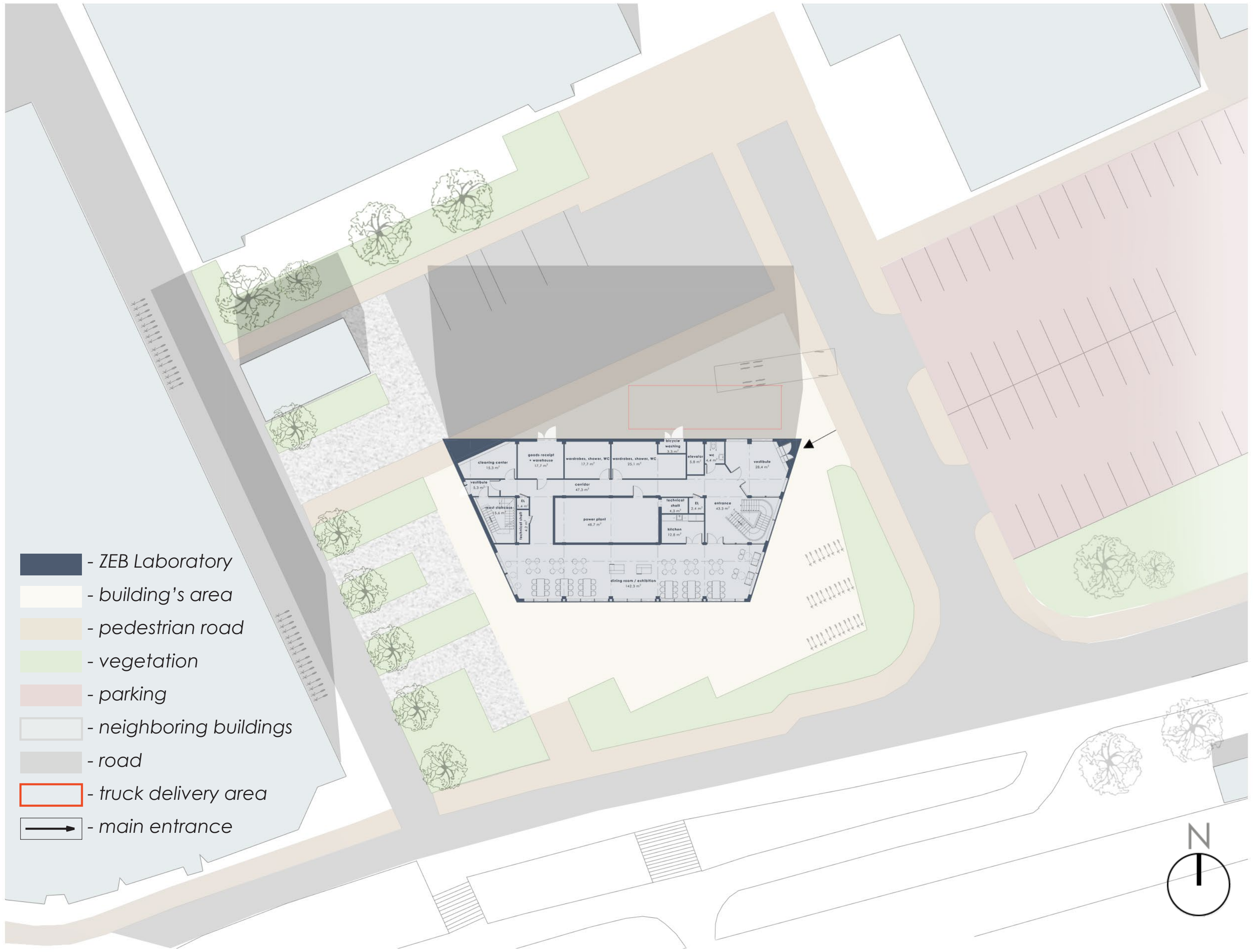


Figure 30: General plan

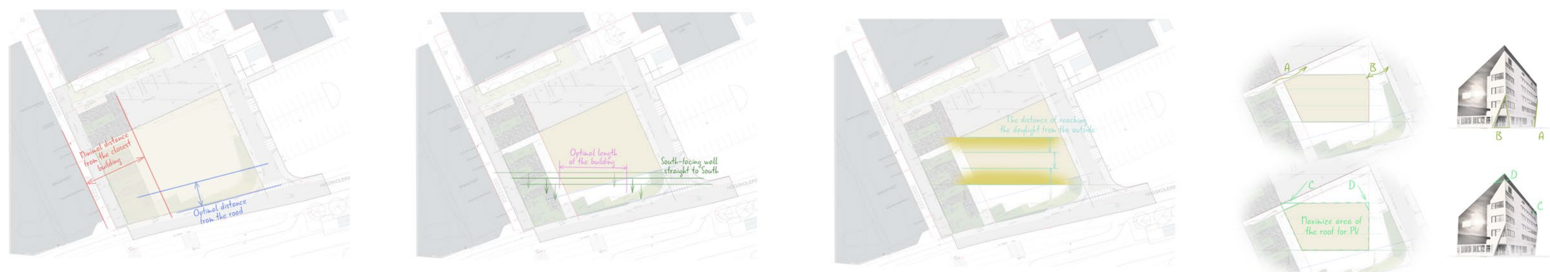


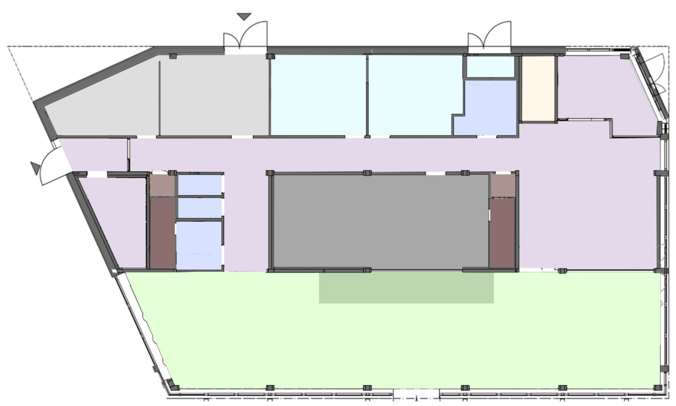
Figure 31: Similar strategies as in existing building

7.2 Plan and zoning of the first floor

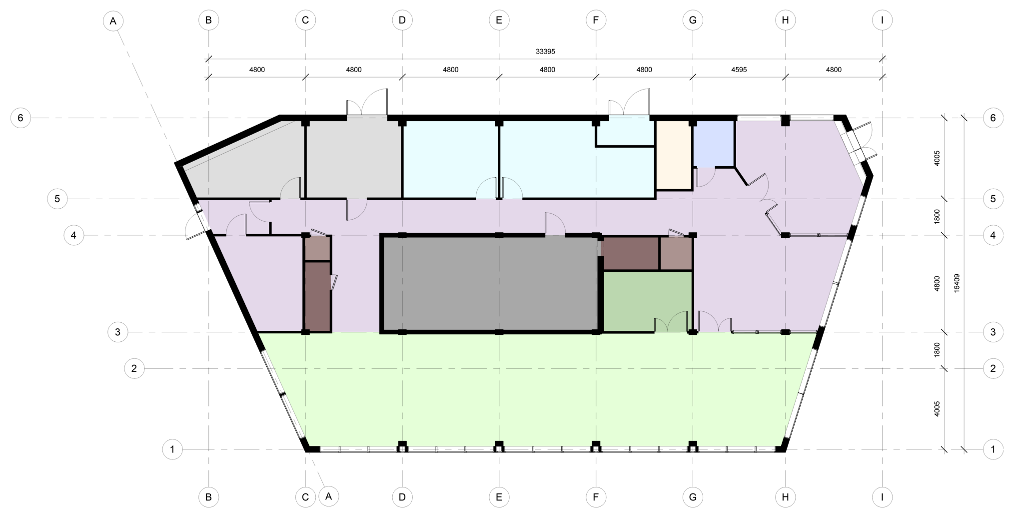
Overall planning remained the same as in existing one, major changes on the entrance area and kitchen.

Entrance area is now a little bit bigger than existing one, however the toilet can be increased and placed as a handicap toilet, thus removing excess area from the main entrance, or that area could be used as a waiting zone.

After interviewing workers in ZEB Lab, we got a feedback about the kitchen on the first floor, as it would be much better to have it enclosed, as if someone starts cooking, then the whole four floors have a smell of that food, due to the type of ventilation they have in existing building (because of the staircase being as a ventilation shaft).



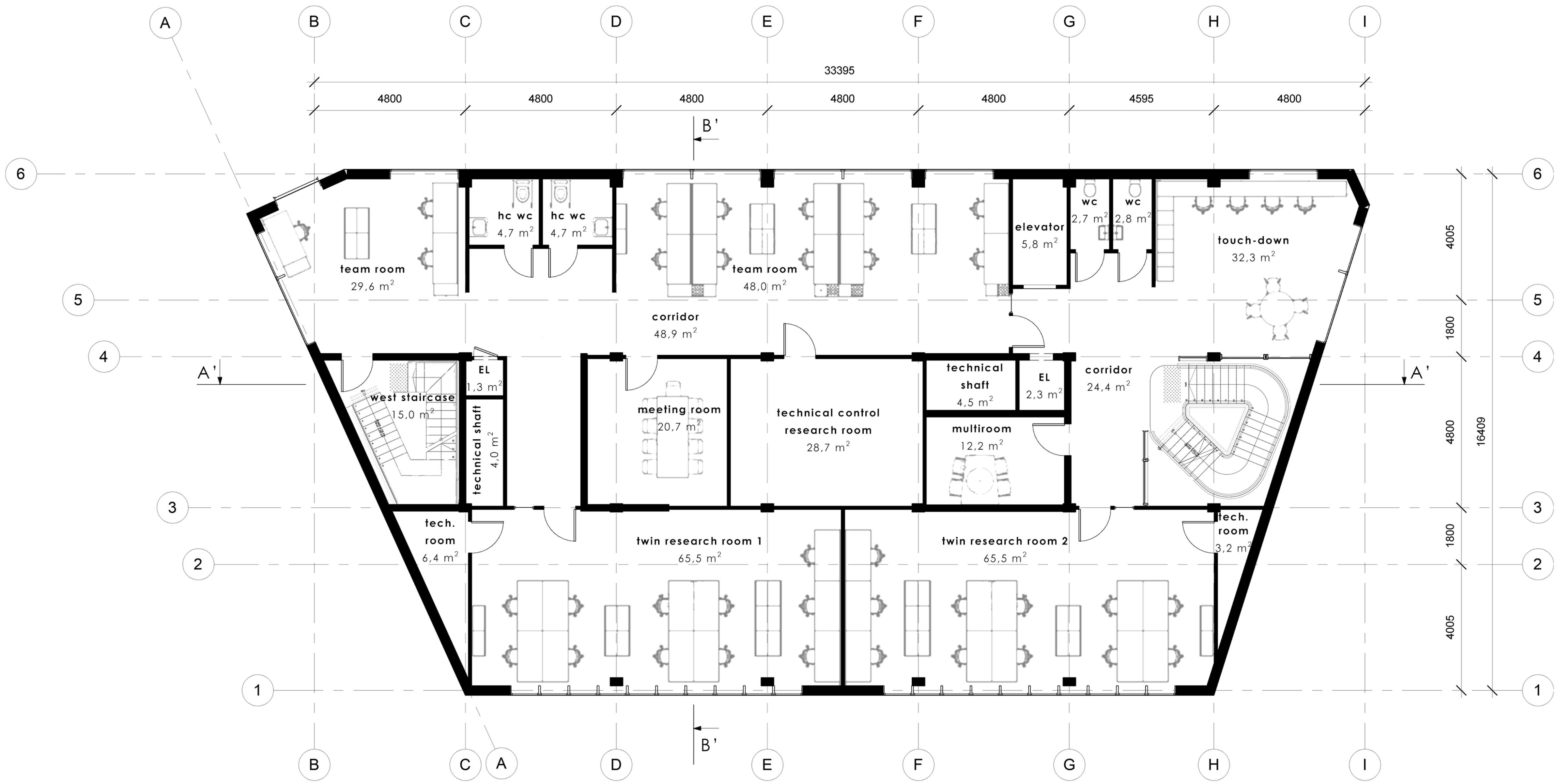
Zoning of existing ZEB Laboratory



Zoning of proposed form

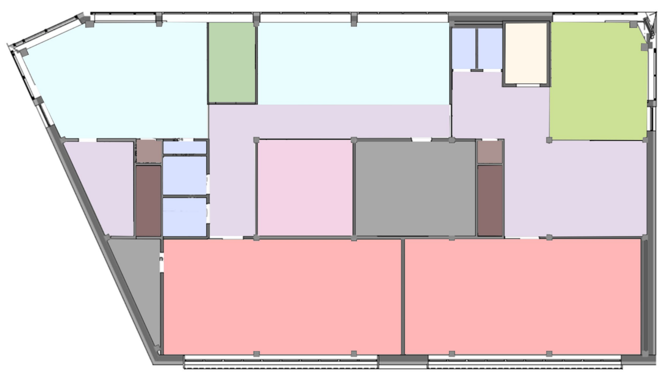
- service rooms
- wardrobes, shower, wc (staff rooms)
- WC
- elevator
- electricity shaft
- technical shaft
- power plant
- entrance and corridor area
- dining room and exhibition
- kitchen

7.3 Plan and zoning of the second floor

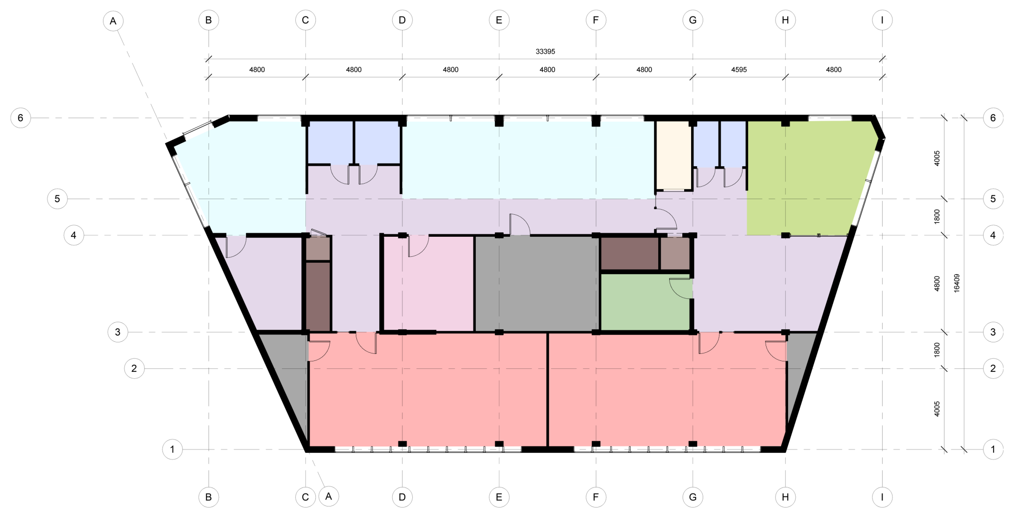


As one of the main goals was to reduce amount of glazing on the north part of the building, I replaced handicap toilets that were in the middle area of existing building to the north wall, and made a multiroom more private in the middle, with help of feedback from workers.

The main staircase is now more compact in comparison with existing one, as the form of it follows the angle of the east wall.



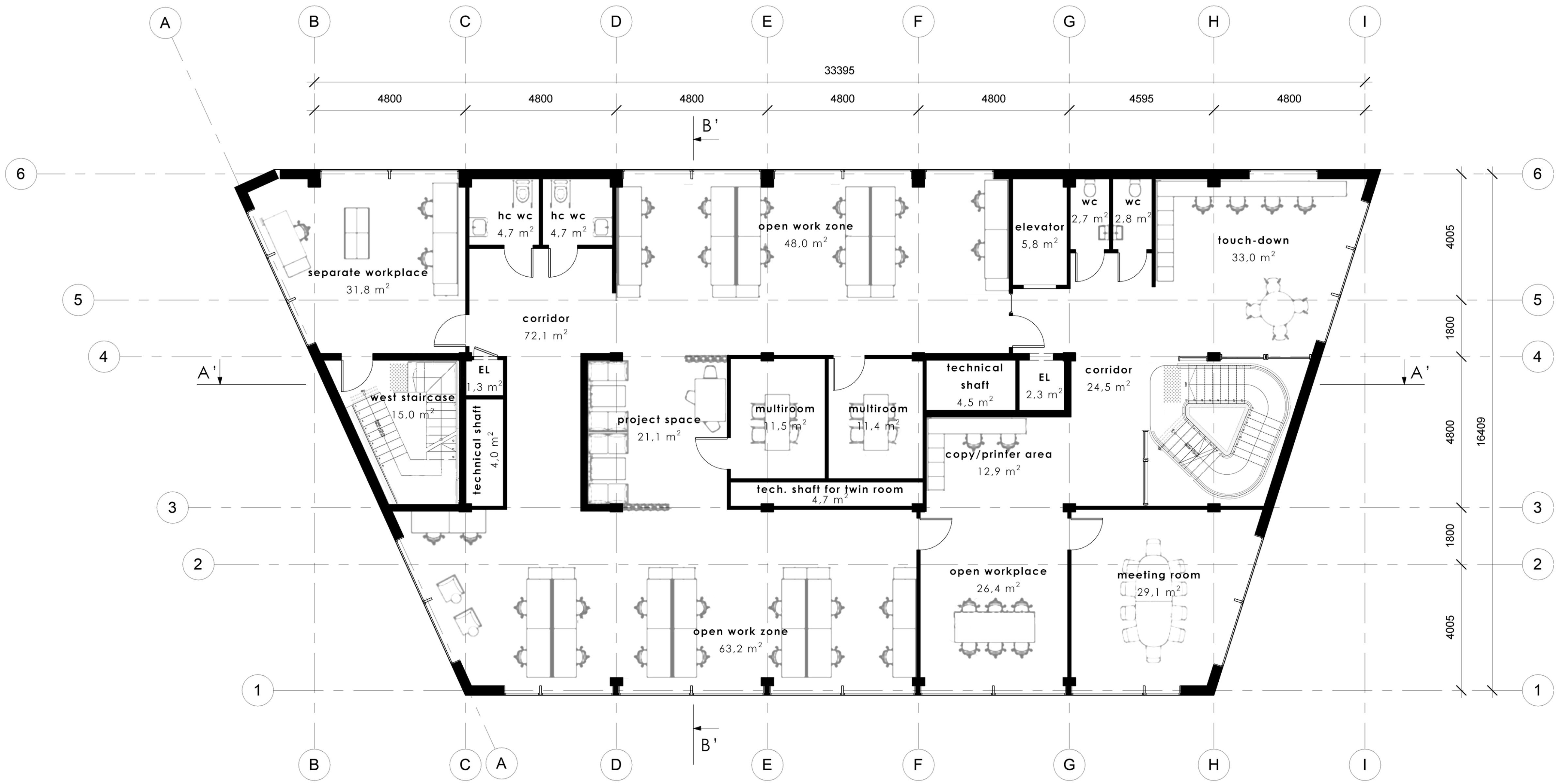
Zoning of existing ZEB Laboratory



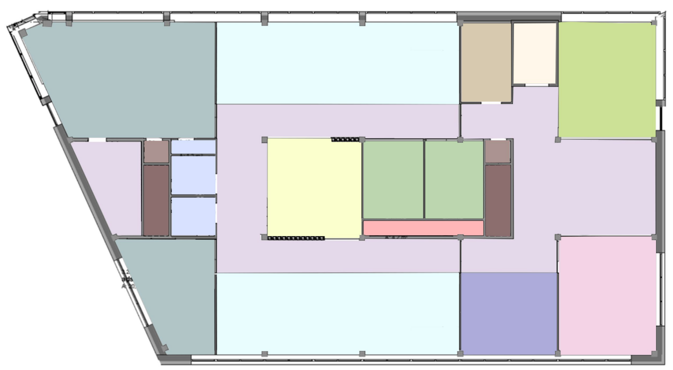
Zoning of proposed form

- twin research rooms
- team rooms
- WC
- elevator
- electricity shaft
- technical shaft
- technical rooms
- staircases and corridor area
- touch-down
- multiroom
- meeting room

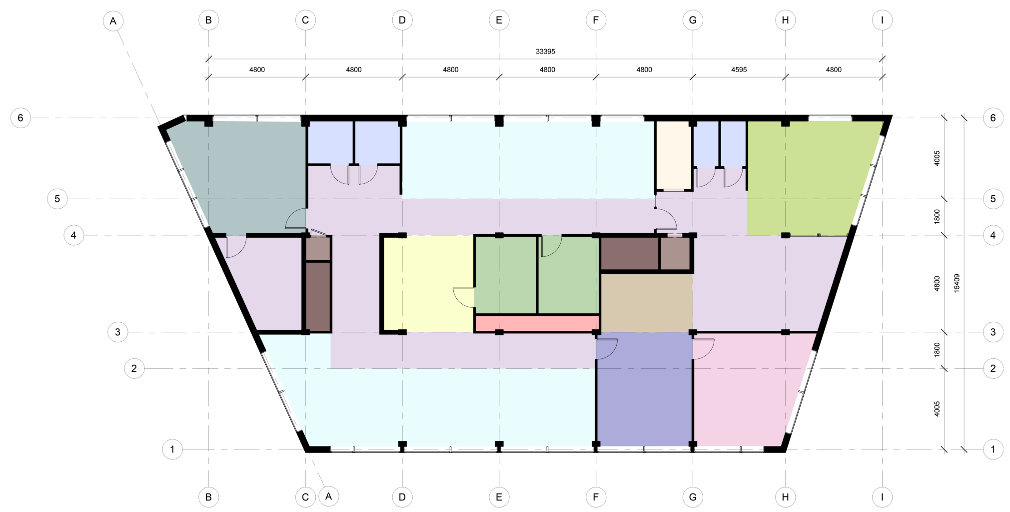
7.4 Plan and zoning of the third floor



The copy/printer area is now replaced more to the middle part of the building, as in existing one that room was not used at all, also it does not require the daylight. Thus, rooms remained flexible as it was planned in existing building, to have variety in changes of the office rooms.



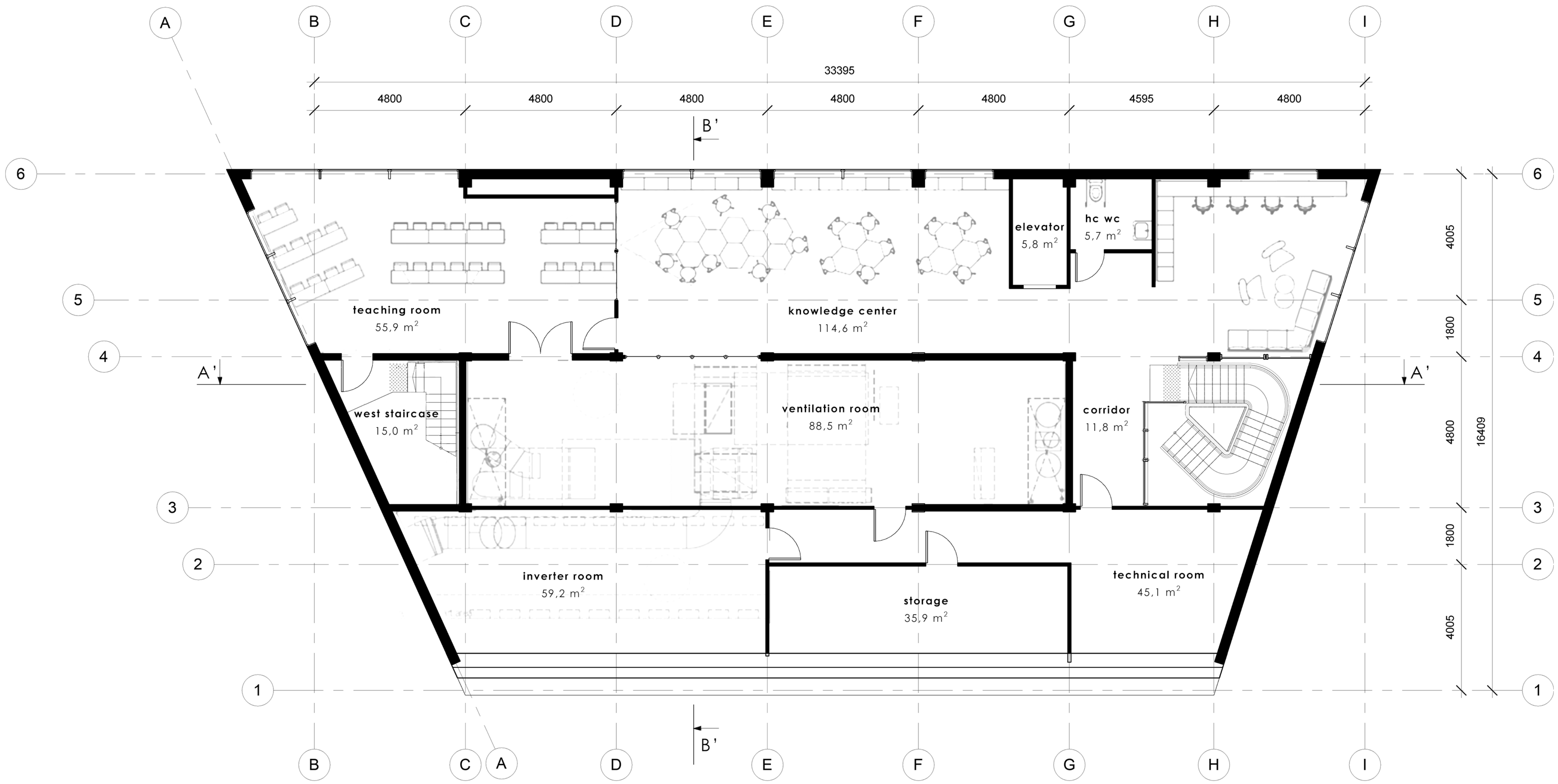
Zoning of existing ZEB Laboratory



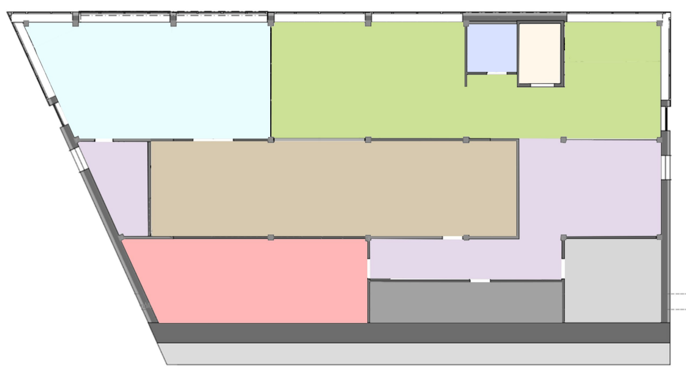
Zoning of proposed form

- twin room shaft
- open work zones
- WC
- elevator
- electricity shaft
- technical shaft
- open workplace
- staircases and corridor area
- touch-down
- multiroom
- meeting room
- separate workplace
- copy/printer area

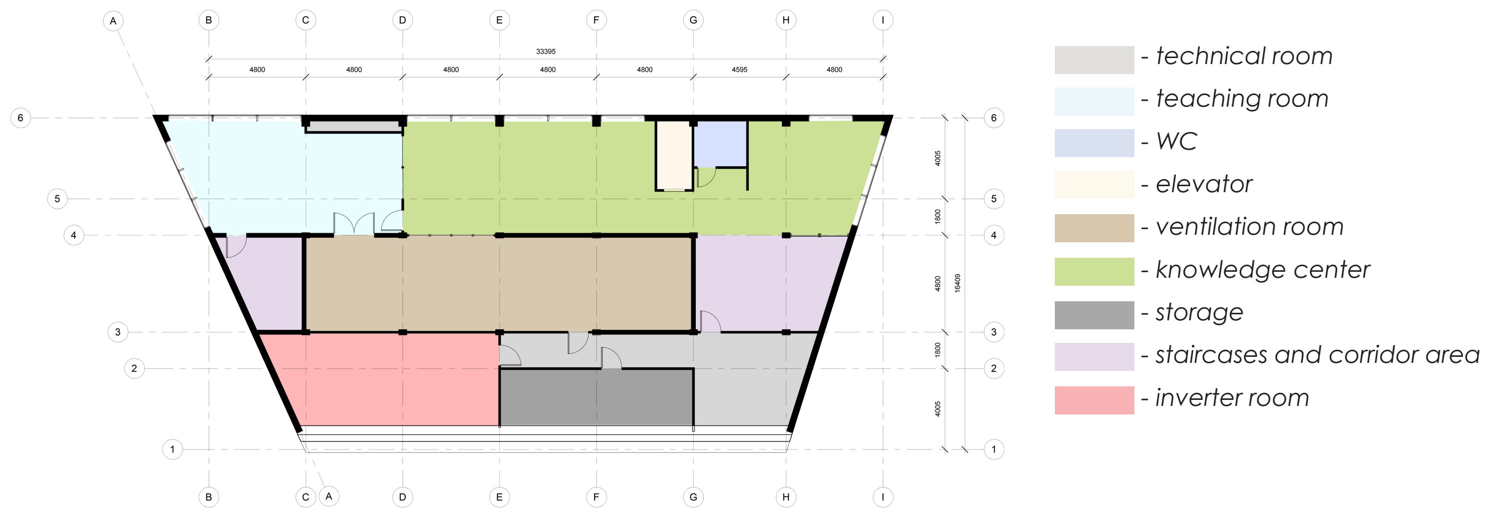
7.5 Plan and zoning of the fourth floor



The fourth floor area remained relatively the same, major change is that the teaching room now has less window area on the north facade, due to technical shafts of toilets bellow.



Zoning of existing ZEB Laboratory



Zoning of proposed form

7.6 Sections

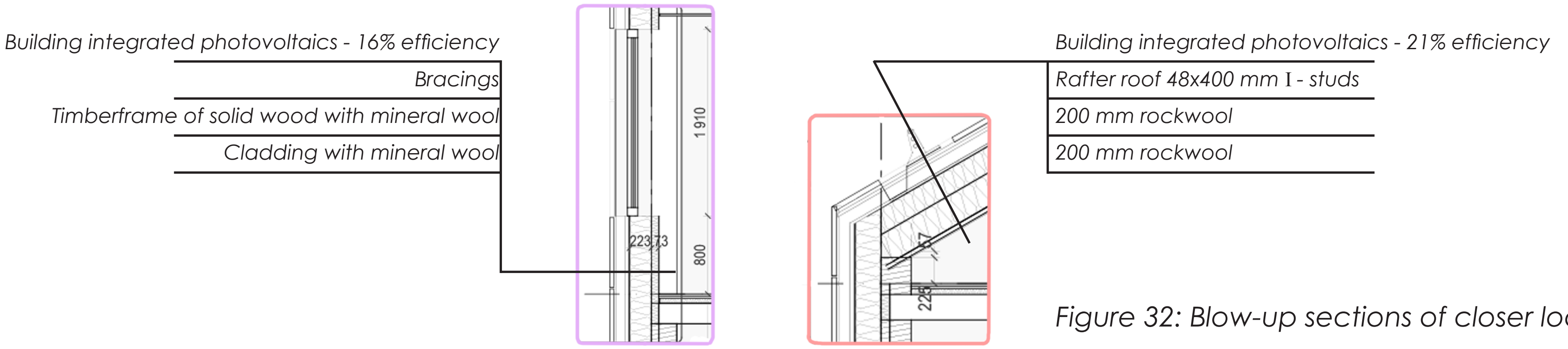


Figure 32: Blow-up sections of closer look at materials

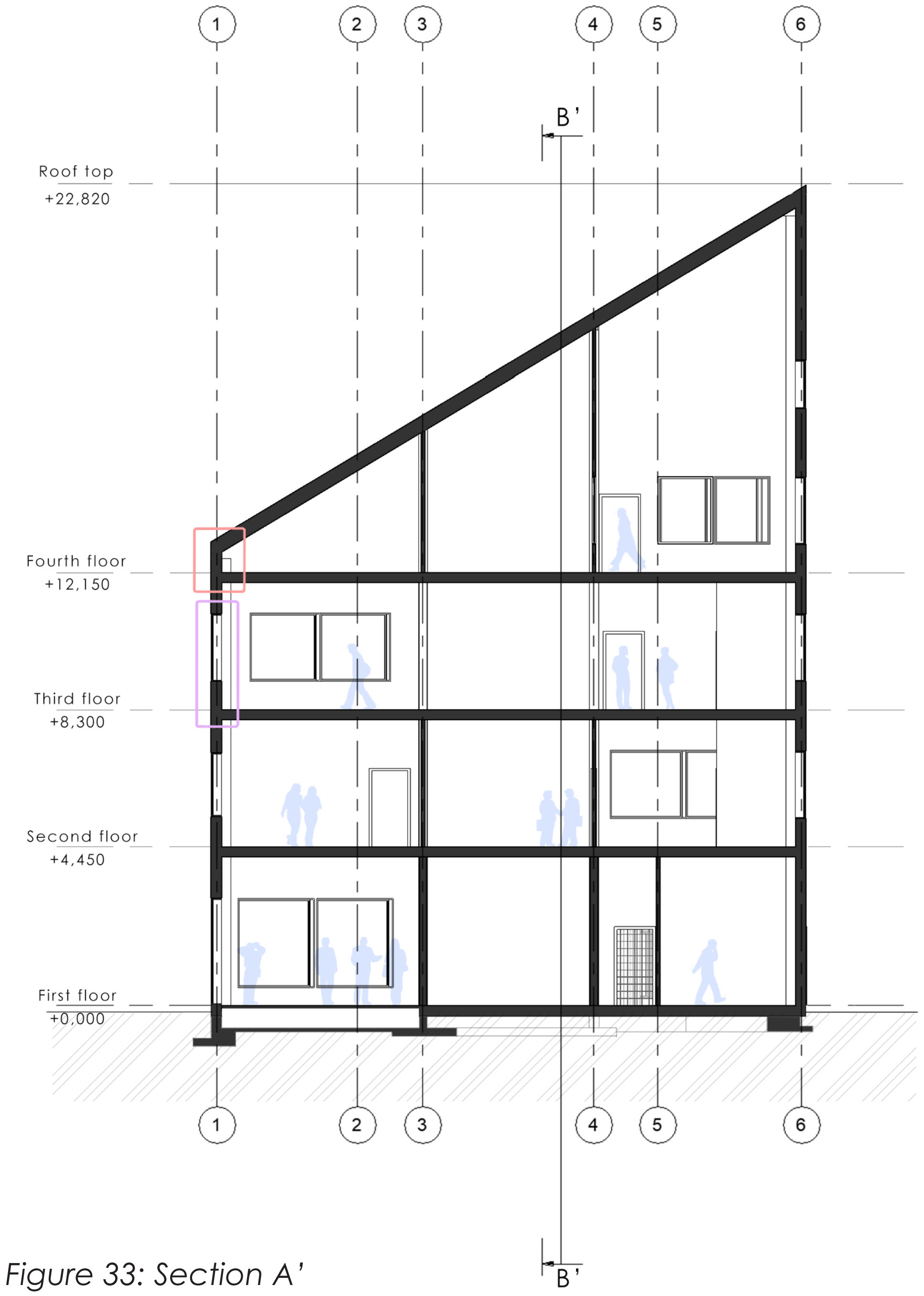


Figure 33: Section A'

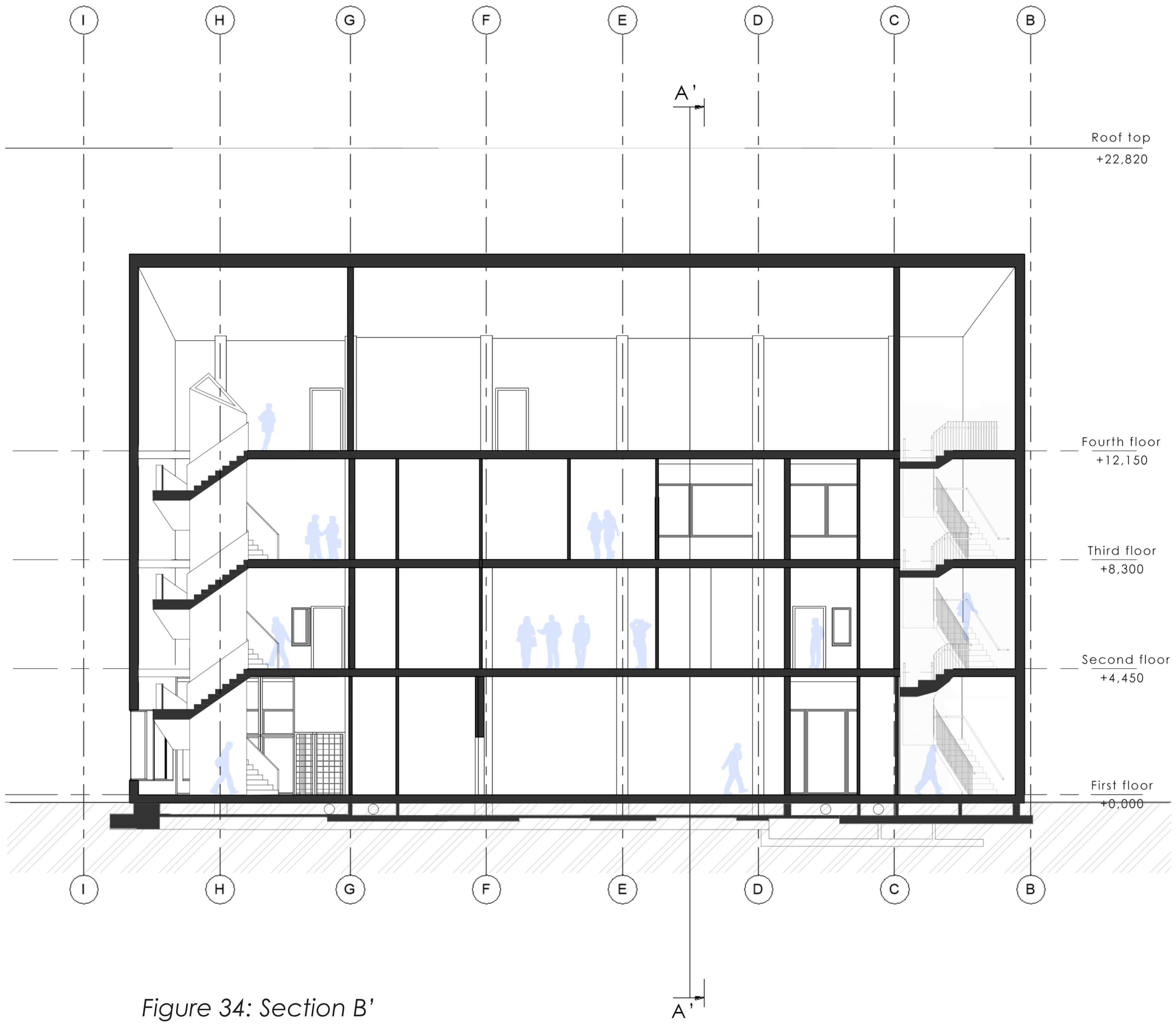


Figure 34: Section B'

7.7 Elevations

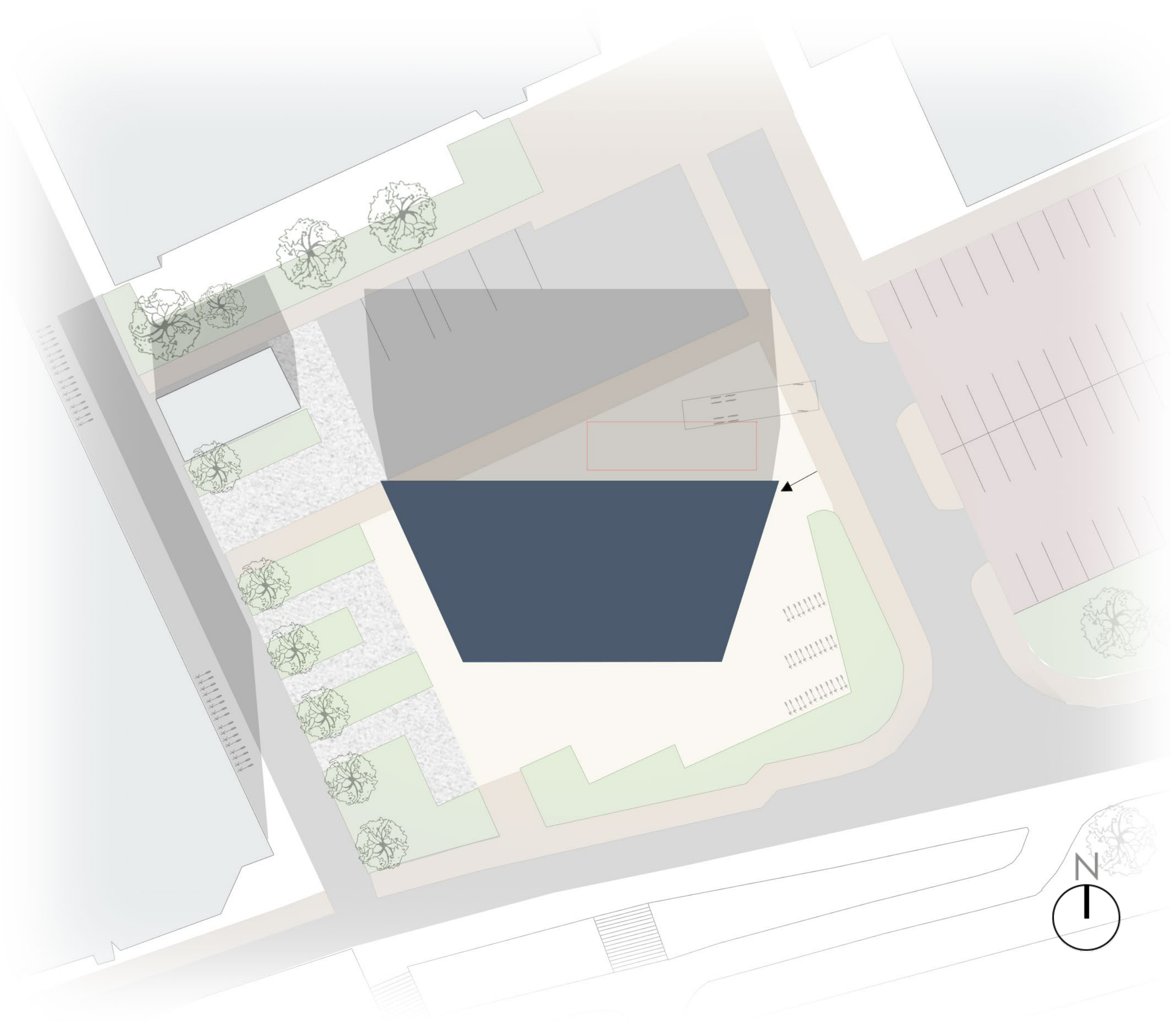


Figure 35: General plan of the site

Figure 36: Elevations of new form

7.8 3D Visualization

Figure 37: 3D visualization

8 DISCUSSION

This thesis's goals are pushing boundaries of passive strategies that can be implemented or improved in existing ZEB Laboratory. At first it was hard to find precise information about existing building, as variety of reports, websites, articles were saying different numbers, values, etc. After help from Erlend Andenæs, I had a clear scope of what to test and change in the building, to find an optimal shape. My limitation was, that I tried to preserve as much as possible from existing building, in other words "modifying" ZEB Lab to see other shapes in action, and my groupmate Soumenh L. was rebuilding completely, so we had a one goal of reaching ZEB - COM level from different ways.

The architectural analysis of existing building was not taken from the architects of ZEB Laboratory. All the assumptions were gathered from lots of sources, such as: all the interviews with the workers in ZEB Lab; after getting feedback and presentation with a tour inside of the building from Erlend Andenæs; digital meeting with Tore Kvande in which we got some answers on our questions; reports, previous master's theses and articles about ZEB Laboratory; some research papers and reports of Norway standards and regulations. All that knowledge helped me to recreate a picture of possible decisions that lead to creation of existing building's form.

After we got simien results from Tore Kvande for ZEB Laboratory, we decided to make our own simulation of existing building in simien, with all the inputs we had from the Energy Concept report of ZEB Laboratory [19], in order to have fair comparison with our new shapes. Also because, we needed simien file, but in the report that we got, we had only inputs and final results, so we anyway needed to make our own simulation of existing ZEB Laboratory.The results became a little bit better than in existing building. However, later when we got presentation of ZEB balance calculation and we compared our simulation to theirs, the results were lower. For example, their ZEB balance was (-0,57) and ours was (-0,17), both conditions are reaching ZEB-COM level, but we wanted to understand why it is different. We realized that it is because of PV production, for instance, for their building it is said that it is (-11.83) and ours is (-11.3), we tried a lot of options in simien but we couldn't reach the result from their presentation, even when we had better results in energy consumption and PV production by kWh/year in comparison with PDF, that we got earlier. Thus, we assumed that this (-0.53) difference occurred because of PV panels that they have on a ground floor of south wall outside of the building, which we did not implement in our calculations. With that assumption we continued on using our simulation results of existing building as the main one in further comparisons.

First simulations were made with Rhino (Grasshopper), as it is very user friendly and flexible software, to make quick analysis of the place, like solar radiation analysis, energy and daylight. Plus of that software is, that it does not require precise input data in the beginning of the shape analysis, and that is why I was using glazing area as a ratio, so that all the shapes had same square meter area of windows as an existing building, to see how different shapes affect overall consumption of the building, also how heating and cooling demand will change. After the realization of the limits of that software, the end simulations were made in Simien as it had more precise data results.

Thesis shows the process of how the worst form in the beginning of the calculations, became the best form in comparison with other shapes and existing building in the end. I begin with experimentations of rotating the existing building, as it is suggested in Victor Olgyay's book "Design with climate" to have a south facing facade turned more to the south-east. That is an optimal placement for the building, however not for the building with photovoltaics, and I was curious to test the existing shape's behaviors in different rotation scenarios. Information that I got from these experimentations helped me to create 5 new possible shapes that could be tested.

At the beginning I had high expectations on the form that is called "Small North form" with the reduction of north-facing area of the building and an increase of south-facing facade would give very good results in energy savings in comparison with existing and the other shapes. Even in the simulation with the same square meter area of glazing that form was leading in decreasing of energy consumption of the building. However, in order to reach ZEB-COM level, reduction of energy consumption of the building by passive strategies was not enough, ZEB balance calculation reached (0,66). Mainly, because of different efficiency of solar panels on facades and roof, 16% and 21% respectively. Even with having much more square meters area of PV panels in comparison with existing building.

Then, I went back to the other forms, with having in mind, that PV production is also a value that should not be excluded from equation, and with having experience with previous "Small North form", my decision went for the "Big North form", which at first glance looks the worst by energy consumption, but in comparison of having smaller PV panel area and larger production of energy that form was the best. In addition to that, south-west and south-east looking facades are better in collecting solar heat gain than north-west and north-east facades in "Small North form".

The best reduction in energy consumption of "Small North form" was happening due to decrease north-facing area of the building, which I implemented in "Big North form" via reducing amount of glazing on the north facade. Reduction of glazing happened due to replanning interior spaces, for example I replaced handicap WC's that was in the middle in existing building, to the north facade. All these changes helped to reduce energy consumption up to (35,7 kWh/m2) and have it slightly lower than the existing form (36,1 kWh/m2).

All the final simulations and comparisons were made with Simien software, as it is the main Norwegian software to calculate ZEB buildings, also the existing building's calculation were made in that software. Simien shows more precise data in comparison with the rhino (grasshopper), as the input values that we put in the simien are more precise, for instance: size and number of the windows and their U-values; all the values of ventilation system and heat gains. Also the results that we get from simien are more informative, especially for ZEB balance calculation the amount of CO_2 emissions from energy use, etc. Probably in rhino it is possible to implement those values too, however with the knowledge I have, it was easier to make final simulations and comparisons in simien.

After finalizing the form, I did additional simulations of daylight condition inside the office areas, and glare analysis. Daylight conditions are similar to the existing building, with having 500 lux in all the office rooms except the middle part of the building where the meeting rooms, technical rooms and staircases are located, which are not require for that amount of daylight. With the glare analysis it can be seen, that shading devices are must be implemented in the south-facing area, as in autumn and winter there will be a lot of direct sunlight.

My proposal is to implement some shading devices such us controllable louvers, as it is more flexible rather than having fully closed window with the roll curtain. Also shading devices should be placed inside of the building, as the major passive strategy that was used in proposed form is increasing solar heat gains in order to reduce energy consumption of the building for heating.

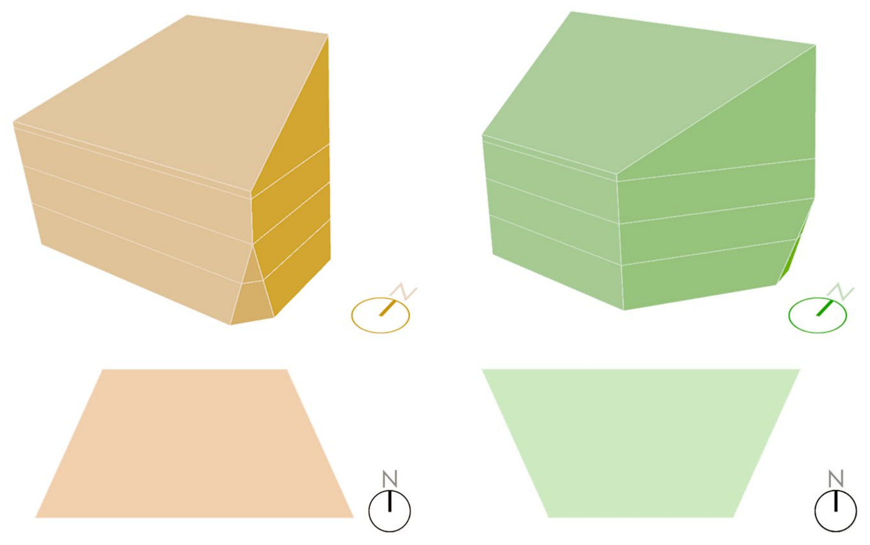


Figure 38: «Small North form» on the left, and «Big North form» on the right

9 CONCLUSION

The set goal of this thesis in becoming ZEB - COM building, with implementing or improving existing passive strategies, and avoiding an increase in material usage, has been reached. ZEB balance of the proposed shape is (-0,22), which is slightly better than the existing building in our simulation. The results are proving that the higher the aim in ZEB classification, the harder to get significant changes in results. Variety of small decisions and lots of tests were made to create the most optimal shape with focus on solar heat gain as the main passive strategy.

First challenge was finding the shape with the lowest energy consumption due to it's form with the same glazing area as an existing building.

Then, second challenge, was need in increase of solar heat gains on the south, west and east facades of the forms, which could help in reduction of energy consumption for heating.

Third challenge was to maintain or increase amount of photovoltaic production on site to reach the required level of ZEB-COM, which lead to testing different shapes depending on their total area of PV panels in comparison with their production of energy.

Fourth challenge was in finding a way of reducing the north-facing glazing area, or north facade area to decrease the amount of heat loss, which lead to replanning of existing building for a new shapes, with reduction of windows on the north facade.

After overcoming all those obstacles, the final form was forging it's shape, and with combination of all the decisions and solutions for those obstacles the final form, with respect to all the design decisions that were made in existing building, reached ZEB-COM level even slightly higher than the existing shape. The final form represents the possibility of improvements that can be made with focusing mostly on passive strategies to reach ZEB-COM level as an existing ZEB Laboratory. And this is not the boundary yet, as in my opinion, there is still some improvements could be made to make the building even better.

10 FURTHER WORK

Further development of this project could be tested with original simien that was used in calculation of existing ZEB Laboratory, that we unfortunately did not get. To see, maybe results could be even better, or worse and find the reason and solution to those new obstacles that can occur.

Other possible shapes could be tested for example more rounded shapes, as in this thesis only used straight walls and simple forms, however with this knowledge the research in finding more fluid or natural form can be very interesting, especially with comparisons to simple shapes. Especially, with the wood structure, as it is harder to make rounded walls from wood without using too much energy for production of those.

Make an LCA analysis of the shapes that were used in thesis, to have more broader look on the changes in situations of different forms. As the amount of window area is reduced in “Big North form” in comparison with existing one, thus the amount of energy use for material production should be also less, which will lead in improvement of result in ZEB balance equation.

As the south part of the building has a problem with a glare, some in depth simulations and research could be done in that way, to improve the daylight conditions especially in autumn and winter, without having to close the whole window with the roll curtain. As this thesis proposed some controllable louvers for improvement of flexibility in different conditions for different zones can be implemented. Also to test out the new technology of self shading (tint changing) windows.

After implementing shading devices inside of the building on the south part, the problems with overheating might occur, thus further indepth analysis with simulations would be needed. To solve the overheating issues, the simulations on ventilation systems with new strategies could be interesting to research. Also in that case for solving overheating, one can re-think on water trombe walls as a shading devices [20], as the water has 4 times more energy intensity than concrete, and the rate of releasing the heat is faster as the water has higher thermal conductivity, which could play as a cooler in summer and heater in winter with the right amount of placement those tubes of water. Because, water is much more environment friendlier than any other material that has been used in trombe walls. As the existing ZEB Lab has a twin rooms, it would be very interesting to test those water tubes in those rooms.

The water is very dangerous for wooden construction in case of accidents, however some time ago the fire was also the problem in case of building wooden high-rises, but we managed to find solutions for those.

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ICONOGRAPHY

Figure 1: Was taken from "A Norwegian ZEB Definition Guideline" report, 2016 -- Last visited 17.05.2022

Figure 2: Was taken from Zeb laboratory website - drawings "https://zeblab.no/drawings" -- Last visited 17.05.2022

Figure 3: Was taken from Zeb laboratory website - drawings "https://zeblab.no/drawings" -- Last visited 17.05.2022

Figure 4: Was made by Alisher Khamitov

Figure 5: Software's logos were taken from google pictures «secondary sources», simulations of each software were made by me

Figure 6: Was taken from Link Arkitecture company from recieved PDF's with plans and sections

Figure 7: Left picture was taken from Zeb laboratory website - drawings "https://zeblab.no/drawings" -- Last visited 17.05.2022. Right picture was made by Alisher Khamitov

Figure 8: Was made by Alisher Khamitov

Figure 9: Was made by Alisher Khamitov

Figure 10: Was made by Alisher Khamitov

Figure 11: Plans were taken from Zeb laboratory website - drawings "https://zeblab.no/drawings" -- Last visited 17.05.2022. Pictures of inside were made by Alisher and Soumenh. Pictures of staircase were taken from secondary source "https://www.midthaug.no/portfolio/zeb-lab-ntnu/" -- Last visited 17.05.2022

Figure 12: Left results were taken from ENERGIKONSEPT report from LINK Arkitektur AS (received from Tore Kvande). Right results were made by Alisher Khamitov

Figure 13: Left results were taken from presentation from Erlend Andenæs. Right results were made by Alisher Khamitov

Figure 14: Was taken from ENERGIKONSEPT report from LINK Arkitektur AS (received from Tore Kvande).

Figure 15: Was taken from ENERGIKONSEPT report from LINK Arkitektur AS (received from Tore Kvande).

Figures from 16 to 31: Were made by Alisher Khamitov

Figure 32: Was taken from Link Arkitecture company from received PDF's with plans and sections

Figures from 33 to 38: Were made by Alisher Khamitov

APPENDIX - A

A.1. All the inputs for simien simulation of existing ZEB Laboratory from PFD from LINK Arkitektur AS (received from Tore Kvande)

Bygningskategori		Kontorbygg	
Stшrrelse		**Inndata**	**Dokumentasjon**
Arealer [m²]	Yttervegger	1238	Tegninger, sist rev. 21.11.2018
	Tak	535	Tegninger, sist rev. 21.11.2018. Skretak gir stшrre takareal enn gulvareal.
	Gulv	440	Tegninger, sist rev. 21.11.2018
	Vinduer, dшrer og glassfelt	477	Tegninger, sist rev. 27.05.2019
Oppvarmet delav BRA (A_{fl}) [m²]		1742	Tegninger, sist rev. 21.11.2018
Oppvarmet luftvolum (V) [m³]		7691	Tegninger, sist rev. 21.11.2018
U-verdi for bygningsdeler [W/m²K]	Yttervegger	0,15	Isolert bindingsverk, t_{iso}=300mm, $t_{stender}$=48mm, λ_{iso}=0,033 W/mK Isolert bindingsverk, t_{iso}=225mm, $t_{stender}$=48mm, λ_{iso}=0,033 W/mK
	Tak	0,09	Isolert sperretak av I-profiler, t_{iso}=450mm, t_{bjelke}=48mm λ_{iso}=0,036 W/mK.
	Gulv	0,10 ekv.	Gulv pe grunn, t_{iso}= 250mm, λ_{iso}=0,038 W/mK.
	Vinduer, dшrer og glassfelt	0,77	Gjennomsnittlig for hele vindus- og dшrleveransen. Opplyst ved mail av 28.09.2020 fra Veidekke entreprenшr.
Arealandel for vinduer, dшrer og glassfelt (γ_{sol}) [%]		27,4	Tegninger, sist rev. 27.05.2019
Normalisert kuldebroverdi (Ψ`) [W/m²K]		0,04	Gitt i 418722-RIBfy-NOT-002.
Normalisert varmekapasitet (c") [Wh/m²K]		81	Massivtrekonstruksjoner. Stшpt kjerne og sele.
Lekkasjetall (n_{50}) [h⁻¹]		0,3	Konseptverdi gitt i 418722-RIBfy-NOT-002. Dokumentert med trykktest.
Temperaturvirkningsgrad (η_T) for varmegjenvinner [%]		85/88	Konseptverdi. God varmegjenvinner, for TEK beregninger. Aggregat kjшringer for NS 3701 luftmengder. Melinger pe eksisterende ventilasjonsaggregater har vist at denne verdien kan vжre pe den usikre side ved kjшring av aggregat pe dellast. I reel beregning er det lagt inn verdi svarende til konseptverdi.
Estimert ers gjennomsnittlig temperaturvirkningsgrad for varmegjenvinner pga. frostsikring [%]		85/88	Konseptverdi. God varmegjenvinner, for TEK beregninger. Aggregat kjшringer for NS 3701 luftmengder

Figure A.1.1: Documentation of key inputs for the energy calculation

Bygningskategori	Kontorbygg	
Stшrrelse	**Inndata**	**Dokumentasjon**
Spesifikk vifteeffekt (SFP) relatert til luftmengder i driftstiden [kW/m³/s]	1,0/ 0,9	Antatt verdi ut fra aggregat kjшring for TEK for balansert system. For passivhus er SFP dokumentert i NOT-RIV-01 ZEB FLEXIBLE LAB - DOKUMENTASJON AV BEREGNET SPESIFIKK VIFTEEFFEKT
Spesifikk vifteeffekt (SFP) relatert til luftmengder utenfor driftstiden [kW/m³/s]	0,5	For balansert system
Gjennomsnittlig spesifikk ventilasjonsluftmengde i driftstiden (V_{on}/A_{fl}) [m³/m²h]	6,0	For balansert system. Mot TEK17: 7,0
Spesifikk ventilasjonsluftmengde utenfor driftstiden (V_{red}/A_{fl}) [m³/m²h]	1,0	For balansert system Mot TEK17: 2,0
Ersgjennomsnittlig (VP//EL/FJV) systemvirkningsgrad/varmefaktor for oppvarmingssystemet [%]	3 / - / 0,89	Prosjektverdi med godt isolerte rшr. Turtemperatur < 45ºC
Ersgjennomsnittlig (VP/EL/FJV) systemvirkningsgrad/varmefaktor for oppvarmning varmt tappevann [%]	3,33 / 1 / -	Projektverdi og verdier for normert beregning
Ersgjennomsnittlig (VP/EL/FJV) systemvirkningsgrad/varmefaktor for oppvarmingssystemet [%]	3,07 /- / -	Projektverdi og verdier for normert beregning
Installert effekt for romoppvarming og ventilasjonsvarme (varmebatteri) [W/m²]	160	Inndata verdi, reelt uttak er vesentlig lavere
Settpunkttemperaturer for oppvarming [əC]	19/21	Standardverdier iht. Tabell A.3 NS 3031:2014. I og utenom driftstid.
Ersgjennomsnittlig kjшlefaktor for kjшlesystemet [%]	2,5	Ingen installert kjшling.
Settpunkttemperaturer for kjшling [əC]	22	Ingen installert kjшling.
Installert effekt for romkjшling og ventilasjonskjшling [W/m²]	0	Ingen installert kjшling.
Spesifikk pumpeeffekt (SPP) [kW/ls]	0,5	Standardverdi.
Driftstid for ventilasjon, oppvarming, kjшling, lys, utstyr, varmtvann og personer	12/12/24/ 12/12/12/ 12	Standardverdier iht. Tabell A.3 NS 3031:2014 for hhv: Belysning og utstyr/ Oppvarming, ventilasjon og personer
Spesifikt effektbehov for belysning i driftstiden [W/m²]	2,4	LENI-dokumentasjon. Beregning fra Glamox
Spesifikt varmetilskudd fra belysning i driftstiden (q''_{lys}) [W/m²]	2,4	LENI-dokumentasjon. Beregning fra Glamox
Spesifikt effektbehov for utstyr i driftstiden [W/m²]	3,2	Brukerbestemt-nive Mot TEK17: 11,0
Spesifikt varmetilskudd fra utstyr i driftstiden (q''_{uts}) [W/m²]	3,2	Brukerbestemt-nive Mot TEK17: 11,0
Spesifikt energibruk for varmtvann i driftstiden (q''_w) [kWh/m²er]	5 / 1	Standardverdier iht. Tabell A.2 NS 3031:2014, For NS 3701 beregning og ZEB COM benyttes 1 kWh/m2 er som avtalt prosjekt spesifikk verdi. Verdien er ikke dokumentert ved beregning, men me dokumenteres i drift.
Varmetilskudd fra varmtvann i driftstiden [W/m²]	0,00	Standardverdier iht. Tabell A.2 NS 3031:2014
Varmetilskudd fra personer (q''_{pers}) i driftstiden [W/m²]	4,0	Standardverdier iht. Tabell A.2 NS 3031:2014

Figure A.1.2: Documentation of key inputs for the energy calculation

Bygningskategori	Kontorbygg	
Stшrrelse	**Inndata**	**Dokumentasjon**
Total solfaktor (g_t) for vindu og solavskjerming (Ш/S/V/N)	0,31	Vinduer, hele bygget: - Tre-lags vindu med lavemisjonsbelegg (g_{tot} =0,45) Vinduer mot sшr som ligger bak transparente solceller: - Tre-lags vindu med lavemisjonsbelegg (g_{tot} =0,35) Solavskjerming mot sшr: - Tre-lags vindu med utvendig solavskjerming (g_{tot} =0,10) Solavskjerming mot шst og vest: - Tre-lags vindu med lavemisjonsbelegg og innvendig screen (g_{tot} =0,35).
Gjennomsnittlig karmfaktor (F_F)	0,2	Standardverdi
Solskjermingsfaktor pga. horisont, nжrliggende bygninger, vegetasjon og evt. bygningsutspring (N/Ш/S/V)	0,74/0,95/ 0,97/0,95	

Figure A.1.3: Documentation of key inputs for the energy calculation

	EL	Fjernvarme	Varmepumpe	Sol	Biobrensel	Gass
Romoppvarming	0	2	98	0	0	0
Tappevann*)**	35	0	65	0	0	0
Ventilasjonsvarme	0	0	100	0	0	0
Kjшlebatterier romkjшling	100*)	0	0	100**)	0	0
Lokal kjшling / romkjшling	100 *)	0	0	100**)	0	0
El.-spesifikt energibehov	100	0	0	100**)	0	0

Figure A.1.4: Coverage of energy requirements in %

A.2. Simien simulations results of existing building from PFD from LINK Arkitektur AS (received from Tore Kvande)

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	54355 kWh	31,2 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	7504 kWh	4,3 kWh/m²
2 Varmtvann (tappevann)	1745 kWh	1,0 kWh/m²
3a Vifter	10676 kWh	6,1 kWh/m²
3b Pumper	675 kWh	0,4 kWh/m²
4 Belysning	13093 kWh	7,5 kWh/m²
5 Teknisk utstyr	17461 kWh	10,0 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	0 kWh	0,0 kWh/m²
Totalt netto energibehov, sum 1-6	105510 kWh	60,6 kWh/m²

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	42516 kWh	24,4 kWh/mЙ
1b El. til varmepumpesystem	20541 kWh	11,8 kWh/mЙ
1c El. til solfangersystem	0 kWh	0,0 kWh/mЙ
2 Olje	0 kWh	0,0 kWh/mЙ
3 Gass	0 kWh	0,0 kWh/mЙ
4 Fjernvarme	1221 kWh	0,7 kWh/mЙ
5 Biobrensel	0 kWh	0,0 kWh/mЙ
6. Annen energikilde	0 kWh	0,0 kWh/mЙ
7. Solstrum til egenbruk	-0 kWh	-0,0 kWh/mЙ
Totalt levert energi, sum 1-7	64278 kWh	36,9 kWh/mЙ
Solstrum til eksport	-0 kWh	-0,0 kWh/mЙ
Netto levert energi	64278 kWh	36,9 kWh/mЙ

Levert energi til bygningen (beregnet)		
Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	42516 kWh	24,4 kWh/mЙ
1b El. til varmepumpesystem	20541 kWh	11,8 kWh/mЙ
1c El. til solfangersystem	0 kWh	0,0 kWh/mЙ
2 Olje	0 kWh	0,0 kWh/mЙ
3 Gass	0 kWh	0,0 kWh/mЙ
4 Fjernvarme	1221 kWh	0,7 kWh/mЙ
5 Biobrensel	0 kWh	0,0 kWh/mЙ
6. Annen energikilde	0 kWh	0,0 kWh/mЙ
7. Solstrum til egenbruk	-28317 kWh	-16,3 kWh/mЙ
Totalt levert energi, sum 1-7	35961 kWh	20,6 kWh/mЙ
Solstrum til eksport	-118197 kWh	-67,9 kWh/mЙ
Netto levert energi	-82236 kWh	-47,2 kWh/mЙ

Figure A.2.1: Budsjett status netto og levert energi 05.10.2020. Budsjett levert energibruk vist uten og med solstrømsproduksjon

Energibudsjett		
Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	54355 kWh	31,2 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	7504 kWh	4,3 kWh/m²
2 Varmtvann (tappevann)	1745 kWh	1,0 kWh/m²
3a Vifter	10676 kWh	6,1 kWh/m²
3b Pumper	675 kWh	0,4 kWh/m²
4 Belysning	13093 kWh	7,5 kWh/m²
5 Teknisk utstyr	17461 kWh	10,0 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	0 kWh	0,0 kWh/m²
Totalt netto energibehov, sum 1-6	105510 kWh	60,6 kWh/m²

Energy supplied to the building (calculated)		
Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42516 kWh	24.4 kWh / m²
1b El. for heat pump system 1c	20541 kWh	11.8 kWh / m²
El. for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	1221 kWh	0.7 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 0 kWh	- 0.0 kWh / m²
delivered energy, total 1-7 Solar	64278 kWh	36.9 kWh / m²
power for export	- 0 kWh	- 0.0 kWh / m²
Net delivered energy	64278 kWh	36.9 kWh / m²

Energy supplied to the building (calculated)		
Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42516 kWh	24.4 kWh / m²
1b El. for heat pump system 1c	20541 kWh	11.8 kWh / m²
El. for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	1221 kWh	0.7 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 28317 kWh	- 16.3 kWh / m²
delivered energy, total 1-7 Solar	35961 kWh	20.6 kWh / m²
power for export	- 118197 kWh	- 67.9 kWh / m²
Net delivered energy	- 82236 kWh	- 47.2 kWh / m²

Figure A.2.2: Net budget status and delivered energy 05.10.2020. Budget delivered energy consumption shown without and with solar power production

APPENDIX - B

B.1. Simien simulation results of existing building from our simulation

Energy budget		
Energy post	Energy needs	Specific energy needs
1st Room heating	40407 kWh	23.2 kWh / m²
1b Ventilation heating (heating	9814 kWh	5.6 kWh / m²
batteries) 2 Hot water (tap water)	0 kWh	0.0 kWh / m²
3a Fans	10454 kWh	6.0 kWh / m²
3b Pumps	595 kWh	0.3 kWh / m²
4 Lighting	13093 kWh	7.5 kWh / m²
5 Technical equipment	17461 kWh	10.0 kWh / m²
6a Room cooling	0 kWh	0.0 kWh / m²
6b Ventilation cooling (dress batteries)	1102 kWh	0.6 kWh / m²
Total net energy requirement, sum 1-6	92926 kWh	53.3 kWh / m²

Energy supplied to the building (calculated)		
Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42044 kWh	24.1 kWh / m²
1b El. for heat pump system 1c El.	19838 kWh	11.4 kWh / m²
for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	975 kWh	0.6 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 0 kWh	- 0.0 kWh / m²
energy delivered, total 1-7 Solar	62857 kWh	36.1 kWh / m²
power for export	- 0 kWh	- 0.0 kWh / m²
Net delivered energy	62857 kWh	36.1 kWh / m²

Energy supplied to the building (calculated)		
Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42044 kWh	24.1 kWh / m²
1b El. for heat pump system 1c El.	19838 kWh	11.4 kWh / m²
for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	975 kWh	0.6 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 29368 kWh	- 16.9 kWh / m²
energy delivered, total 1-7 Solar	33489 kWh	19.2 kWh / m²
power for export	- 121590 kWh	- 69.8 kWh / m²
Net delivered energy	- 88101 kWh	- 50.6 kWh / m²

Figure B.1.1: Net budget status and delivered energy. Budget delivered energy consumption shown without and with solar power production

Annual CO2 emissions		
Energy products	Emissions	Specific emissions
1a Direct el.	5466 kg	3.1 kg / m
1b El. for heat pump system 1c El.	2579 kg	1.5 kg / m²
for solar collector system 2	0 kg	0.0 kg / m²
Oil	0 kg	0.0 kg / m²
3 Gas	0 kg	0.0 kg / m²
4 District heating	73 kg	0.0 kg / m²
5 Biofuels	0 kg	0.0 kg / m²
6. Other energy source	0 kg	0.0 kg / m²
7. Solar power for own use	- 3818 kg	- 2.2 kg / m²
Total emissions, total 1-7	4300 kg	2.5 kg / m²
Solar power for export	- 15807 kg	- 9.1 kg / m²
Net CO2 emissions	- 11507 kg	- 6,6 kg / m²

Figure B.1.2: Annual CO2 emissions for calculation of ZEB Balance

Energiproduksjon solceller [kWh]													
Panel	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des	Totalt
Produsert PV Roof	868	3845	8557	12840	15634	15844	15528	12470	7959	3943	1284	153	98924
Produsert PV South Wall	255	1139	1951	2307	2150	1988	2065	1921	1506	941	383	15	16622
Produsert PV West Wall	181	852	1757	2681	3042	2984	3104	2714	1688	843	268	22	20136
Produsert PV East Wall	68	384	1138	1932	2650	2836	2648	1940	1078	469	112	19	15276
Sum produsert	1372	6220	13403	19760	23476	23652	23345	19046	12231	6196	2047	209	150958
Levert til bygning	780	2022	3163	3276	3335	3458	3628	3496	2864	2004	1146	195	29368
Eksportert til nett	592	4198	10240	16484	20141	20194	19717	15551	9367	4191	902	14	121590

Figure B.1.3: Energy production from PV panels

B.2. Simien simulation results of “Small North from”

Energy budget		
Energy post	Energy needs	Specific energy needs
1st Room heating	37843 kWh	21.7 kWh / m²
1b Ventilation heating (heating	9767 kWh	5.6 kWh / m²
batteries) 2 Hot water (tap water)	0 kWh	0.0 kWh / m²
3a Fans	10454 kWh	6.0 kWh / m²
3b Pumps	610 kWh	0.4 kWh / m²
4 Lighting	13093 kWh	7.5 kWh / m²
5 Technical equipment	17461 kWh	10.0 kWh / m²
6a Room cooling	0 kWh	0.0 kWh / m²
6b Ventilation cooling (dress batteries)	1102 kWh	0.6 kWh / m²
Total net energy requirement, sum 1-6	90330 kWh	51.9 kWh / m²

Energy supplied to the building (calculated)		
Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42059 kWh	24.1 kWh / m²
1b El. for heat pump system 1c El.	18795 kWh	10.8 kWh / m²
for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	913 kWh	0.5 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 0 kWh	- 0.0 kWh / m²
energy delivered, total 1-7 Solar	61767 kWh	35.5 kWh / m²
power for export	- 0 kWh	- 0.0 kWh / m²
Net delivered energy	61767 kWh	35.5 kWh / m²

Energy supplied to the building (calculated)		
Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42059 kWh	24.1 kWh / m²
1b El. for heat pump system 1c El.	18795 kWh	10.8 kWh / m²
for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	913 kWh	0.5 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 29170 kWh	- 16.7 kWh / m²
energy delivered, total 1-7 Solar	32597 kWh	18.7 kWh / m²
power for export	- 110345 kWh	- 63.3 kWh / m²
Net delivered energy	- 77748 kWh	- 44.6 kWh / m²

Figure B.2.1: Net budget status and delivered energy. Budget delivered energy consumption shown without and with solar power production

Annual CO2 emissions		
Energy products	Emissions	Specific emissions
1a Direct el.	5468 kg	3.1 kg / m
1b El. for heat pump system 1c El.	2443 kg	1.4 kg / m
for solar collector system 2	0 kg	0.0 kg / m²
Oil	0 kg	0.0 kg / m²
3 Gas	0 kg	0.0 kg / m²
4 District heating	68 kg	0.0 kg / m²
5 Biofuels	0 kg	0.0 kg / m²
6. Other energy source	0 kg	0.0 kg / m²
7. Solar power for own use	- 3792 kg	- 2.2 kg / m²
Total emissions, total 1-7	4187 kg	2.4 kg / m²
Solar power for export	- 14345 kg	- 8.2 kg / m²
Net CO2 emissions	- 10157 kg	- 5,8 kg / m²

Figure B.2.2: Annual CO2 emissions for calculation of ZEB Balance

Energiproduksjon solceller [kWh]													
Panel	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des	Totalt
Produsert PV Roof	867	3839	8545	12822	15612	15822	15506	12453	7947	3937	1282	153	98785
Produsert PV South Wall	339	1516	2597	3071	2861	2646	2748	2557	2005	1253	510	20	22123
Produsert PV West Wall	50	166	474	971	1722	1944	1838	1280	629	253	69	22	9417
Produsert PV East Wall	48	160	457	935	1698	2018	1812	1145	587	243	66	22	9191
Sum produsert	1303	5681	12073	17799	21892	22430	21904	17435	11167	5686	1927	217	139515
Levert til bygning	773	1939	3071	3289	3345	3473	3633	3503	2861	1961	1121	201	29170
Eksportert til nett	530	3742	9003	14509	18547	18957	18271	13933	8306	3725	805	16	110345

Figure B.2.3: Energy production from PV panels

B.3. Simien simulation results of “Big North from”

Energy budget		
Energy post	Energy needs	Specific energy needs
1st Room heating	38958 kWh	22.4 kWh / m²
1b Ventilation heating (heating	9716 kWh	5.6 kWh / m²
batteries) 2 Hot water (tap water)	0 kWh	0.0 kWh / m²
3a Fans	10454 kWh	6.0 kWh / m²
3b Pumps	595 kWh	0.3 kWh / m²
4 Lighting	13093 kWh	7.5 kWh / m²
5 Technical equipment	17461 kWh	10.0 kWh / m²
6a Room cooling	0 kWh	0.0 kWh / m²
6b Ventilation cooling (dress batteries)	1102 kWh	0.6 kWh / m²
Total net energy requirement, sum 1-6	91378 kWh	52.5 kWh / m²

Energy supplied to the building (calculated)		
Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42044 kWh	24.1 kWh / m²
1b El. for heat pump system 1c El.	19222 kWh	11.0 kWh / m²
for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	940 kWh	0.5 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 0 kWh	- 0.0 kWh / m²
energy delivered, total 1-7 Solar	62205 kWh	35.7 kWh / m²
power for export	- 0 kWh	- 0.0 kWh / m²
Net delivered energy	62205 kWh	35.7 kWh / m²

Energy supplied to the building (calculated)		
Energy products	Delivered energy	Specific energy delivered
1a Direct el.	42044 kWh	24.1 kWh / m²
1b El. for heat pump system 1c El.	19222 kWh	11.0 kWh / m²
for solar collector system 2	0 kWh	0.0 kWh / m²
Oil	0 kWh	0.0 kWh / m²
3 Gas	0 kWh	0.0 kWh / m²
4 District heating	940 kWh	0.5 kWh / m²
5 Biofuels	0 kWh	0.0 kWh / m²
6. Other energy source	0 kWh	0.0 kWh / m²
7. Solar power for own use Total	- 29281 kWh	- 16.8 kWh / m²
energy delivered, total 1-7 Solar	32925 kWh	18.9 kWh / m²
power for export	- 121515 kWh	- 69.8 kWh / m²
Net delivered energy	- 88590 kWh	- 50.9 kWh / m²

Figure B.3.1: Net budget status and delivered energy. Budget delivered energy consumption shown without and with solar power production

Annual CO2 emissions		
Energy products	Emissions	Specific emissions
1a Direct el.	5466 kg	3.1 kg / m
1b El. for heat pump system 1c El.	2499 kg	1.4 kg / m
for solar collector system 2	0 kg	0.0 kg / m²
Oil	0 kg	0.0 kg / m²
3 Gas	0 kg	0.0 kg / m²
4 District heating	70 kg	0.0 kg / m²
5 Biofuels	0 kg	0.0 kg / m²
6. Other energy source	0 kg	0.0 kg / m²
7. Solar power for own use	- 3806 kg	- 2.2 kg / m²
Total emissions, total 1-7	4229 kg	2.4 kg / m²
Solar power for export	- 15797 kg	- 9.1 kg / m²
Net CO2 emissions	- 11568 kg	- 6.6 kg / m²

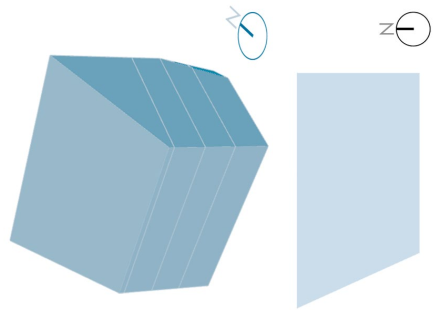
Figure B.3.2: Annual CO2 emissions for calculation of ZEB Balance

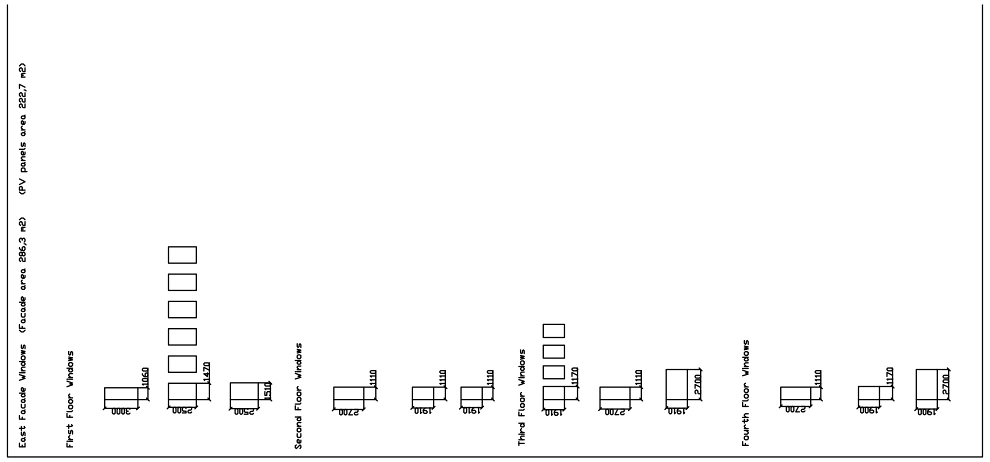
Energiproduksjon solceller [kWh]													
Panel	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des	Totalt
Produsert PV Roof	867	3839	8545	12822	15612	15822	15506	12453	7947	3937	1282	153	98785
Produsert PV South Wall	218	975	1670	1975	1840	1701	1767	1645	1289	806	328	13	14227
Produsert PV West Wall	174	819	1688	2576	2922	2866	2982	2607	1621	809	257	21	19340
Produsert PV East Wall	155	717	1641	2428	2954	3018	2898	2282	1395	701	235	20	18444
Sum produsert	1413	6349	13543	19800	23328	23407	23153	18986	12253	6253	2103	206	150796
Levert til bygning	781	2003	3134	3261	3336	3456	3626	3492	2858	1995	1146	192	29281
Eksportert til nett	632	4346	10409	16539	19992	19951	19527	15494	9395	4258	957	15	121515

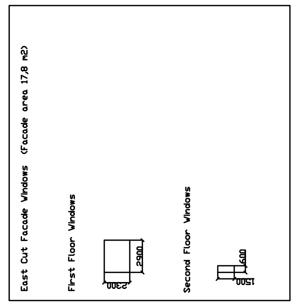
Figure B.3.3: Energy production from PV panels

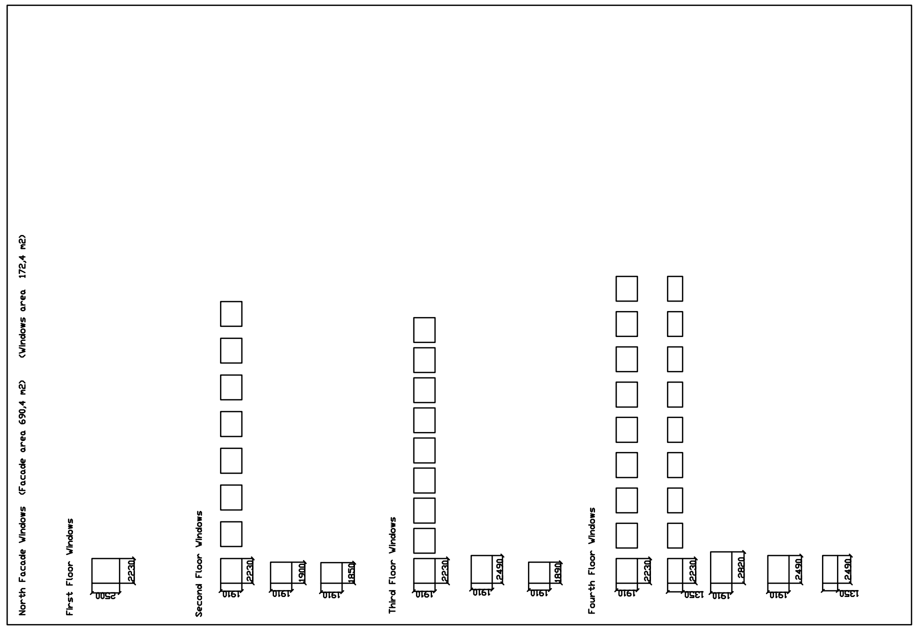
APPENDIX - C

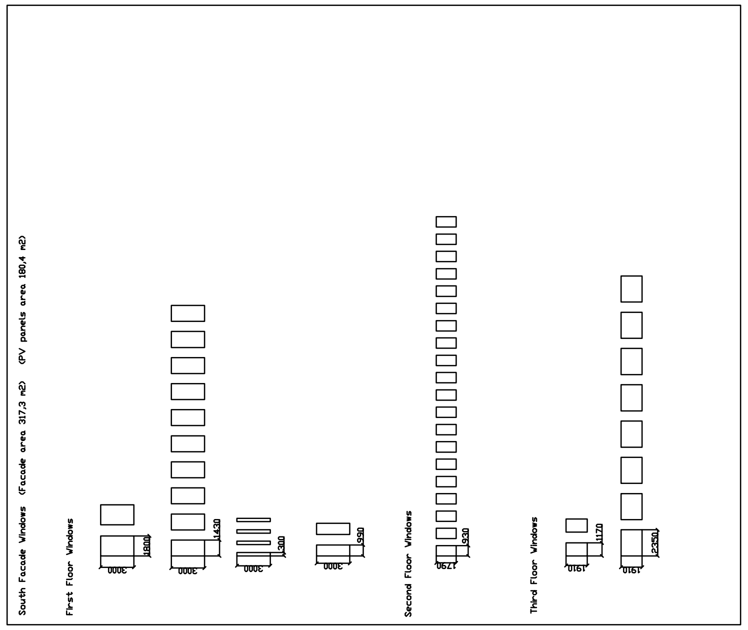
C.1. Type of windows in existing building and their areas











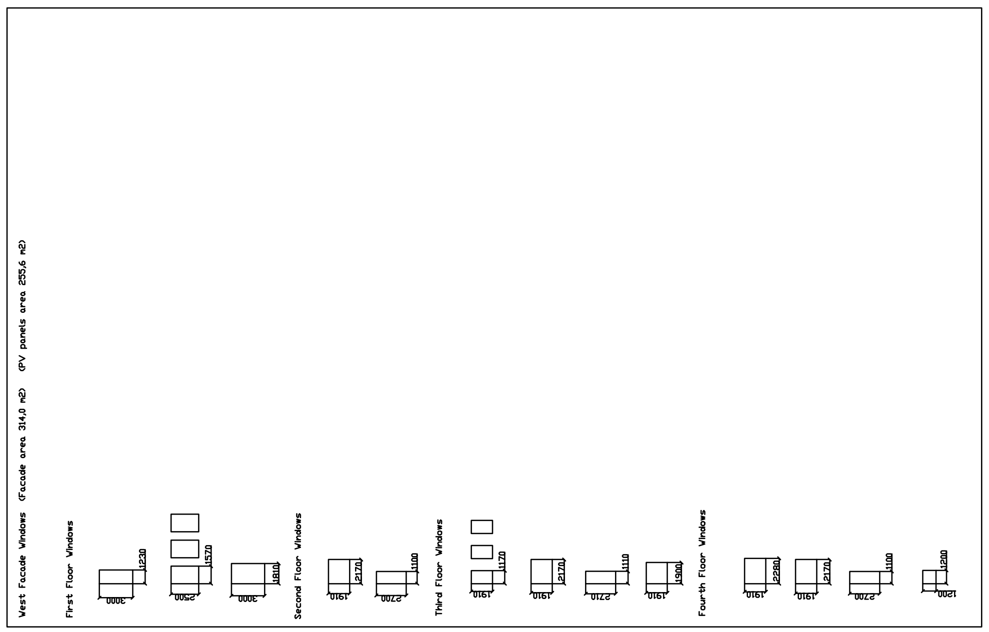
Existing Form

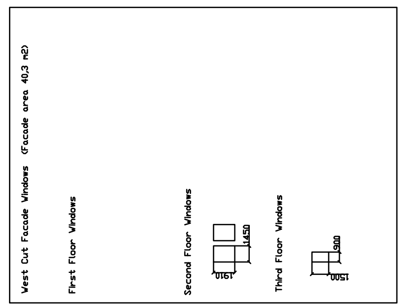
(Windows area 445,9 m2)
(From some research paper it is 429 m2)

PV area 1228,1 m2

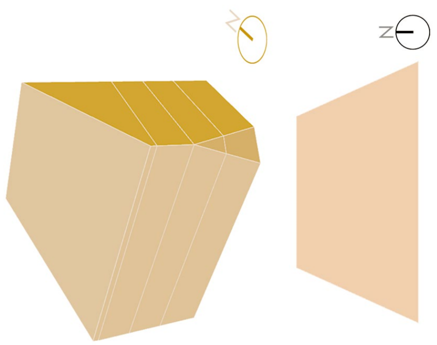
(Window area on W/S/E 258,9 m2)

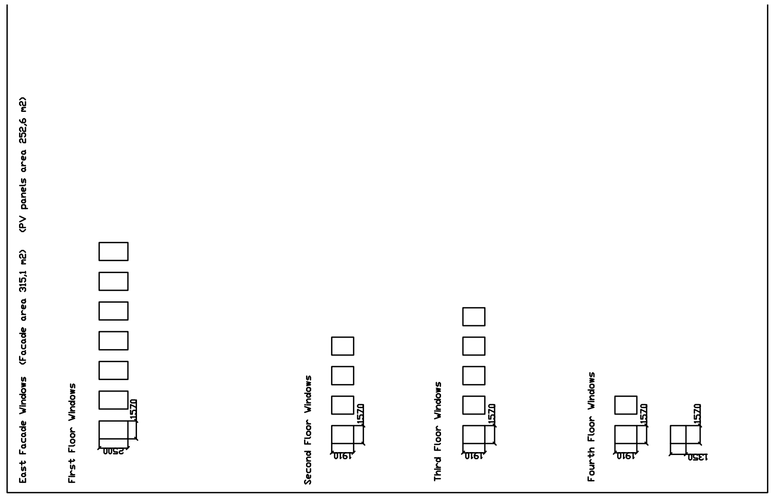
PV area on W/S/E 658,7 m2

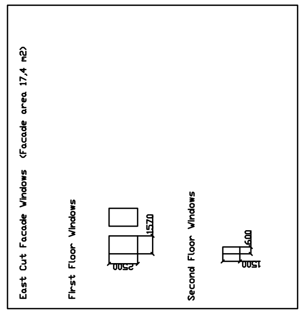


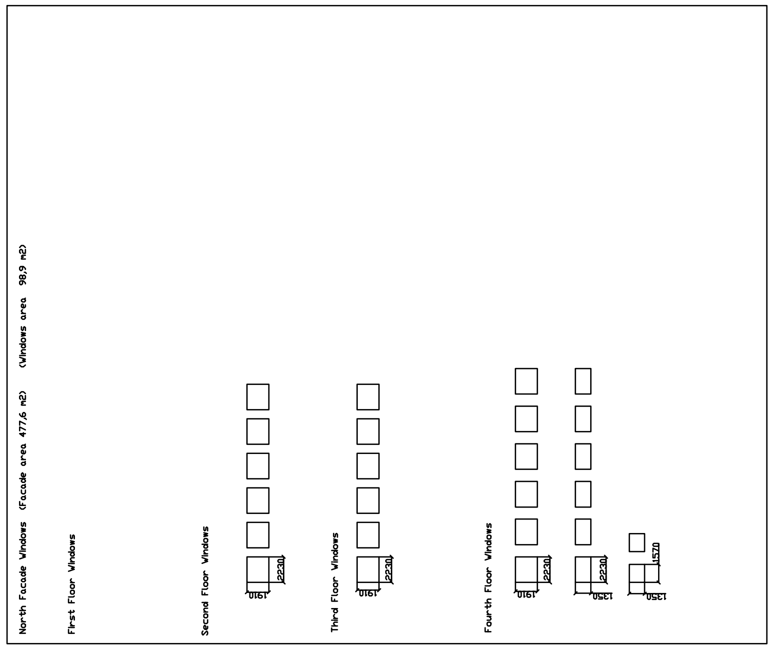


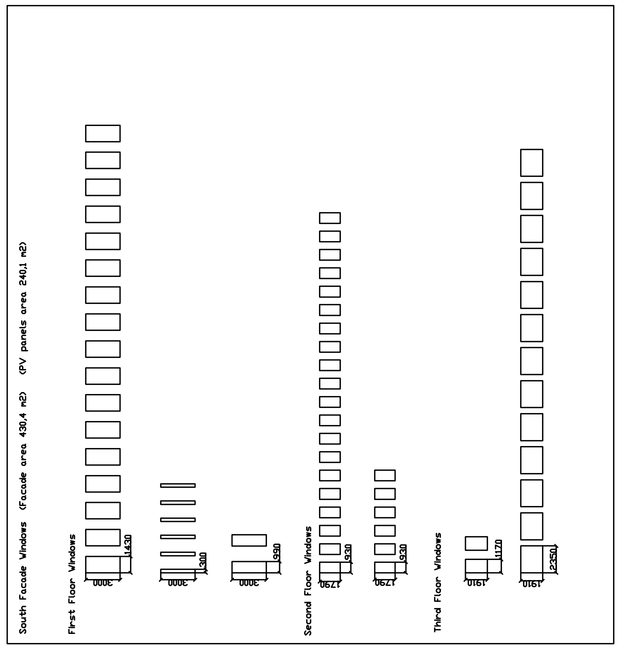
C.2. Type of windows in “Small North form” and their areas







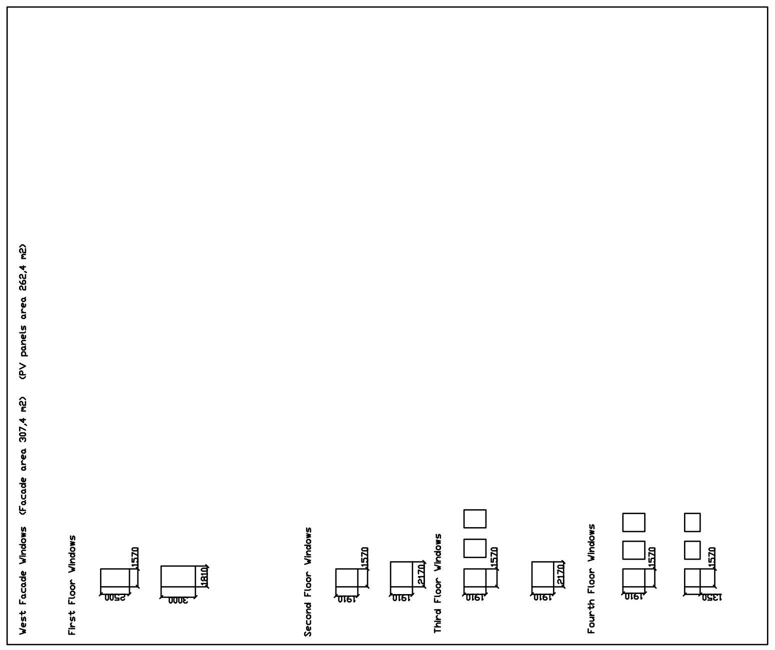


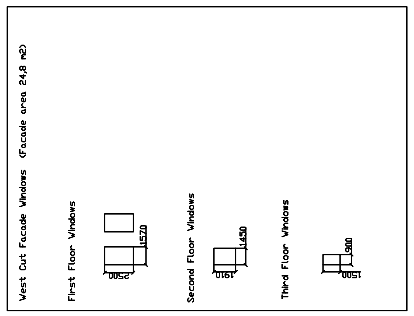


New Form

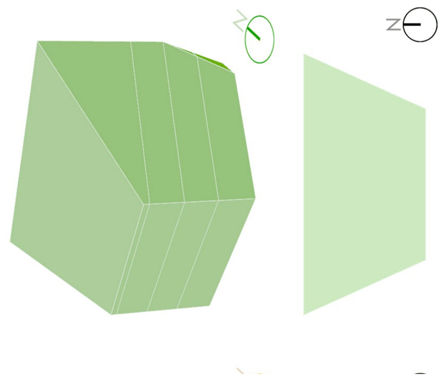
(Windows area 417,6 m2)

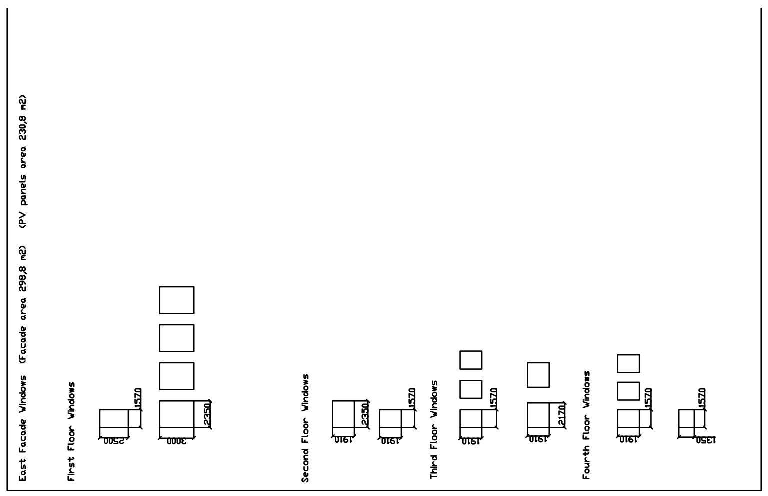
PV area 1232,7 m2

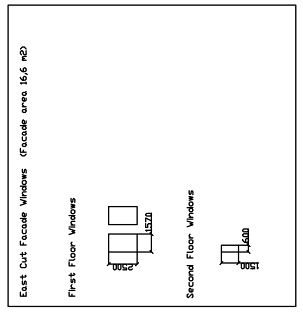


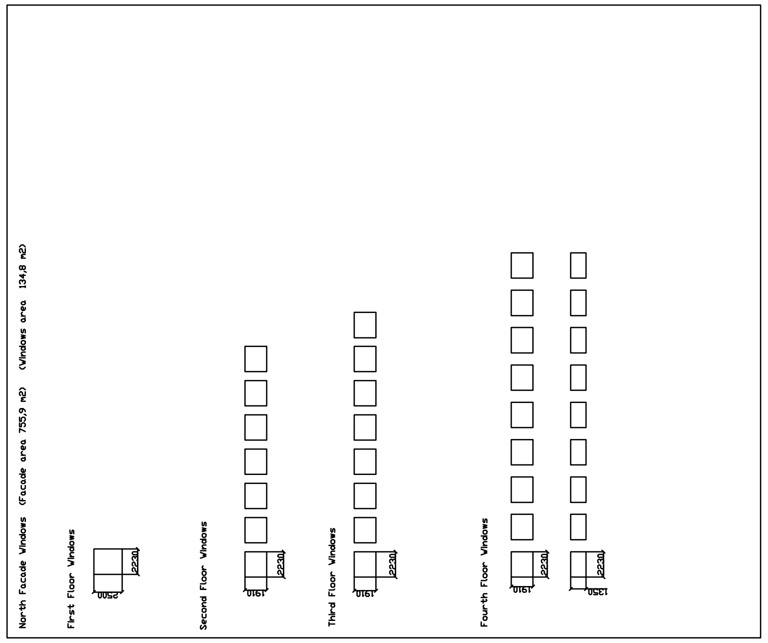


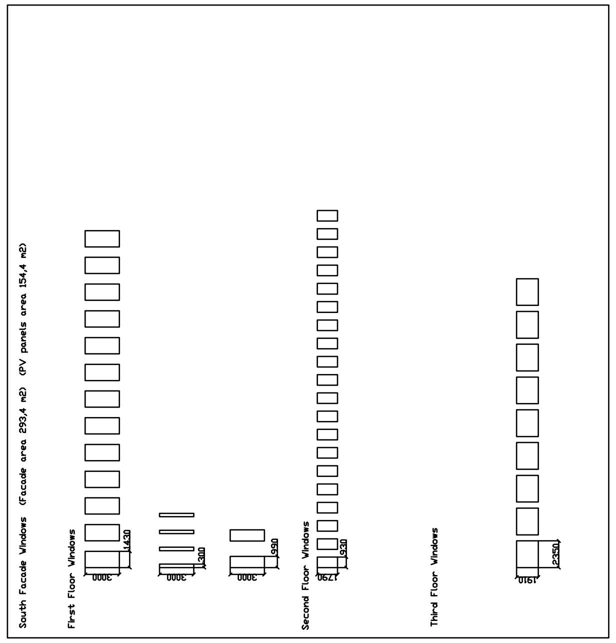
C.3. Type of windows in “Big North form” and their areas











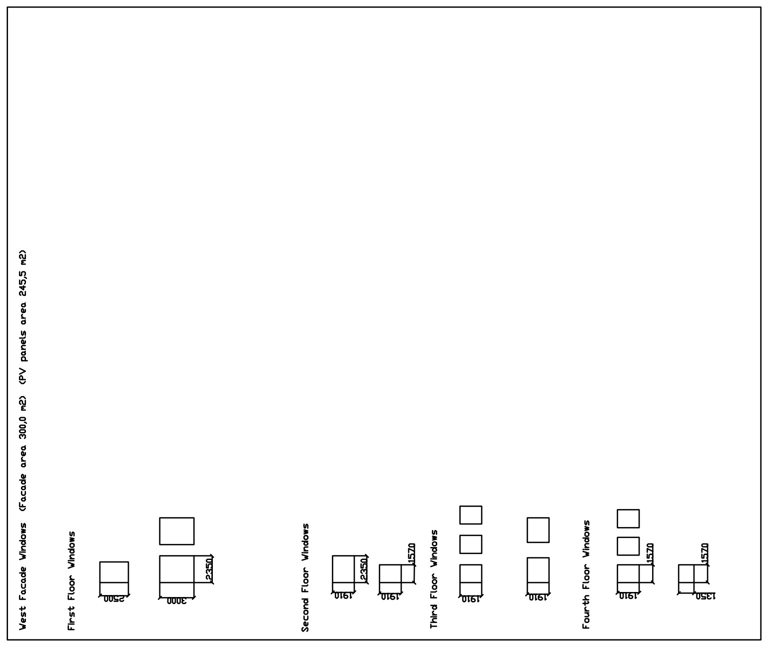
Big North Final

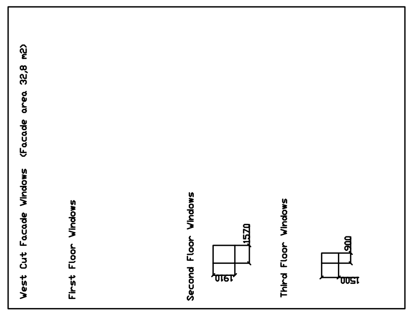
(Windows area 409,4 m2)

PV area 1199,3 m2

(Window area on W/S/E 261,5 m2)

PV area on W/S/E 630,7 m2





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