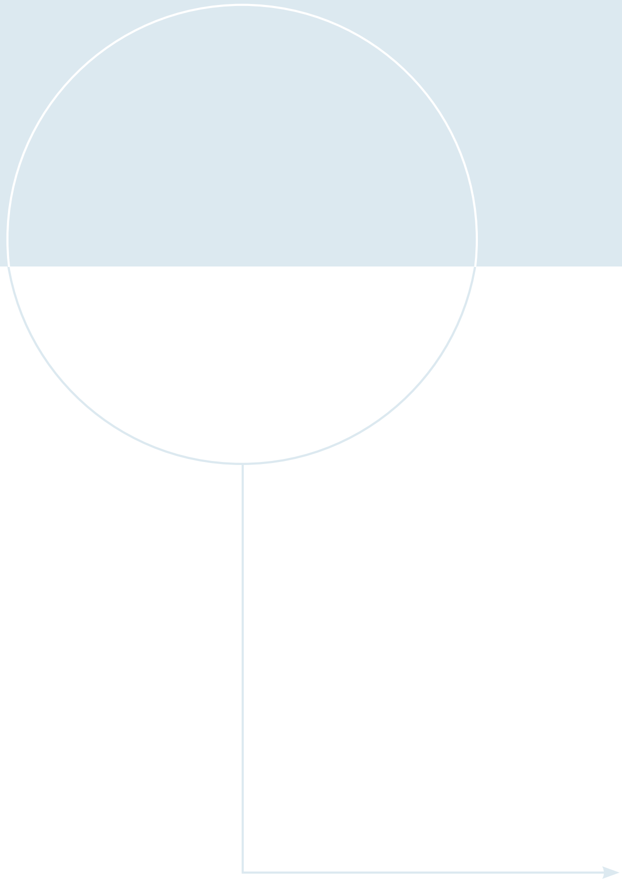

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Building performance simulation of the new "ZEB Laboratoriet"

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Energy and the Environment
Submission date: June 2020
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Preface

This master thesis concludes a two year master's program in Energy and the Environment by the Department of Energy and Process Engineering at the Norwegian University of Science and Technology (NTNU) in Trondheim. The thesis comprises 30 ECTS credits and was written spring 2020 during the COVID-19 pandemic.

A simulation model of the new building "ZEB Laboratoriet" was developed in the software IDA ICE for this thesis. Furthermore, various alternations of the building design were simulated and analysed.

I would to thank supervisor Vojislav Novakovic for guidance and helpful advises during the work-period of the thesis. Additionally, thanks to Hans Martin Mathisen and Tore Kvande for providing answers and information about the building "ZEB Laboratoriet". I would also like to thank John Clauss for providing help regarding the software IDA ICE.

Trondheim, 10-06-2020

Andrea E.H. Søraas

Andrea E.H. Søraas

Abstract

The Norwegian Zero Emission Building Laboratory (ZEB Laboratoriet) is currently under construction at the NTNU Gløshaugen campus in Trondheim. The building will consist of office and teaching facilities, and is four storeys high with a total area of approximately 1800 m^2. The building is designed to achieve the level "ZEB-COM" based on a defined lifetime of 60 years. This master thesis focuses on establishing a simulation model capable of representing the building "ZEB Laboratoriet".

The dynamic simulation software IDA ICE was utilized to create a model of the "ZEB Laboratoriet". This was conducted based on information and parameters obtained from design documentation. The developed model can be used for the future research and development work to be conducted at the "ZEB Laboratoriet".

Several alternations of the building design were simulated and analysed for two rooms in the building, the twin rooms. This consist of altering opening of windows, installing PCM in the ceiling and altered occupancy pattern. The results show that both the cooling measures, opening of windows with temperature control and PCM in the ceiling, have a positive effect on the thermal environment. By installing PCM are the temperature fluctuations in the room reduced. Furthermore, simulation of people working overtime shows how the input values regarding occupancy in a building performance simulation tool affect the resulted energy usage.

The implementation of PCM with a thickness of 0.1 m for the entire ceiling resulted in the lowest maximum temperature of all the cooling measures, with a decrease of 0.6°C. Moreover, the energy usage was reduced for most of the cooling measures, but none resulted in a considerable reduction. Additionally, the negative consequences by installing windows which can never be opened are visible, as the maximum temperature in the zone is increased by 0.5°C .

Further work regarding building performance simulation for the "ZEB Laboratoriet" includes obtaining as built documentation when available. In that way, the model in IDA ICE can be adjusted if something has been altered in the construction process. Furthermore, after the test operation of the building is completed can the measured energy usage be compared with the results from IDA ICE. In that way can the model be evaluated, adjusted and validated.

Sammendrag

Det norske nullutslippsbygget "ZEB Laboratoriet" er for øyeblikket under konstruksjon ved Gløshaugen campus på NTNU i Trondheim. Bygget vil bestå av kontor og undervisningsområder og er fire etasjer høyt med et areal på rundt 1800 m^2. Bygget er designet for å oppnå ambisjonsnivået "ZEB-COM" over en tidsperiode på 60 år. Denne masteroppgaven fokuserer på å utarbeide en simuleringsmodell av bygget "ZEB Laboratoriet".

Det dynamiske simuleringsprogrammet IDA ICE ble brukt til å lage en modell av "ZEB Laboratoriet". Dette ble utført basert på informasjon og parametere hentet fra design dokumentasjon. Den utviklede modellen kan brukes til fremtidige forsknings- og utviklingsarbeid som skal gjennomføres på "ZEB Laboratotiet".

Flere endringer av bygningsdesignet ble simulert og analysert for to rom i bygget, tvillingrommene. Dette består av åpning av vinduer, installere PCM i himling og endre bruksmønster for personer. Resultatene viser at begge kjøletiltakene, åpning av vinduer med temperaturregulering og PCM i himling, har en positiv effekt på det termiske miljøet. Ved å installere PCM reduseres temperatursvingningene i rommet. I tillegg viser simulering av personer som jobber overtid hvordan inngangsverdier for bruksmønster i et bygningssimuleringsprogram påvirker den resulterende energibruken.

Implementering av PCM med en tykkelse på 0,1 m for hele himlingen resulterte i den laveste maksimale temperaturen av alle kjøletiltakene, med en reduksjon på 0,6°C. Videre ble energiforbruket redusert for de fleste tiltakene, men ingen resultere i en betydelig reduksjon. I tillegg er de negative konsekvensene ved å installere vinduer som aldri kan åpnes i et rom synlig, da den maksimale temperaturen i sonen øker med 0,5°C.

Videre arbeid vedrørende bygningssimulering for "ZEB Laboratoriet" inkluderer innhenting av som bygget-dokumentasjon når det er tilgjengelig. På den måten kan modellen i IDA ICE justeres dersom noe er endret i byggeprosessen. Etter at testoperasjonen av bygningen er fullført, kan den målte energibruken sammenlignes med resultatene fra IDA ICE. På den måten kan modellen evalueres, justeres og valideres.

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Nomenclature

Abbreviations

AHU	Air Handling Unit
ASHRAE	The American Society of Heat, Refrigerating and Air-Conditioning Engineers
BIM	Building information modeling
BIPV	Building integrated photovoltaic
BPS	Building Performance Simulation
DHW	Domestic Hot Water
GUI	Graphical user interface
HP	Heat pump
HVAC	Heating, Ventilation and Air Conditioning
IDA ICE	IDA Indoor Climate and Energy
IEA	International Energy Agency
IFC	Industry Foundation Classes
LCA	Life cycle assessment
NTNU	Norwegian University of Science and Technology
PV	Photovoltaic
PCM	Phase change material
RH	Relative Humidity
SFP	Specific fan power
UFAD	Underfloor air distribution
ZEB	Zero Emission Building/Zero Energy Building

Chapter 1

Introduction

1.1 Background

In order to achieve the Paris Agreement and reduce the global greenhouse gas emissions, the implementation of renewable energy and sustainable solutions are essential. A report from the International Energy Agency (IEA) stated that in 2017 were buildings responsible for 36% of worldwide energy utilization and approximately 40% CO_2 emissions [23]. Accordingly, there is a huge potential to reduce the energy consumption and emissions from the building industry.

The Norwegian Research Center on Zero Emission Buildings (ZEB) was established in 2009 and focuses on eliminating greenhouse gas emissions caused by buildings [59]. Currently, the building "ZEB Laboratoriet" is under construction at the NTNU Gløshaugen campus in Trondheim, Norway. The design process started in 2016 and the takeover of the building is planned to be in August 2020 [63]. The building will be four storeys high with an area of 1800 m^2 to be used for both office-space and education. The building is designed to achieve the ZEB-COM level by using innovative technical solutions, and in that way, in addition to on-site renewable energy production, compensate for greenhouse gas emissions regarding construction, operation and materials related to the building.[41]

Previously have the buildings ZEB Living Lab and ZEB Test Cell Laboratory been constructed at Gløshaugen and used for experimentation. The "ZEB Laboratoriet" will act as a research arena, where different solutions for technology and materials are to be tested and analysed in strong connection with the users of the building [63]. The building has also been named ZEB Flexible Lab, due to the focus on flexibility of the building design [60].

1.2 Objective and aim

The objective of this assignment is to give support to the future research and development work planned to be conducted at the “ZEB Laboratoriet” by establishing a simulation model capable of representing the building, all its technical facilities, the interaction with the user as well as the flexibility that the building is designed for.

The following tasks are to be considered:

1. Based on the work conducted in the Project Assignment, propose a model for building performance simulation of the “ZEB Laboratoriet” using the software IDA-ICE. The model is to be capable of representing the building itself, all its technical facilities, the interaction with the user as well as the flexibility that the building is designed for. Analyze and discuss its appropriateness, advantages and weaknesses.
2. Analyse and discuss potential needs for building performance simulations for the future research and development work planned to be conducted at the “ZEB Laboratoriet”.
3. Apply the developed model to analyze energy use of the “ZEB Laboratoriet” for different purposes (i.e. heating, cooling, ventilation) for potential altered solutions of the building envelope, energy supply solutions or technical installations.
4. Make a draft proposal (6-8 pages) for a scientific paper based on the main results of the work performed in the master thesis.
5. Make proposal for further work on the same topic.

The listed tasks were set in January 2020. During the work period, some changes have been conducted for the task description. Firstly, task 3 could not be carried out since the researchers involved in the "ZEB Laboratoriet" have not jet decided on any specific experiments to conduct in the future. Instead, different alternations of the building design and operation were selected to model and simulate based on suggestions from supervisor. Furthermore, this also affects task 2 considering no specific potential altered solutions were given. Therefore, this task was discussed more generally and not very detailed. Moreover, a draft proposal for a scientific paper (task 4) was also not done because of no defined future experiments at this moment.

1.3 Method

This report will firstly present general theory about regulations for constructing buildings in Norway and various energy efficient buildings, with an emphasis on zero emission buildings (ZEB). Following, general information regrading the building "ZEB Laboratoriet" is presented. This includes for instance location, ambitions, research and energy supply. Lastly, a litterateur study concerning phase change materials and building performance simulation is also included.

The method for developing a model of the "ZEB Laboratoriet" firstly consists of collecting data and information about the building. This was obtained form professors at NTNU who are involved in project. The information is further used to develop a simulation model of the "ZEB Laboratoriet" by utilizing the software IDA ICE 4.8. The developed model is further used to simulate and analyse different altered solutions of the building design. The alternations are studied based on thermal environment and energy usage. Lastly, the findings are discussed and relevant uncertainties are presented. In addition, the model itself is discussed and further work is presented. Moreover, a discussion of building performance simulation regarding the future research to be conducted at the "ZEB Laboratoriet" is also included.

1.4 Limitations

Initially was the plan to apply the developed model in IDA ICE to analyze energy use of the “ZEB Laboratoriet” for potential altered solutions of the building envelope, energy supply solutions or technical installations. However, this was not possible to conduct since there are no planned experiments at the moment. As a result, this task of this thesis was changed. Instead, a few different alternations of the building design and operation were selected based on suggestions from supervisor.

Furthermore, different levels of modeling were done for the building in IDA ICE. For the detailed model was the building divided into zones based on solar heat gains and temperature, whereas for the simplified model was one zone inserted for each story.

Validating a simulation model created in a building performance simulation tool is significant. This was not conducted for this thesis since the building is still under construction.

Chapter 2

Literature review

Relevant information and literature regarding the objective and theme of this thesis is presented in this chapter. This includes the regulations for construction works in Norway, energy efficient buildings, the building "ZEB Laboratoriet", phase change material and building performance simulation.

2.1 Regulations on technical requirements for construction works

Regulations on technical requirements for construction works ("Byggteknisk forskrift - TEK17") presents different minimum requirements which a building must fulfill in order to be constructed legally in Norway. For instance, chapter 13 in TEK17 states requirements regarding indoor climate and health and §13-3 is about ventilation for office buildings. TEK17 came into force in July 2017 and replaced the previous regulation from 2010 (TEK10).[12]

Chapter 14 in TEK17 states requirements concerning energy efficiency and energy supply solutions. For example, it is required that the total net energy demand for an office building must not be grater than 115 kWh/m^2 heated gross internal area per year. Additionally, TEK17 states demands for energy efficiency which is shown in table 2.1.[12]

The Norwegian standard NS 3031:2014 *Calculation of energy performance of buildings - Method and data* is to be used when verifying the requirements stated in TEK17, energy labeling of buildings, BREEAM NOR and the passive house standards NS 3700 and NS 3701 [54]. The standard describes methods for calculations and documentation for the energy performance and efficiency of a building [52]. Additionally, the standard SN/TS 3031:2016 *Energy performance of buildings - Calculation of energy needs and energy supply* exist as a supplement

Table 2.1: Requirements in TEK17 [12].

Element	**Requirement**
U-value external wall	≤ 0.22 W/m^{2}K
U-value roof	≤ 0.18 W/m^{2}K
U-value floor on ground and facing open air	≤ 0.18 W/m^{2}K
U-value door and window	≤ 1.2 W/m^{2}K
Leakage figure at 50 Pa pressure differential	≤ 1.50 h^{-1}

for energy calculations. The methods described in the standard can be used to document nearly zero energy buildings (nZEB) and plus energy buildings [51]. Furthermore, a new Norwegian specification was released on the 31st of March 2020: SN-NSPEK 3031:2020 [55]. This is a revised version of NS/TS 3031:2016 and replaces this document, which is now withdrawn [53].

2.2 Energy efficient buildings

All new buildings in Norway must follow the requirements listed in TEK17. Additionally, some buildings are being constructed to be more energy efficient and environmentally friendly than the building regulations. This chapter will briefly present and describe various types of these targets.

Passive houses are characterized of having a low energy demand [45], which is due to implementing passive measures [29]. This included for instance better insulation of the building envelope, a compact design and solar shading [45]. Considering this, passive houses have stricter requirements compared to TEK17. In Norway are the criteria for passive houses listed in the Norwegian standards NS 3700 for residential buildings and NS 3701 for commercial buildings.

Zero energy buildings includes both the terms net and nearly zero energy buildings, NZEB and nZEB. Moreover, the abbreviation "ZEB" used for both zero energy building and zero emission building. In Norway is NZEB defined as a building where on-site renewable energy production is equal to the yearly energy demand of the building.[47] In 2020 shall all new buildings in EU be nearly zero energy [22].

Plus energy buildings are more ambitious compared to a passive house and zero energy building, considering the building produces more energy than what is used during its lifespan. This includes the energy usage related to materials, construction, operation and demolishing.[42] However, energy for technical equipment is often excluded [47]. Unlike passive houses, there is no standard regarding plus energy buildings in Norway.

Moreover, zero emission buildings focuses on the greenhouse gas emissions related to all aspects of a building. These buildings aims at producing renewable energy which balance out the CO_2 emissions from the buildings lifespan.[47] ZEB is described in more detail in chapter 2.3.

A comparison between the energy demand and on-site energy production for different building categories of detached houses is shown in figure 2.1. The figure is a translation of a Norwegian figure obtained form SINTEF Byggforsk (2015) [47]. The figure clearly shows how the yearly energy demand is notably decreased for energy efficient buildings compared to the average standard for exciting buildings today.

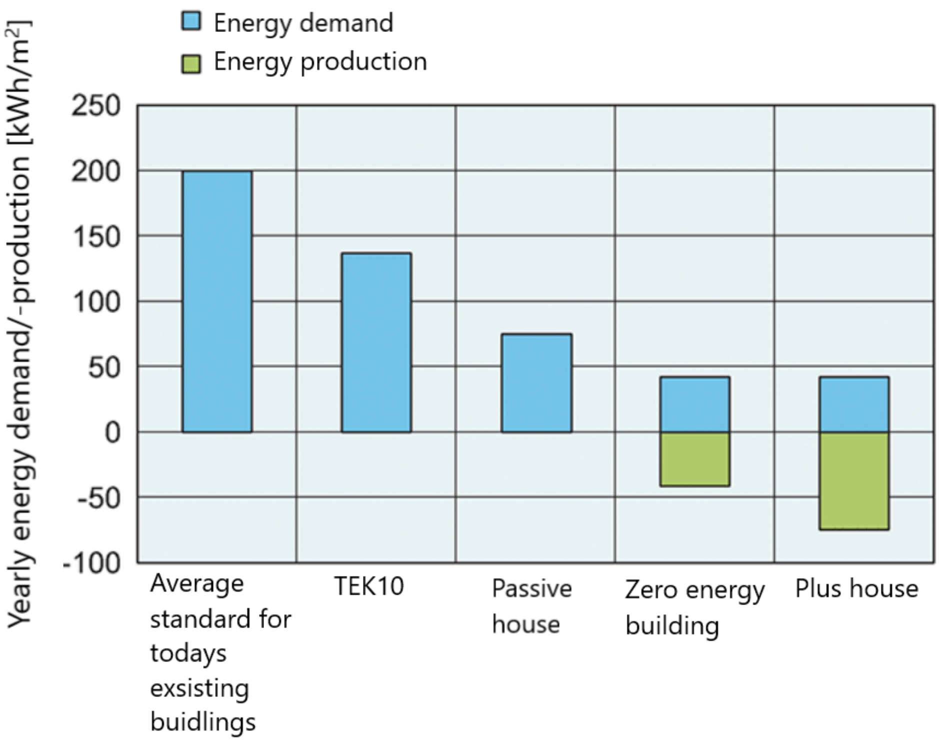

Figure 2.1: Yearly energy demand/-production for different types of detached houses [47].

2.3 Zero Emission Buildings

The Norwegian Research Centre on Zero Emission Buildings (ZEB) was established in 2009, and work towards the aim of putting an end to greenhouse gas emission related to the entire lifespan of a building by creating products and solutions [58]. The ZEB Centre has previously been involved in nine different pilot building projects where three of them are located in Trondheim. These are the residential building "ZEB Living Lab", the office building "Powerhouse Brattørkaia" and the high school "Heimdal VGS" [22].

ZEBs have renewable energy production corresponding to the building's greenhouse gas emissions throughout its lifetime. This may involve materials, operation and demolition, depending on selected ambition level. Using solutions which reduces the overall energy demand of the building, and thus reducing the required amount of on-site energy production, is an important aspect in order to achieve ZEB. The solutions include building form, materials, technical installations etc. The research centre operates with several different definitions of a ZEB building. The most ambitious type is ZEB-COMPLETE, where the building must generate renewable energy equal to emissions from the complete lifespan. An explanation of the different abbreviations used in context with ZEB are shown in table 2.2. In order to calculate the emissions related to the building can a life cycle assessment (LCA) be conducted.[48]

Table 2.2: Explanation of the different abbreviations related to ZEB [48].

Letter	**Meaning**	**Description**
EQ	Equipment	Electrical equipment
C	Construction	Construction, including transport and installation of building materials
O	Operation	Energy use for the operation of the building
M	Materials	Production of materials
PLET	-	Use, maintenance, repair and rehabilitation
E	End of life	Demolition and disposal

Figure 2.2 clarifies the relation between CO_2 emissions and renewable energy production for ZEBs. The diagram shows how the energy production (green circles) can balance out the emissions (orange circles) and the circles imply the proportions between the components related to the different stages [22].

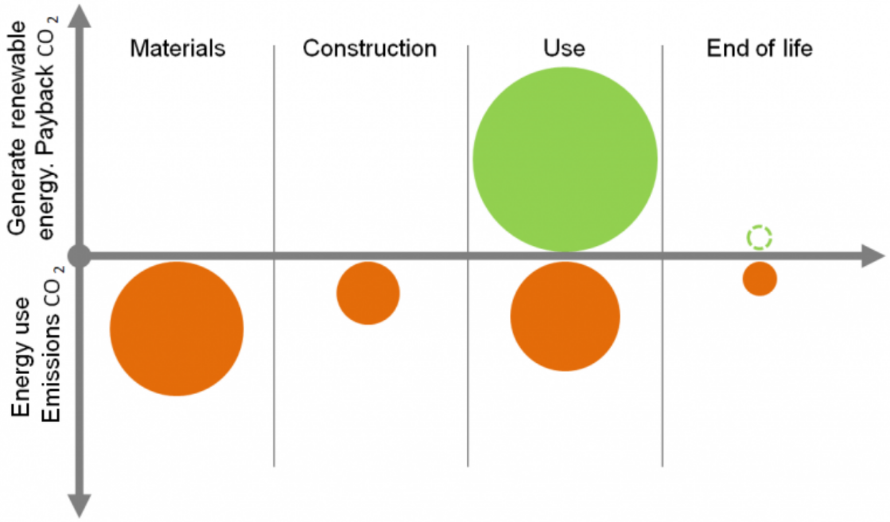

Figure 2.2: Correlation between CO_2 emissions and renewable energy for ZEB [18].

The relation between the five different ambition levels which the ZEB Centre operates with, can be seen in figure 2.3 [62]. The text in parenthesis is the life cycle stages which is taken into account for the various levels.

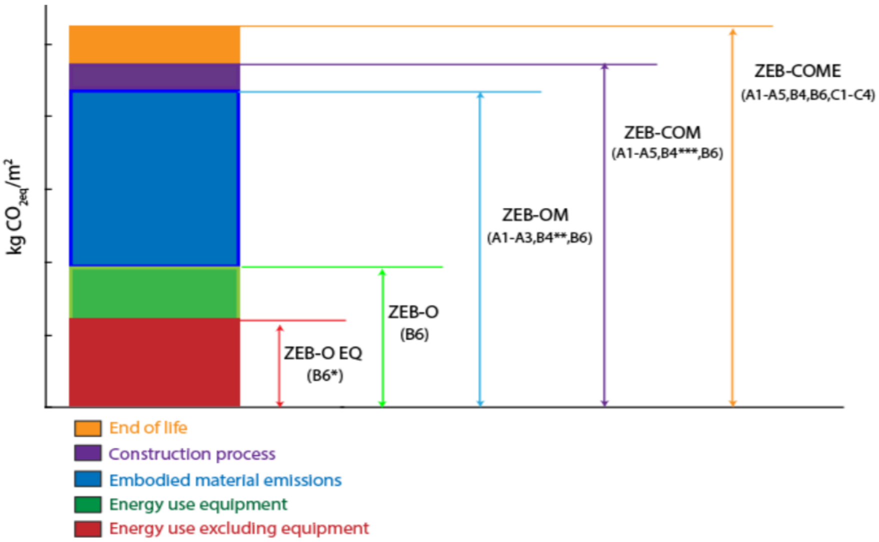

Figure 2.3: ZEB ambition levels [18].

2.4 ZEB Laboratoriet

The following sections presents information regarding the building "ZEB Laboratoriet" (further referred to as ZEB Lab), which is currently in the construction phase at NTNU's campus Gløshaugen in Trondheim. NTNU and SINTEF are the construction clients for the project.

2.4.1 Location and climate

The city Trondheim is located next to Trondheimsfjorden, approximately in the middle of Norway. The weather is mild and humid, and the city is distinguished by unstable weather. Based on the Köppen-Geiger climate classification system is Trondheim classified as Cfb [65]. The average yearly normal temperature is 5.8°C [49] and design outdoor temperature -19°C [20]. The annual average precipitation is 850 mm/year at Tyholt in Trondheim [46]. Moreover, the air pollution in Trondheim is characterized as low [36], and based on the last thirteen months (August 2018 - September 2019) was the average wind speed 2.5 m/s [34].

2.4.2 Ambitions and aims

The aim for the ZEB Lab is to achieve the level ZEB-COM with a time perspective of 60 years [63]. This means that on-site renewable energy production must compensate for the CO_2 emissions from construction, operation and materials related to the building. An illustration of the building is shown in figure 2.4.

Figure 2.4: Illustration of the ZEB Lab [63].

The ZEB Lab will increase the competence and knowledge regarding the building type ZEB, considering it will function as an research arena [63]. Furthermore, it will beneficial for both FME Zero Emission Neighbourhoods in Smart Cities (ZEN) and SFI (Centre for Research-based Innovation) Klima 2050 [28]. Moreover, new technological solutions will be installed and used in the building. An aim by doing this is that the ZEB Lab will contribute to risk reduction for the Norwegian construction industry [27].

There are several ambitions for the building. Time *et al.* (2019, p.6-7) writes the following:

> NTNU and SINTEF have a set of ambitions for the ZEB Laboratory. These are, in prioritised order:
>
> 1. The building should be a model project and achieve ZEB-COM level (simulated over a 60 years perspective)
> 2. Separate control and measurement systems
> 3. Flexibility in design and use of energy and climatisation systems
> 4. Flexibility in design of working space
> 5. Continuous selection of new materials and improvements by rebuilding parts of the facades
> 6. Adaptation of the building to climate change

2.4.3 Research and flexibility

Research and experimentation are focal points for the building [63]. The building was previously given the name ZEB Flexible Lab [57], due to the focus on flexibility of the overall design of the building [60]. For instance, the facade and windows on the south facade of first floor can be altered [63]. Additionally, components and new technical installations can be changed and installed in the building, which enables more research opportunities [41, 62]. Moreover, the building will be equipped with different ventilation operations. This makes it possible to conduct experiments on energy consumption and thermal comfort by using senors [63]. Furthermore, two rooms called the twin rooms are included in the building, with the intention of conduction research and testing [63]. This is described more in depth in section 2.4.4.

Previously have the buildings ZEB Living Lab and ZEB Test Cell Laboratory been constructed on Gløshuagen campus, which have been used for testing and investigation. The construction of ZEB Lab enables research and experimentation of new technologies on vaster area, as well as studying the effect various elements have on a larger construction. The building will also act as a living lab.[63] The occupants are to use the building for office-work and education. Their independent utilization of the area (opening of windows, lighting control, time spent at the office etc.) will result in alternations of the loads, which affect the energy consumption in the building. In that way, the occupants contribute to research on the building.[62]

2.4.4 Overview of the building

Selecting building materials with a low CO_2 footprint has been conducted for the ZEB Lab, in combination with reduced use of materials [28]. The foundation is made of low carbon concrete, while the rest of the building mainly consist of wood [28]. A large part of the building's outer surface consist of photovoltaic (PV) solar panels [63], and the external surfaces which are exposed for limited sunlight consist of timber cladding [28]. This can be seen in figure 2.5 where the black material on the building surface are PV panels. The ZEB Lab is oriented towards south with a pitched roof of 30°in order to achieve best utilization of sunlight [28].

Figure 2.5: Illustration of the ZEB Lab [41].

The building integrated photovoltaic (BIPV) solar panels will supply electrical energy to the building. This energy production will compensate for the CO_2 emissions in order to reach the ZEB-COM requirement. An air source heat pump is selected to cover the thermal energy demand in the building. The heat pump will collect heat from the outdoor air and surplus energy from the inverters. Furthermore, a phase change material (PCM) heat storage will be implemented. The storage will be used in combination with the heat pump and the PV panels. Figure 2.6 shows how the different energy supplies are connected together to cover the energy demand of the building and achieve the ZEB-COM level.[63]

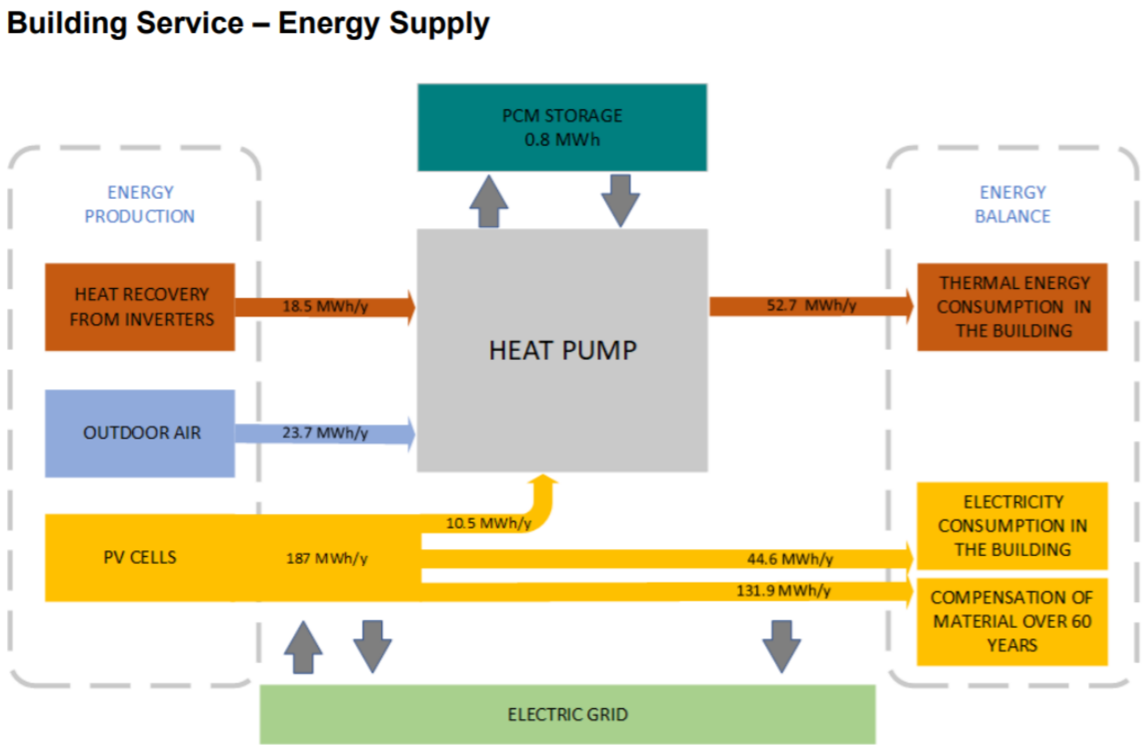

Figure 2.6: Overview of the energy supply and usage in the building [63].

Twin room

Two identical office rooms are placed in the south end of first floor, see figure C.2 in appendix C, and are called the twin rooms. The rooms are intended for investigation and research. Accordingly, the design and operation of these rooms are in some ways different than the other areas in the same floor. Firstly, the rooms have an individual HVAC system. Additionally, the rooms have their own technical room, which can be seen in figure C.2. Furthermore, the rooms have significantly more sensors compared to the rest of the building. The sensors monitors temperature, RH, CO_2 concentration, air change rates, illuminance, etc.[63]

It is possible to apply cooling for the twin rooms. The supply air first enters the rooms individual AHU, where a heating and cooling coil is installed. The coils are connected to the hyrdronic heating system. An electric heating coil is also installed in the AHU. The rooms also have the possibility for natural ventilation through windows and extracting ducts.[63]

2.5 Phase change material

Phase change material (PCM) are materials which changes phase from solid to liquid and vice versa inside the temperature range for that particular material [11, 25]. During these processes, the material absorbs and releases heat at approximately constant temperature [11, 43]. In that way, PCM can be used for latent heat storage. The storage capacity for PCM is given in equation 2.1, where m is the mass of the material [kg], C_p is the specific heat capacity [kJ/kgK], T is the temperature [K], a_m is the melted fraction of the material and Δh_m is the enthalpy of fusion (latent) [kJ/kg] [35].

$$Q = \int_{Ti}^{Tm} mC_p dT + ma_m \Delta h_m + \int_{Tm}^{Tf} mC_p dT \tag{2.1}$$

Delgado *et al.* (2019) point out that it seems like there are not many studies which focuses on installation of PCM in roofs and ceilings. The intention of installing PCM in roofs or ceilings, is that the material will store heat from solar radiation through windows and other heat gains in a room, resulting in a decrease of temperature fluctuations in the room [11]. A few articles about PCM in roof/ceiling were found. Firstly, the building ZEB Living Lab at NTNU Gløshaugen campus has installed PCM in the roof [9]. A layer of 15 cm plywood is exposed to the room and 0.5 cm of PCM is placed above this in the roof construction. Another study investigated the effect of implementing PCM of different volumes in internal ceilings and walls in Italy, alternating the PCM thickness in the range of 5 to 15 cm [40]. The software TRNSYS was utilized for the study. Furthermore, a study in Denmark used PCM panels as suspended ceiling with a thickness of 2.5 cm in a climate chamber [2]. The PCM was part of a system with photovoltaic/thermal (PV/T) panels, hot- and cold water tank.

2.6 Building performance simulation

Hensen and Lamberts (2011, p.3) defines building performance simulation (BPS) as: "Computational building performance modeling and simulation [...] is multidisciplinary, problem-oriented and wide(r) in scope. It assumes dynamic (and continuous in time) boundary conditions, and is normally based on numerical methods that aim to provide an approximate solution of a realistic model complexity in the real world" [21]. BPS draws on several different disciplines, which is illustrated in figure 2.7 [19].

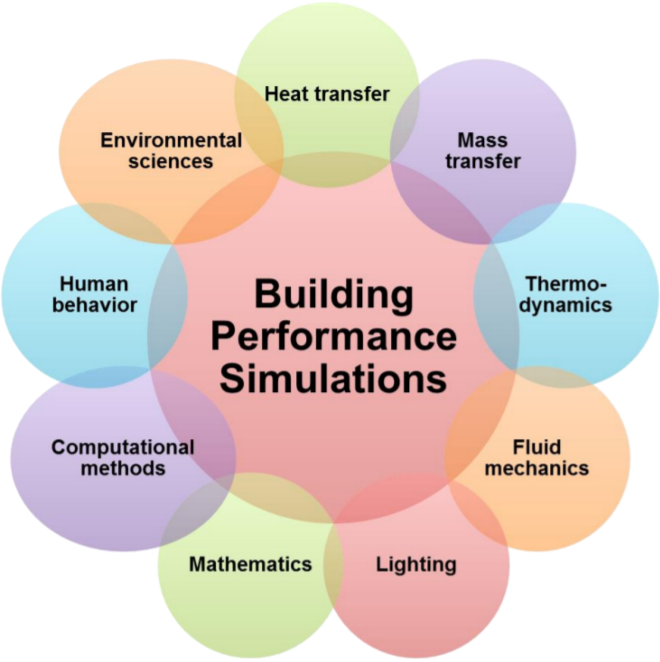

Figure 2.7: Different disciplines BPS is based on [19].

BPS has become a significant appliance when designing and planning buildings today, in accordance with the increasing digitization and development in technology. By conducting energy simulations for buildings, there is a potential to decrease the expenses related to energy [50]. Software offers the users the possibility to investigate different solutions and compare the outcome, and in that way find the best suited approach for the building design [50]. Furthermore, effective BPS can result in a decrease of the consequences the industry have on the environment [21]. The BPS field is constantly developing [21], but is often not up to date with the latest technological solutions [33].

2.6.1 Simulation software

It differentiates between three different procedures for determining the energy and power need of a building: empirical, static and dynamic method. The listed methods are characterized by decreased simplification and increased complexity regarding the calculations. This is related to the implementation of details, the amount of parameters and time resolution. Dynamic methods are the most exact.[37] Furthermore, there exist several different simulation programs regrading building performance, with variable degree of complexity. The following sections will presents some dynamic simulation software.

SIMIEN

SIMIEN is a Norwegian program used to assess energy use and indoor environment in buildings, and is validated according to NS-EN 15265:2007 [38, 39]. The software is developed by ProgramByggerne [38], and is widely used in Norway for evaluation against the requirements in TEK17 and the passive house standard, as well as energy labeling. SIMIEN does not have a visualisation of the model and the user can thus not see the building in 3D. Furthermore, SIMIEN aims at conducting simple and fast simulations. All the simulations in the software have a timestep of 15 minutes, where SIMIEN assumes a static condition of the building.[44]

IDA ICE

IDA Indoor Climate and Energy (IDA ICE) is a software developed by the Swedish company EQUA Simulation AB and was first launched in 1998 [16]. The software offers the possibility to analyse for instance the indoor climate and conduct investigation related to energy use in buildings [17], by creating one or more zones. Furthermore, CAD files and IFC models can be uploaded into the software [17], which simplifies the modeling process. The software has hourly time step for the simulation and also offers the possibility for sub-hourly time step [70]. IDA ICE is validated according to CEN Standard EN 15255:2007 and 15265:2007 [15].

TRNSYS

TRNSYS is a BPS program utilized to simulate transient systems [64], and has been accessible for 45 years [61]. This includes for instance energy simulation of buildings and renewable energy systems (PV, solar thermal, heat pumps etc.) [64].

The time steps during the simulation can range from 15 to 60 minutes [50]. Furthermore, it is also possible to run the software with a time step of 0.1 seconds [50]. TRNSYS has the capability of implementing other mathematical models into the software [10]. Thus, the user can utilize other software tools, for instance Matlab or Excel, to create new elements which does not exist in TRNSYS's library [10].

EnergyPlus

EnergyPlus is an open-source software used for simulating energy demand in buildings [14], and has been available since 2001 [66]. The program consists of text files as input and output[14], meaning it does not have a graphical user interface (GUI). However, third-party software can be utilized to visualise the building, such as OpenStudio and DesignBuilder [14, 50].

ESP-r

ESP-r is an abbreviation for Environmental Systems Performance - Research and is a software used for BPS [68]. The program can be used to assess the energy performance of a building [69]. The software is created to run on the operating system Linux, although it can be used on Windows directly or within the Cygwin environment [68]. According to Sousa (2012), it is needed with competence and skills to use ESP-r, which further calls for an extensive undertaking in training and learning of the software [50].

Comparison

It was selected to use the software IDA-ICE for conducting the various task of this master thesis. However, other BPS software may also be suited to conduct the same procedures. This section will present some main advantages and disadvantages related to the BPS programs described above.

According to a report by Jarić *et al.* (2013) is TRNSYS the most complete BPS program out of Energy Plus and IDA ICE [24]. However, considering the report is from 2013, this may not longer be the case since simulation software are continuously developing. The report also point out that other programs may be more suitable. A drawback regarding TRNSYS is the ability to upload files from AutoCad into the program, which the software does not support [50].

Several BPS software have the function of combining various physical domains [33]. This is illustrate in figure 2.8. Here it can been seen that EnergyPlus and IDA ICE have the function of applying daylight models in the software, unlike ESP-r, TRNSYS [33]. Simulation of daylight is not relevant for this specific thesis. However, it might be an interest point for future research at the ZEB Lab.

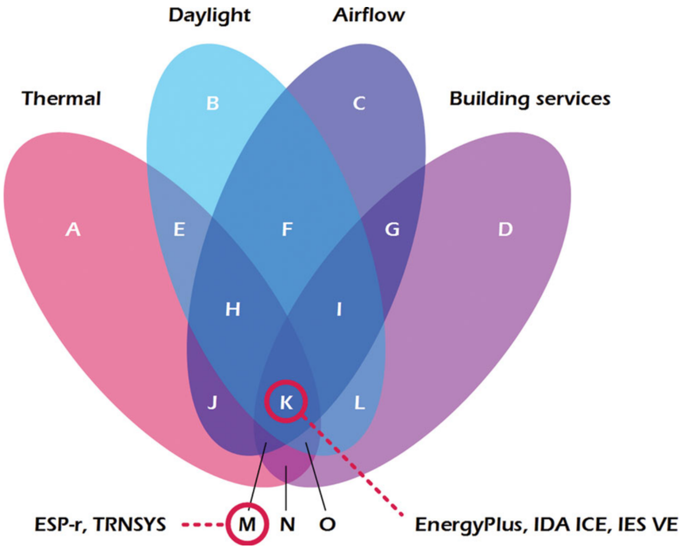

Figure 2.8: Overview of domain combinations for several BPS software [33].

A disadvantage for SIMIEN and EnergyPlus is the visualisation of the building. Although, it is possible to use other software in collaboration with EnergyPlus to visualize the building. These software does not have the ability for the user to see the model, which may cause that inaccuracies occurs easier. When simulating complex buildings with many different zones, a visualisation of the model makes it significantly easier to verify if the input is correct as the user can maintain an overview of the model. Furthermore, it also makes it easier for others to work on the model as well.

A report from the ZEB Research Centre (2010) points out that SIMIEN is easier to become competent in and operate, compared to EnergyPlus, TRNSYS and ESP-r where it is necessary with more learning and in dept knowledge of the software [13]. However, SIMIEN have some limited simulation possibilities. This includes for instance no detailed modeling for the energy system, no function for simulating displacement ventilation or daylight in a zone.

A master thesis from 2017 called "Use of Building Energy Simulation Software in Early-Stage of Design Process" performed a comparison between several simulation tools [30]. The BPS programs EnergyPlus, IDA ICE and ESP-r was among others included in the analysis. The thesis state that neither EnergyPlus or ESP-r does have regulatory compliance. Whereas for IDA ICE it is possible to purchase an extension which comply with ASHRAE 90.1, which is an energy standard for buildings.

As previously mention does EnergyPlus only have text files as output, contrary to ESP-r which has graph as output and IDA ICE which has both graphs and reports. A ranking between the software based on calculation quality regarding reliability and complexity is also included in the thesis. EnergyPlus and ESP-r is rated as "high" regarding both categories, whereas IDA ICE is ranked as "medium to high" for reliability and "medium" concerning complexity.[30]

2.6.2 Modeling approach

When creating a simulation model of a building, the selected modeling approach is a significant factor regarding the desired outcome. It differs between whole building and zone approach [8]. A building can be separated into different "zones". This is conducted by regarding the volume inside the zone to have nearly the same uniform air temperature. This will typically be an individual room or a set of rooms which have approximately the same thermal properties. Creating zones in a building enables the possibility to study for instance heat transfer occurring in the zone.[21]

If the intention of a BPS is to evaluate the overall energy performance, a whole building approach may be most applicable. This because the result of the simulation will be approximately equal to a zone approach, since energy is an extensive quantity. This means that energy is dependent upon the physical size of a system, i.e. the volume of the building in this case, whereas temperature on the other hand is an intensive quantity and does not depend upon this. Therefore, in order to simplify the calculations and modeling, creating fewer zones can be conducted and give the same results.[8]

However, when the aim of the BPS is to study the thermal properties, a zone approach should be applied. This is done in order to achieve a most accurate replicate of the temperature progressions in the different areas in the building. Therefore, all relevant rooms for the simulation must be created as separate zones in the model.[8]

2.6.3 Uncertainties

There will always be uncertainties present in experiments and research. Related to BPS, different types of uncertainties may be present. Firstly, specification uncertainty which occurs as a consequence of insufficient detailed information. For instance, regarding the early stages of a building process can this be control set-points and window area. Scenario uncertainty is another type, which is about the uncertainty present for outer elements affecting the building. For instance, the actions of occupants and real life weather circumstances.[7]

The presence and behavior of people have a impact on the energy performance of buildings. It differs between active and passive effects of people on buildings [21]. Passive effects are caused by the presence of occupants. People continuously release heat, vapor and odor, depending upon ambient temperature, metabolic rate, activity and clothing level [37]. This will for instance affect the required air flow rate form the ventilation to achieve acceptable indoor air quality.

Active effects of people are a result of users controlling different installations in the building. Examples of this are windows, lighting and space heating units, which the user can alternate to the desired level. How these active effects are defined in the model will have an impact on the results on the building's performance. Therefore, to obtain accurate results, it is important to define reliable and realistic user behaviour in the model.[21]

Moreover, uncertainty regarding modeling will always be present. This is related to the limitations of the simulation software. Some simplifications has to be done when creating a model of a building, as it is impossible to create an exact replica of the real-life building. Lastly, numerical uncertainty which is related to the selected time steps.[7]

Chapter 3

Methodology

This chapter describes how the building ZEB Lab was modeled in the software IDA ICE. Additionally, various simplifications and approaches which were carried out in order to model the building in the software. Firstly, specific information about the building was collected and the building was then modeled in IDA ICE based on these parameters.

3.1 Data collection

Information about the ZEB Lab was mainly collected by contacting professors at NTNU who are involved in the project: professor Hans Martin Mathisen at the department of Energy and Process Engineering and professor Tore Kvande at the department of Civil and Environmental Engineering. Data and parameters were obtained by communication through emails and meeting. Additionally, the report "ZEB Laboratory - Research Possibilities" published in August 2019 by SINTEF was used to obtain information.

3.1.1 Location and climate

Figure 3.1 displays the location of the ZEB Lab at NTNU's campus Gløshaugen in Trondheim [32]. The orientation of the building is 0°north, meaning that the tilted roof is 180°south, based on the figure. The coordinates for the buildings site is 63°24'N and 10°24'E [26]. The building is located next to the NINA building and Byggtekniske laboratorier.

Figure 3.1: Map of the ZEB Lab [32].

3.1.2 Building envelope

The ZEB Lab will be constructed with a compact volume and a pitched roof towards south. The exterior structure will consist of facades with insulated wooden framing, ventilated roof and insulated floor on the ground. The loadbearing system for the building is made of wood and large part of the building's outer surface consist of PV panels [63]. The U-values related to each building element are presented in table 3.1, in addition to the normalized thermal bridge factor and normalized leakage figure.[1]

Table 3.1: Building envelope values [1].

Element	**Value**
U-value external wall	0.15 W/m^2K
U-value roof	0.09 W/m^2K
U-value floor on ground	0.10 W/m^2K
U-value doors and windows	0.8 W/m^2K
Leakage figure at 50 Pa pressure differential	0.3 h^{-1}
Normalized thermal bridge factor	0.04 W/m^2K

The structure of the different construction elements are listed in the tables below (table 3.2, 3.3, 3.4 and 3.5), based on information from the report "ZEB Flexible lab: bygningsmessige energiytelser" [67] and drawings of the building construction.

Table 3.2: Construction of floor on ground.

Material	**Thickness [mm]**	**Thermal conductivity (λ) [W/mK]**
Concrete	100	
Plastic sheet		
EPS-insulation	250	0.038

Table 3.3: Construction of external wall.

Material	**Thickness [mm]**	**Thermal conductivity (λ) [W/mK]**
Timber cladding	22	
Ventilated gap	84	
Wind barrier (polypropylene)		
Timber framework wall and insulation	223	0.033
Vapour barrier (plastic sheet)		
Insulation	73	0.033
Cladding/gypsum	13	

Table 3.4: Construction of internal floor.

Material	**Thickness [mm]**	**Thermal conductivity (λ) [W/mK]**
Chipboard	48	
Insulation	50	
Wood	210	

Table 3.5: Construction of roof.

Material	**Thickness [mm]**	**Thermal conductivity (λ) [W/mK]**
PV with mounting system	104	
Ventilated gap	98	
Roofing		
Plywood	21	
I-beam (c/c 600mm) with insulation	450	0.038
Wind barrier		
Gypsum	13	

3.1.3 Windows and doors

Triple glazed windows filled with argon will be used in the building [31, 67]. Ten of the window types have a g-value of 0.08. The remaining windows have a g-value between 0.45 and 0.5. A frame factor of 0.2 was used in the energy calculations in the project and is a standard value [1]. Furthermore, the windows and doors have together an average U-value of 0.8 W/m^{2}K. The window's qualities are listed below.

- U-value = 0.8 W/m^{2}K
- G-value = 0.45 - 0.5 / 0.08
- T_{vis} = > 0.7

3.1.4 Energy supply

An air source heat pump is selected to cover the thermal energy demand in the building. The heat pump will collect heat from the outdoor air and surplus energy from the inverters [63]. Inverters for the PV panels are placed in a seperate room in the third floor, see figure A.4 in appendix A. The heat pump will have a COP of 3.33 [1]. The building will also be able to use district heating, seeing as it is connected to district heating based on the system schematics of the heating system from [4].

The PV panels covers the entire roof, in addition to parts of the facades [63]. The roof has a slope of 30° towards south, where 302 PV panels will be installed, see figure A.6. The ground floor consists of wood panel and no PV panels on the external surface. PV panels are also installed on the pergola on the south side of the ground floor. The north facade is designed with PV panels on the third floor above the ceiling, see figure B.1 in appendix B. Different PV panels will be installed on the roof, facade and pergola, and the PV panels on the roof have an efficiency of 21.5%.

Table 3.6 displays the coverage ratio of the energy supplies for the different systems in the building which was used for simulations in SIMIEN. SIMIEN was used to validate the ZEB Lab regarding the energy requirements in TEK17. The entire electricity usage in the building is covered by the production from the PV panels.[1]

Table 3.6: Energy coverage given in percentage [1].

Energy post	**Electricity (El) [%]**	**District heating [%]**	**Heat pump [%]**	**PV [%]**
Space heating	0	2	98	0
DHW	35	0	65	0
Heat for ventilation	0	0	100	0
El.-specific energy demand	100	0	0	100

3.1.5 Space heating

Waterborne radiators will be installed in each floor [1], and the supply and return temperatures are 47°C and 35°C [4]. Cooling will only be installed for the twin rooms and the PV inverter room located on the third floor. Cooling for the twin rooms is described in section 2.4.4.

3.1.6 Ventilation

The following information was mostly obtained from communication trough emails with Hans Martin Mathisen September 2019.

The ZEB Lab is designed with hybrid ventilation, which combines mechanical and natural ventilation. Regarding the natural ventilation, some of the windows are automatically controlled whereas others can be opened manually. For the mechanical system are different displacement ventilation solutions implemented throughout the building.

The canteen in the ground floor is designed with underfloor air distribution (UFAD). For the first floor will the air be distributed to the zones through porous suspended ceiling, where some of the ceiling boards supplies air. The twin rooms in the first floor have individual HVAC system, but with supply air from the duct from the central unit in the third floor. In the second floor will the air will be supplied through slots. The third floor is designed with conventional displacement ventilation, where the supply air terminals are located next to or in the walls near the floor.

Furthermore, all toilets, wardrobes etc. only have extract terminals. The reaming areas in the building have extract through the main staircase. An illustration of the staircase is shown in figure 3.2 and a picture from the building site can be seen in figure 3.3. The staircase will be used as extract during operation of both the mechanical and natural ventilation [63]. During operation of natural ventilation will the extract air leave the building through fire hatches located at the top of the stair.

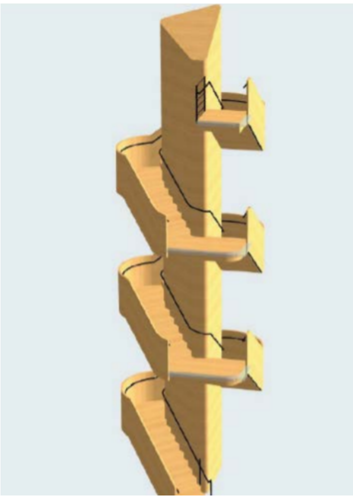

Figure 3.2: Sketch of staircase [63].

Figure 3.3: Picture of the staircase form the building site [28].

There are two air handling units (AHU) in the building, which are placed in the third floor. The AHUs serves each the east and west side of the building, and the ducks are thus located in two different shafts. This can be seen in the floor plans in appendix A and furnishing plans in appendix C. There is no mechanical cooling installed for AHUs. An illustration of one of the AHU is displayed in figure 3.4 (both AHU consists of the same components), and consist of damper, filter, heat recovery exchanger, fan, heating coil and sound attenuator.

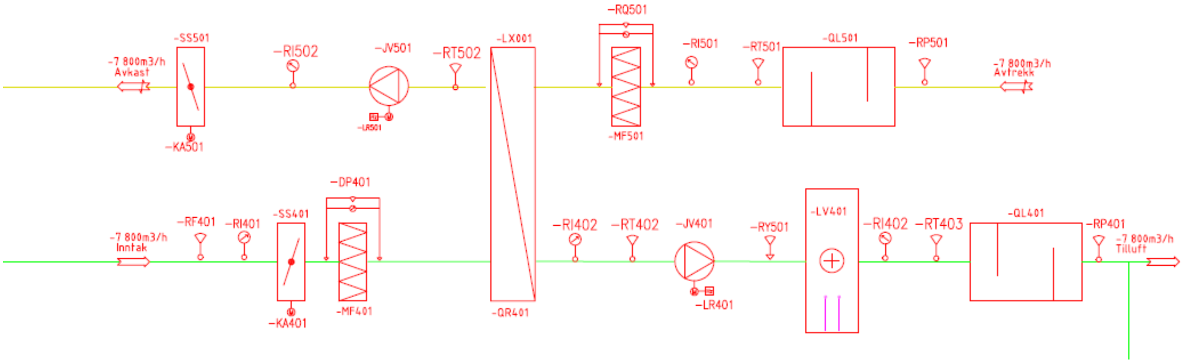

Figure 3.4: Illustration of AHU from the system schematics [3].

3.1.7 Energy recovery

A heat recovery exchanger is placed in each of the two AHUs on the third floor [3]. Here, the extract air transfer heat to the supply air before leaving the building. For the energy simulations conducted in the software SIMIEN was an efficiency of 85 % assumed for the heat exchanger [1]. Additionally, a heat exchanger is connected between the heat pump and the inverts for the PV panels.This can be seen in figure 2.6 where the heat pump exploits heat recovery from the inverters.

3.1.8 Building automation

The company Siemens AS delivers the automation system for the building. An overview of the monitoring and control system is shown in figure 3.5 [63]. An indoor positioning system will be installed in the ZEB Lab, which calculates the occupants position. This is achieved with the users mobile phones and sensors located in the ceiling.[71]

Regarding space heating, each radiator will be equipped with temperature sensor and control. Additionally, each floor will have a sensor which measures the relative humidity (RH) in each room. The occupants in the building will not be able to adjust the temperature locally. Regard-

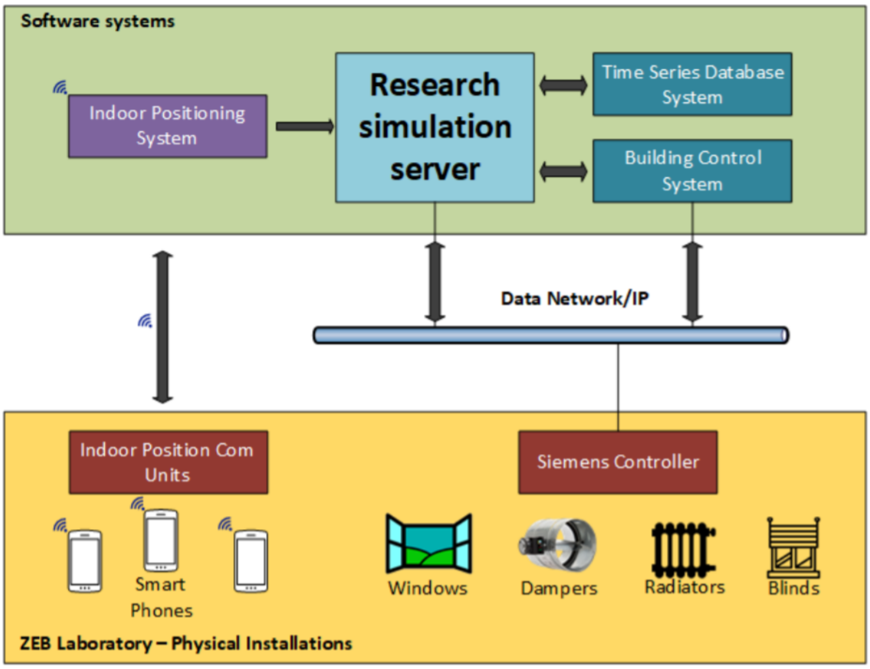

Figure 3.5: Preliminary overview of the monitoring and control system[63].

ing the ventilation will temperature, motion and CO_2 sensors be installed for demand control ventilation (DCV).[71]

Control of the lighting in the building will be done both automatic and manually. For zones which are affected by daylight, a combined motion- and daylight sensor will be implemented. Furthermore, all rooms will have motion sensor which turns the light on/off. The office space, meeting rooms, canteen and classrooms will have the possibility to dim the lighting through the occupants cellphones.[71]

The windows will be equipped with ZIP screens which can be controlled both automatically and manually. The ZIP screens will automatically be raised completely down/up by a set-point for the light intensity and solar radiation. This regulation applies to all ZIP screens on the same facade. For each room can the ZIP screens be lower or raised to a desired position by the user, which controls the screens by their cellphones. For safety precautions will the ZIP screens be raised up during high wind speeds or low temperatures.[71]

The motorised windows in the building can be controlled locally to a desired position by the occupants through their cellphones [71]. Selected windows allows the possibility for users to manually open and close the windows. This is shown in appendix B, which is an overview of the facades. The areas marked with orange are motorized and the purple areas are manually controlled. The remaining windows can not be opened.

3.2 Modeling of the ZEB Lab in IDA ICE

The model of ZEB Lab was created in the software IDA ICE based on floor- and furniture plans, Norwegian standards, system schematics and several other documents related to the building project. Much of this information is presented in chapter 3.1.

3.2.1 Location and climate

In IDA ICE was the location set to be Trondheim/Vernes, downloaded from the software's database. Additionally, climate parameters for Trondheim was imported into the model from the database. The file, NOR_TRONDHEIM-VERNES_012710(IW2).PRN, is a weather file for Værnes developed by ASHRAE, the American Society of Heat, Refrigerating and Air-Conditioning Engineers. Værnes is approximately 26.5 km northeast of Trondheim [26].

Figure 3.1 was used to measure and calculate the location and length of the surrounding buildings to account for shading. The height of the buildings were estimated based on physical observations on the building site. Figure 3.6 is a screenshot from IDA ICE which display the ZEB Lab and shading buildings. The line in front of the south facade represents the pergola. The orientation of the building was modeled to be 0° north, which can be seen in the figure, in accordance with information stated in section 3.1.1.

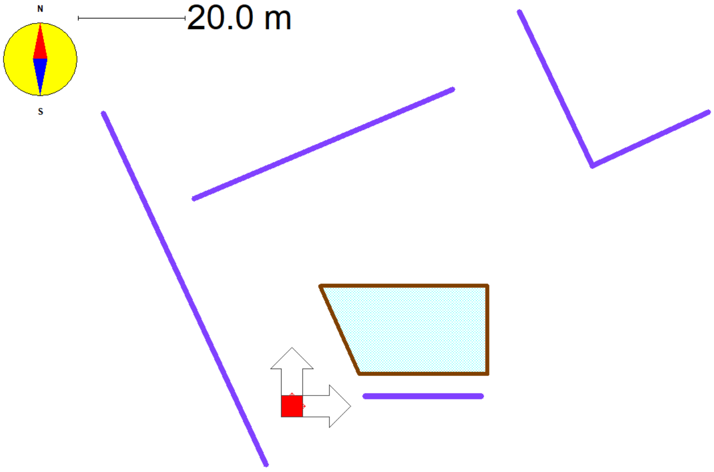

Figure 3.6: Screenshot of the building site and orientation in IDA ICE.

3.2.2 Building geometry

The structure of the building was made by importing DWG-files of the floor plans into IDA ICE. In that way, the building body was drawn based on the placement of external walls on the floor plans. Two of the external walls of the building are sloped inwards, the northeast and northwest corners, which is illustrated in the figures of the facades in appendix B and figures in section 2.4. This specific shape of the walls was not modeled in IDA ICE and is explained more in depth in section 3.2.7. Figure 3.7 and 3.8 are screenshots from IDA ICE and shows the 3D model of the building. Transparent PV panels will be installed on the pergola in-front of the south facade on the ground floor (can be seen in figure 2.4). Accordingly, the pergola was modeled to be transparent in IDA ICE, although the transparency of the shading element is not visible in the screenshot from IDA ICE.

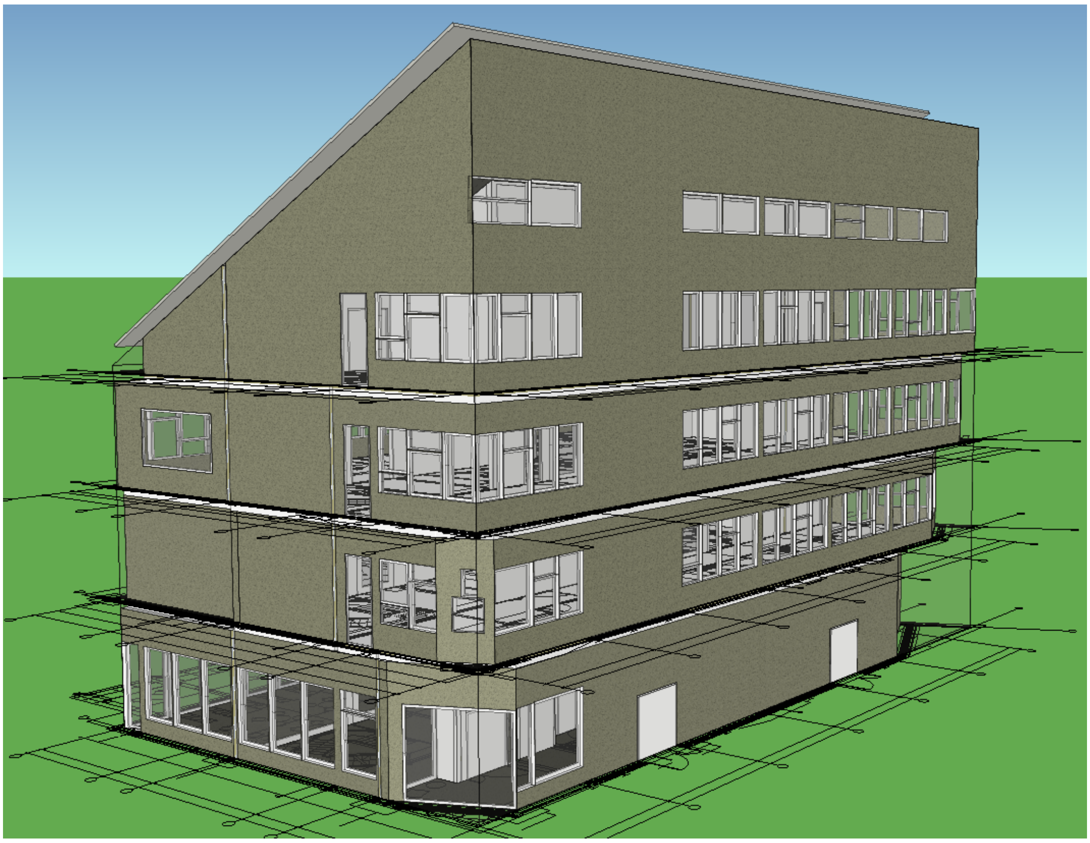

Figure 3.7: Screenshot of the building in IDA ICE towards southwest.

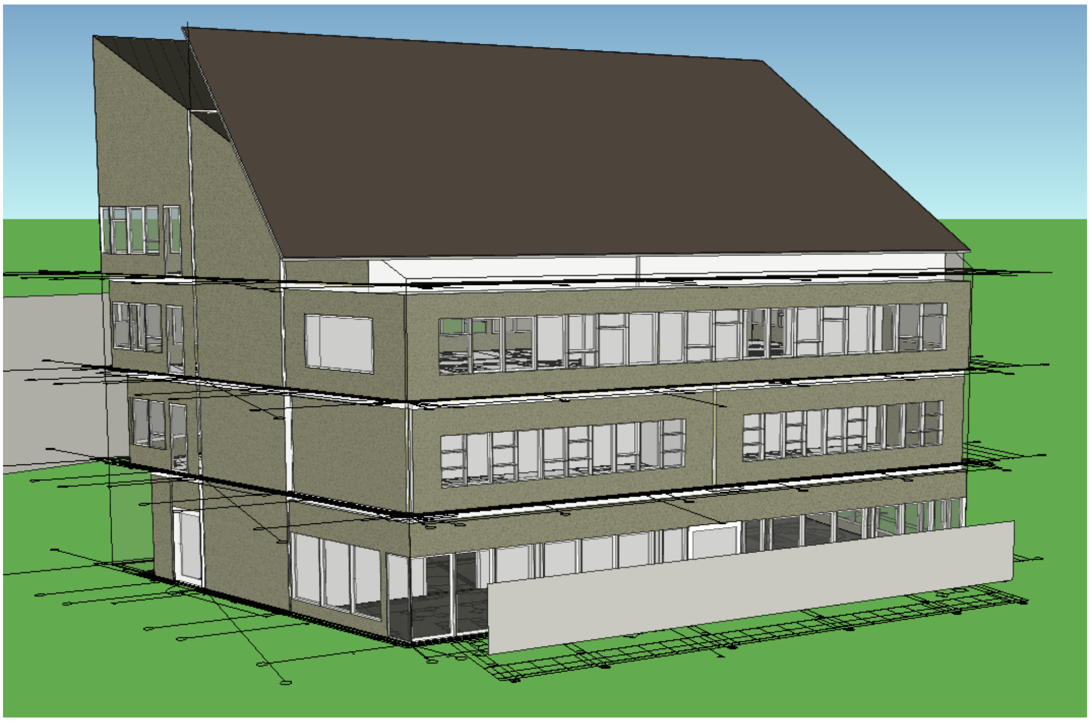

Figure 3.8: Screenshot of the building in IDA ICE towards northeast.

The zones in the building were created based on the internal and external walls. Zones located on the same floor were modeled with same height, with the exception of the third floor where the roof is tilted. The height of each zone was obtain from figure B.5 and are shown in table 3.7. The height listed for the third floor is the maximum.

Table 3.7: Heights in the ZEB Lab.

Floor	Total height [mm]	Height from top of floor to bottom of floor [mm]
Ground	4450	4146
First	3850	3546
Second	3850	3546
Third	9520	-

Mainly were four zones created in IDA ICE for each floor. One for the side staircase (bitrapp), one for the south part of the floor, the middle and north. The boundary between the zones was set based on the location of internal walls. The reason for creating three zones was to take into consideration the impact of solar radiation thought the windows. The areas located south will experience more heat and light from the Sun, compared to the rooms in the middle with limited windows. Additionally, the rooms on the north end of the building will experience less solar radiation through the windows due to the Sun's path.

The side staircase (bitrapp) was created as an individual zone with a height that extents to the roof of the building. This was done since the staircase is completely closed from the rest of the building with no heating units, meaning the temperature will be lower here. The twin rooms in the first floor were created as two individual zones. The reason for this is due to the research which will take place in the rooms. The inverter room in the third floor was also modeled as a single zone in order to apply cooling to the room. The following figures (3.9, 3.10, 3.11 and 3.12) display how each floor in the building were divided into several zones for the simulation in IDA ICE. Between the established zones were doors, openings and windows inserted based on floorplans and an IFC-model of the ZEB Lab.

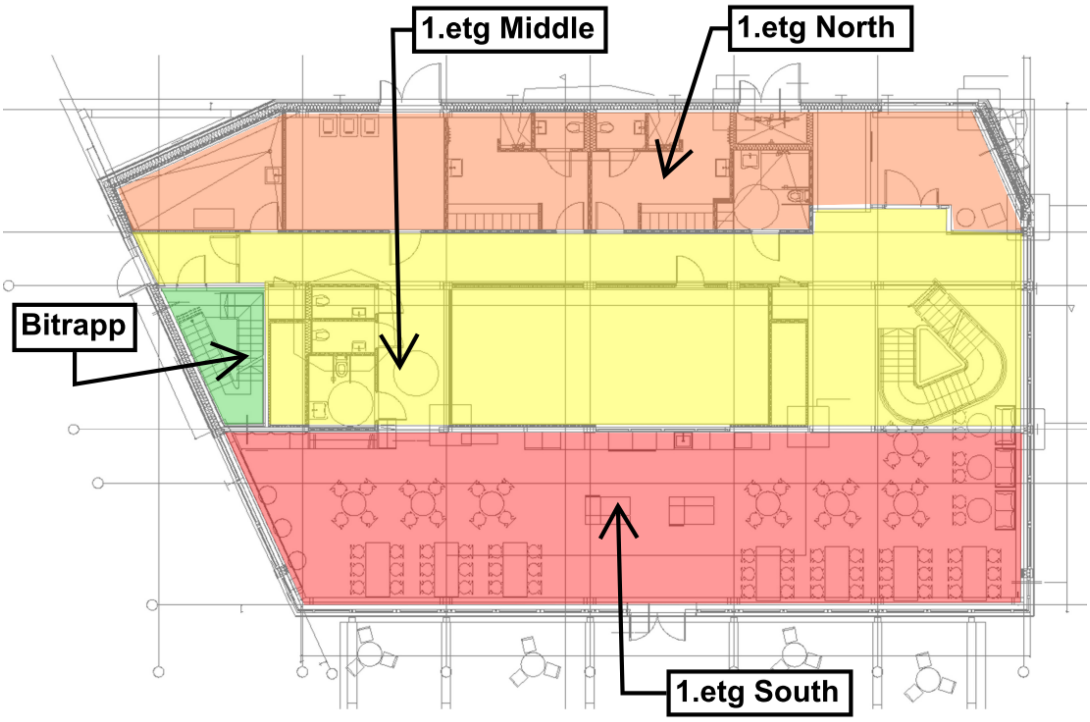

Figure 3.9: Overview of division of zones in the ground floor.

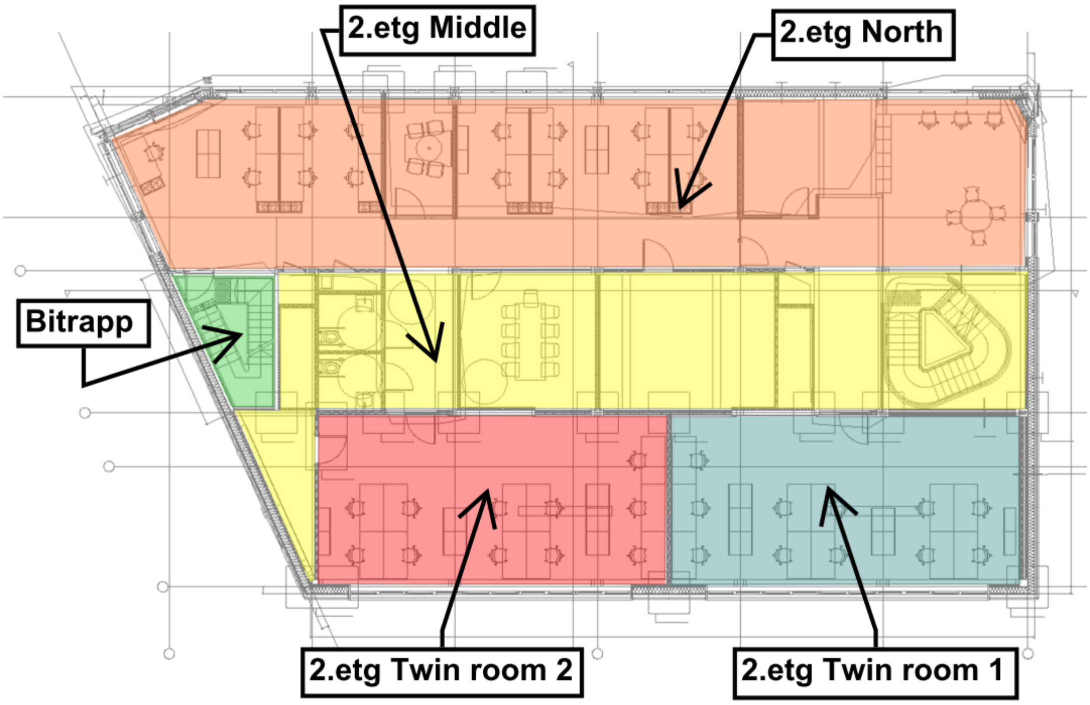

Figure 3.10: Overview of division of zones in the first floor.

Figure 3.11: Overview of division of zones in the second floor.

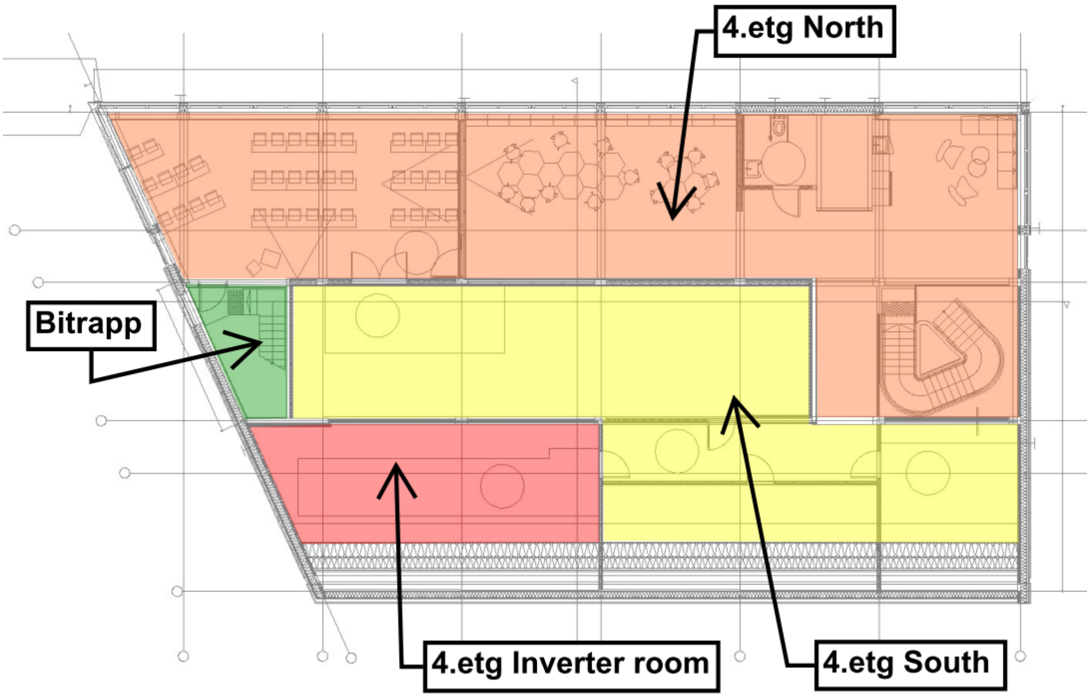

Figure 3.12: Overview of division of zones in the third floor.

An overview of the zones and accompanying floor area modeled in IDA ICE are shown in table 3.8. The names given each zone are the same labels which are displayed in the figures above.

Table 3.8: Overview of zones and accompanying floor area in IDA ICE model.

Floor	**Zone**	**Floor area [m^2]**
Ground	1.etg North	102.2
-	1.etg Middle	172.2
-	1.etg South	146.6
First	2.etg North	168.4
-	2.etg Middle	124.7
-	2.etg Twin room 1	66.8
-	2.etg Twin room 2	66.8
Second	3.etg North	171.9
-	3.etg Middle	116.8
-	3.etg South	144.3
Third	4.etg North	204.3
-	4.etg Inverterroom	45.8
-	4.etg South	142.5
Entire length of the building	Bitrapp	11.1

3.2.3 Building envelope

The building envelope was modeled with the information listed in section 3.1.2. Some adjustments were conducted for the layers in the construction elements in order to obtain the stated U-value i table 3.1. This is explained more in depth in section 3.2.7.

An Industry Foundation Classes (IFC) data model of the building was used to measure the geometry, recess depth and height above the floor for the different windows, doors and openings. The software Solibri was used to conduct these measurements. The windows were then modeled in IDA ICE based on the placement on the floor plans with the qualities mentioned in section 3.1.3. For the east and west facade are some of the PV panels transparent. These specific windows was modeled with a lower T$_{vis}$ value to account for the reduced solar radiation through the windows. The location of these windows can be seen from figure B.2 and B.4 in appendix B.

The window frame was set to be 20% of the total window area, based on [1]. All windows were model with external blinds for shading. The automatically operated windows was modeled with "PI temperature control". No control function was inserted for the manually operated windows.

3.2.4 Energy supply

Only the PV panels on the roof was simulated in IDA ICE, which is explained in section 3.2.7. This was accomplished by inserting the parameters listed in table 3.10. The total area of PV panels was found by multiplying the area of one panel with the total number of panels on the roof. Table 3.9 shows implemented parameters for the PV system.

Table 3.9: Parameters for the PV system in IDA ICE.

Description	**Value**
Roof area with PV panels [m^2]	507.3
Azimuth [°]	0 (south)
Tilt [°]	30
η_{PV} [%]	21.5

The energy system for heating was designed by conduction an analysis of maximum power demand based on design outdoor temperature for Trondheim in IDA ICE. This is called a "heating load" simulation in IDA ICE, and was conducted with no internal heat gains and ideal heaters in all zones.

An ambient air to water heat pump was modeled as base heating and an electric boiler as top heating. This is based on table 3.6 and the heat pump covers approximately 88% of the total energy demand for heating according to the stated values. However, unlike SIMIEN, it is not possible to select energy coverage ratio in IDA ICE. In IDA ICE is the thermal energy system modeled based on the total heating capacity of the components. Therefore, it was assumed that the electric boiler will cover 100% of the power demand for DHW on the design outdoor temperature, and that the heat pump will cover the reaming power demand. Heat pumps are usually designed to cover 40-70% of a buildings net power demand. The division of design power is shown in table 3.10, along with other relevant parameters for the heating system.

Table 3.10: Parameters for the energy system in IDA ICE.

Description	Value
Total heating capacity [kW]	55.7
Max capacity electric boiler [kW]	6.7
$\mathrm{COP}_{\mathrm{el}}$ [%]	1
Total heating capacity heat pump [kW]	49
$\mathrm{COP}_{\mathrm{heatpump}}$ [%]	3.33
Heat pump model in IDA ICE	A2W_HP_MODEL

A PCM heat storage will be installed in the building ZEB Lab as part of the energy system. However, this was not modeled in IDA ICE. IDA ICE has the possibility of implementing PCM as a layer in a building construction, but it was not detected any possibilities of modeling an actively used PCM unit as a part of the energy system.

3.2.5 Technical systems

Heating and cooling

Waterborne radiators were implemented in most zones, with supply- and return temperature of 47°C and 35°C. The design power for the radiators was inserted based on results from the "heating load" simulation (mentioned in paragraph 3.2.4). Some of the rooms will not be installed with radiators, such as the side staircase and the technical rooms in the third floor, based on the system schematic [5, 6]. Therefore, the zone "Bitrapp", "4.etg Inverterrom" and "4.etg South" was modeled without any heating unit. Moreover, the zone "4.etg Inverterrom" was modeled with a cooling unit. Setpoints for heating and cooling for the building are shown in table 3.11, along with a reference for where the information is collected from.

Table 3.11: Parameters for heating and cooling in IDA ICE.

Description	**Value**	**Reference**
Temperature setpoint for heating [°C]	21	SN/TS 3031:2016
Temperature setpoint for cooling [°C]	24	SN/TS 3031:2016

Ventilation

In IDA ICE was one AHU modeled, combining the values for the two AHUs in the ZEB Lab. A heating coil, fans and heat recovery exchange were modeled in the AHU. Parameters for the AHU are shown in table 3.12 and for ventilation on zone level in table 3.13, along with a reference for where the information is collected from.

Table 3.12: Parameters for AHU in IDA ICE.

Description	**Value**	**Reference**
SFP [kw/(m^3/s)]	1.0	[1]
Rated flow of fan [m^3/h]	15 600	[3]
Heat exchanger efficiency [%]	85	[1]
Temperature setpoint for supply air [°C]	18	

Table 3.13: Parameters for ventilation on zone level in IDA ICE.

Description	**Value**	**Reference**
VAV control	Temperature and CO_2	[71]
Minimum air supply [m^3/m^{2}h]	1	[1]

For the twin rooms was the maximum supply airflow set to be 18 m^3/m^{2}h based on system schematics of the ventilation system ([3]). Additionally, the supply air for the technical rooms located on the third floor ("4.etg Inverter room" and "4.etg South") was based on the system schematics of the ventilation system, and was 7.4m^3/m^{2}h for the main switchboard room. It was problematic to use values form the ventilation system schematics of the ZEB Lab, seeing as some areas which are supplied by the same terminal in the ZEB Lab has been divided into separate zones for the model in IDA ICE. Therefore, the maximum supply airflow for the remaining zones in the building was calculated according to §13-3 in TEK17.

3.2.6 Usage of building

For internal gains and usage of the building was information from the report "Energikonsept"[1] from the building project used. Additionally, values from SN/TS 3031:2016 [56] were used when no specific values regrading the building were stated in the report. An overview of the values and time schedule related to the various elements are shown in table 3.14. Vacation was not included in the model in IDA ICE, but public holidays in Norway were implemented.

Table 3.14: Values and time schedule for usage in the ZEB Lab.

Element	**Value and reference**	**Time schedule**
Occupancy	1.2 Met and 0.85 ± 0.25 Clo	07-17 (10/5/52)
Lighting	3 W/m^2 [1]	07-17 (10/5/52)
Technical equipment	3.2 W/m^2 [1]	07-17 (10/5/52)
DHW	5 $kWh/m^2 \cdot year$ [56]	07-17 (10/5/52)

The operating time and power variation given in SN/TS 3031:2016 were used in IDA ICE. The values for power variation in SN/TS were manipulated from being specific values to be expressed as a percentage. This was done in order to have the ability of using specified values form the project (which does not correspond with SN/TS) with the varying usage pattern expressed in SN/TS. Lighting, technical equipment and occupancy are shown in figure 3.13, where technical equipment and occupancy have the same power variation. Figure 3.14 display DHW.

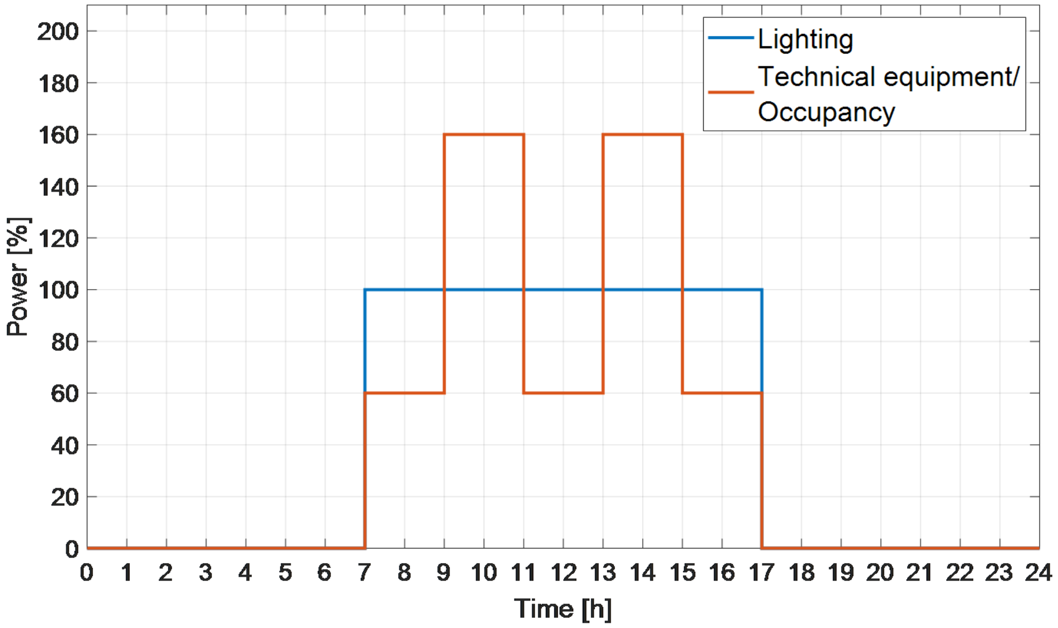

Figure 3.13: Power variation of lighting, equipment and occupancy during a working day.

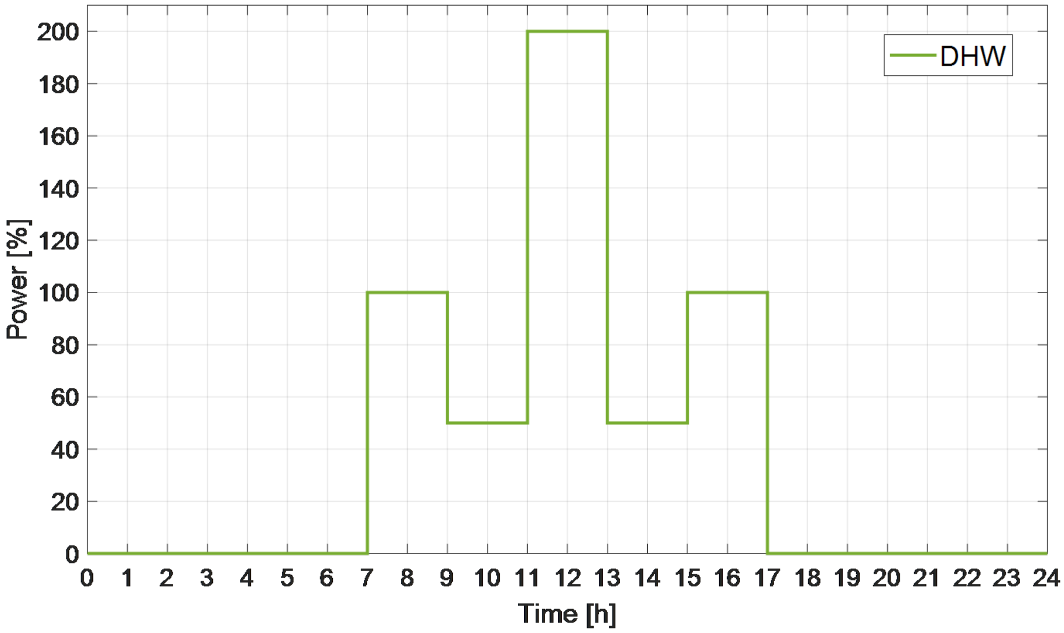

Figure 3.14: Power variation of DHW during a working day.

Occupancy

An activity level of 1.2 met corresponding to sedentary activity was implemented. The number of people present in the building was based on the fixed sitting arrangements shown on the furniture overview in appendix C. In order to account for people being present in the zones without fixed sitting arrangements, it was assumed that a few people would always be present in the meeting room etc. during the day. Therefore, the number of occupants in zones with fixed sitting arrangements were inserted with approximately 1-3 people less, assuming these people are located in meeting rooms. This only applies to the first and second floor and the division of occupants is displayed in table 3.15.

Table 3.15: Number of people in zones.

Zone	Number of people
2.etg Twin room 1	10
2.etg Twin room 2	10
2.etg Middle	4
2.etg North	13
3.etg South	15
3.etg Middle	4
3.etg North	18

The ground floor mainly consists of a canteen, meaning the number of occupants is not consistent during the day and have a peak during lunchtime. For that reason, the load displayed in figure 3.13 was not used for the ground floor. Instead, it was assumed that lunchtime would be between the time 11:00 - 13:00 and that people would eat sporadically during that time. Additionally, it was assumed that around 20% of the people would leave the building during lunchtime to buy food elsewhere, since the canteen does not offer this. Therefore, the load of occupants was set to 40% during the time 11:00 - 13:00. Furthermore, it was assumed that it would always be a person present in the other rooms on the ground floor, and the usage patterns from SN/TS was implemented there.

Lighting

To simplify was one lighting object inserted for each zone in the building. The luminous efficacy [lm/W] was calculated based on product information and lighting sketches. An average for all the armatures in each story was used in IDA ICE, shown in table 3.16. In IDA ICE was the lighting modeled to be regulated based on daylight in the zone.

Table 3.16: Lighting in IDA ICE.

Floor	**Average luminous efficacy [lm/W]**
Ground	120
First	125
Second	120
Third	127

3.2.7 Approaches and simplifications

This section will present approaches and simplifications which were conducted when the building was developed in IDA ICE. Some of this is already mentioned in the previously paragraphs, such as the AHU, occupant-load and lighting.

Building geometry

Two of the external walls of the building are oblique, the northeast and northwest walls. This specific shape of the walls was not modeled in IDA ICE. The reason for this is limited knowledge about the software. Professors at NTNU were contacted regarding this, however none of them knew if it was possible to create this in IDA ICE. An email was also sent to EQUA, but no feedback has been received. Therefore, an approach was conducted instead. An L-shape of the wall was made for each floor, creating a shape similar to a reverse staircase. This can be observed in figure 3.7 and 3.8.

The building body was created based on the shape of the third floor. Walls in zones which aligns with the shape of the building body is automatically set to external walls and the rest to internal walls. This means that the oblique walls were by default set to internal walls. To account for the heat losses which will occur here, the walls was defined as external by using the function "connect to face". In that way, the walls can be thermally connected to a selected part of the building body. The walls was connected to the external walls who’s orientation was most similar.

U-value

In IDA ICE is the U-value of a construction element calculated based on the layers of material. A layer is defined with a thickness [m] and a specific material. For a material includes values for specific heat, density and thermal conductivity. Only the thermal conductivity for the different insulations were provided. However, the thickness was obtained for most of the materials. Therefore, standard values from IDA ICE's database were used, with the exception of thermal conductivity for the insualtions. This resulted in a U-value which did not match the stated U-value. Thus, the thickness for the insualtions were reduced in order to obtain the stated U-value.

PV panels

There was not detected any possibilities implementing PV panels for different azimuths and slopes in IDA ICE. Moreover, professor at NTNU was contacted regrading this and did neither know if this was feasible to conduct in IDA ICE. Therefore, only the PV panels on the roof was simulated.

Ventilation

For the ZEB Lab is the ventilation type displacement ventilation, but this was not included in model. In IDA ICE it is possible to select two different zone model fidelity: energy and climate. The simulation of displacement ventilation is not possible to run when energy model is selected. However, the climate model is limited only to zones with a rectangular shape. Therefore, displacement ventilation was only simulated for the twin rooms and "3.etg Middle". Completely mixed ventilation was implemented for the reaming zones.

3.3 Modeling of altered solutions of the ZEB Lab in IDA ICE

The initial idea was to apply the developed model to analyze energy use of the ZEB Lab for the different research experiments which are planned to be carried out at the ZEB Lab. However, after contacting researchers who are involved in the project, it was discovered that at the moment there are no experiments planned to be conducted in the nearest future. Therefore, a few different alternations of the building design and operation were selected based on suggestions from supervisor.

Furthermore, the supervisor suggested to only apply and analyze different altered solutions for the twin rooms. As previously mentioned in chapter 2.4.4, will these rooms be specifically used for research. Therefore, it seemed fitting to apply alternations of various elements for these two rooms. This consist of altering opening of windows, installing PCM in the ceiling and altered occupancy pattern. The PCM heat storage for the ZEB Lab was not included in the IDA ICE model. Therefore, it was decided to study the affect of installing PCM in the ceiling of the twin rooms instead.

3.3.1 Simplifications

Considering only the twin rooms were going to be altered and analyzed, the model of ZEB Lab in IDA ICE was simplified. This was done in order to shorten the simulation time. Firstly, the two twin rooms were merged together to form one zone, and is therefore further referred to as twin room instead of rooms. Furthermore, the model was reduced to one zone for each story, with the exception of the twin room. Additionally, the number of window was reduced, with the exception of the twin room. This was achieved by adding up the width of all the windows in order to insert one large window, and was only done for the window located next to each other. The simplified model is used as base model for the applied alternations.

3.3.2 Opening of windows

Figure 3.15 shows the south facade of the twin rooms, obtained from figure B.3 in appendix B. The windows which are marked in orange have motorized control, purple manually control and the remaining windows can not be opened. Three different scenarios were established regarding opening of windows for the twin room, which is listed below. Accordingly, three different models were created in IDA ICE and simulated. No other parameters than the windows were altered in the simulation models. The affect of alternating opening possibilities were analysed by studying the thermal environment on a warm week in Summer, as well as energy usage.

Figure 3.15: South facade of the twin rooms.

1. Motorized (orange) windows open according to PI temperature control (base model)
2. Manually (purple) and motorized (orange) windows open according to PI temperature control
3. All windows closed

3.3.3 PCM in ceiling

Three different scenarios were established regarding implementing PCM as a layer in the ceiling of the twin room. Three different thicknesses of PCM were applied to the base model, which are listed below. This results in three different volumes of PCM (the ceiling area is constant in all three cases), and hence three different storage capacities. Accordingly, three different models were created in IDA ICE and simulated. The affect of alternating PCM thicknesses were analysed by studying the thermal environment on a a warm week in Summer, as well as energy usage. The reason for simulating different volumes of PCM was to investigate their affect on temperature stabilisation in the room.

1. $\mathrm{h}_{\mathrm{PCM}} = 0.005$ m
2. $\mathrm{h}_{\mathrm{PCM}} = 0.02$ m
3. $\mathrm{h}_{\mathrm{PCM}} = 0.1$ m

The database in IDA ICE contains one material available to add as a PCM layer in a building construction, which is the material SP21E from the manufacturer Rubitherm. This was added to the existing ceiling construction for the twin room, in addition to 0.013m gypsum since it appears that PCM is usually not directly exposed towards a room based on studies presented in section 2.5.

3.3.4 Altered occupancy pattern

The ZEB Lab will be used by employees and students at NTNU. Therefore, it is reasonable that some people will be working overtime at the office, for instance PhD candidates. For that reason, it was decided to simulate a scenario where some occupants are present in the twin room beyond the standard time schedule from SN/TS 3031:2016, which is a more realistic use of the building. This was achieved by altering the occupancy pattern to study the effect this has on the thermal environment and energy usage.

It was assumed that 5 people would be working overtime and be present at the office until 8 PM. The schedule for internal gains from occupants in IDA ICE was altered accordingly and is shown in figure 3.16. It is a modification of the graph displayed in figure 3.13, and is extended to represent power variation for a working day with 5 people working overtime in the zone.

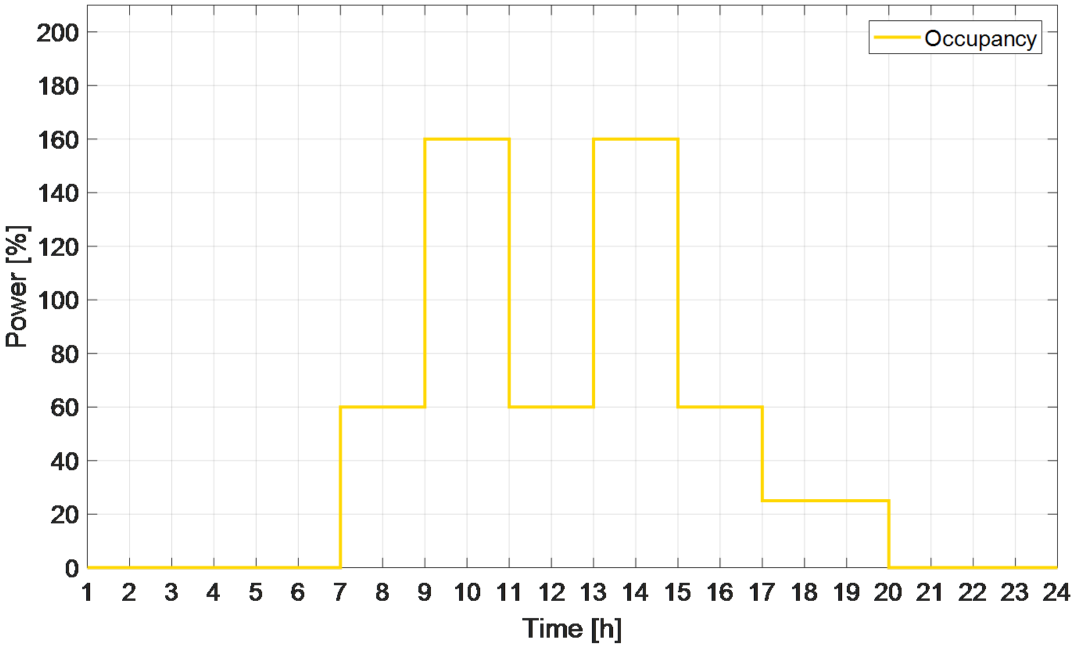

Figure 3.16: Power variation of occupancy during a working day with overtime.

The lighting in the building will be installed with motion detector sensors. It was assumed that the people will be working overtime in the same room, and the lighting was therefore modeled to be 100% during overtime. This can be seen in figure 3.17. Regarding technical equipment was the time schedule extended until 8 PM. This is displayed in figure 3.17 together with lighting.

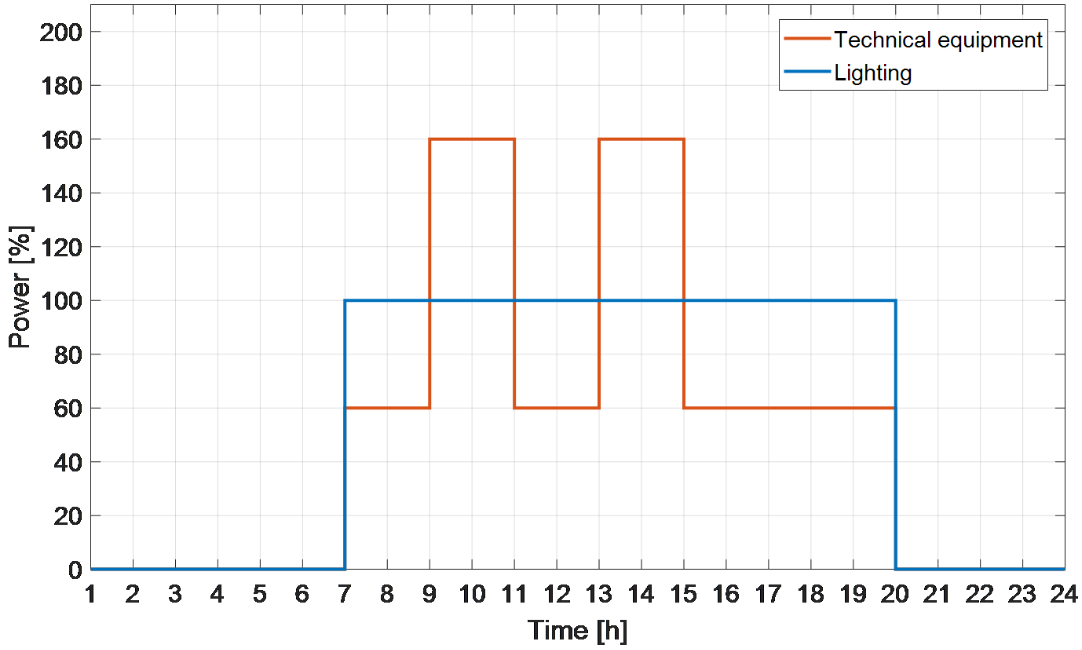

Figure 3.17: Power variation of lighting and technical equipment during a working day with overtime.

Opening of windows

Three different scenarios were established regarding opening of windows together with the altered occupancy pattern. This was conducted in the same way as described previously in section 3.3.2, with the same three window opening controls. The affect of alternating opening possibilities and altered occupancy pattern were analysed by studying the thermal environment on a warm week in Summer, as well as energy usage.

PCM in ceiling

Three different scenarios were also established regarding implementing PCM as a layer in the ceiling of the twin rooms together with the altered occupancy pattern. The implementation of PCM in the ceiling was conducted in the same way as described previously in section 3.3.3, with the same three different thicknesses of PCM. The affect of alternating PCM volumes and altered occupancy pattern were analysed by studying the thermal environment on a warm week in Summer, as well as energy usage.

3.3.5 Overview of altered solutions

This section is a summary of the previous sections regarding the altered solutions. The listed case numbers for each scenario are used throughout this thesis. Case 1 is the base model for all simulations which all altered solutions are compared against. It is the simplified model of the ZEB Lab.

Group 1: Opening of windows

1. Motorized windows open according to PI temperature control (base model)
2. Manually and motorized windows open according to PI temperature control
3. All windows closed

Group 2: PCM in ceiling (the windows is set to be like in case 1)

4. h_{PCM} = 0.005 m
5. h_{PCM} = 0.02 m
6. h_{PCM} = 0.1 m

Group 3: Altered occupancy pattern and opening of windows

7. Case 1 with altered occupancy pattern
8. Case 2 with altered occupancy pattern
9. Case 3 with altered occupancy pattern

Group 4: Altered occupancy pattern and PCM in ceiling

10. Case 4 with altered occupancy pattern
11. Case 5 with altered occupancy pattern
12. Case 6 with altered occupancy pattern

Chapter 4

Results

The following paragraphs presents the results regrading the main model of ZEB Lab, simplified model of ZEB Lab as well as the altered solutions applied to the simplified model. This includes energy usage and temperature variations.

4.1 Main model

The energy generation over a year from the PV panels on the roof is shown in table 4.1, along with the energy production sold to the grid. The energy usage over a year for the different energy posts in the detailed model of ZEB Lab in IDA ICE is displayed in table 4.2, in addition to the total energy usage. Figure 4.1 illustrates relation between the energy usage fir the different energy posts. Ventilation heating is the energy used for the heating coil in the AHU and the ventilation cooling is the energy used for the cooling coil in the AHU.

Table 4.1: Energy production from PV panels on the roof.

Energy post	**Generated energy [kWh/year]**	**Sold energy [kWh/year]**
PV panels on roof	107 950	79 136

Table 4.2: Energy usage for ZEB Lab in IDA ICE.

Energy post	**Energy usage [kWh/year]**
Space heating	41 529
Ventilation heating	3857
Domestic hot water (DHW)	8393
Fans	5847
Pumps	112
Lighting	12 678
Technical equipment	13 638
Space cooling	12
Ventilation cooling	0
Total	86 066

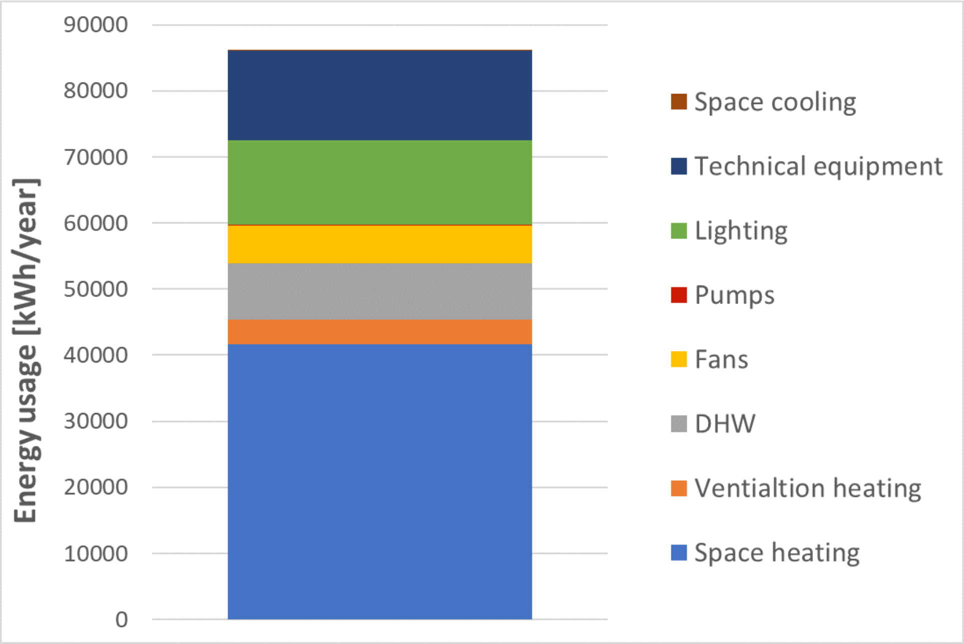

Figure 4.1: Energy usage for the different energy posts in ZEB Lab IDA ICE model.

4.1.1 Twin rooms

The energy balance for the two twin rooms is shown in table 4.3. Additionally, the total energy balance for the two rooms is also included, by adding the values together. The values which are negative are losses in the zone and the positive values are supplied to the zone.

Table 4.3: Energy balance for the twin rooms in main model of ZEB Lab.

Element of balance	**Energy for twin room 1 [kWh/year]**	**Energy for twin room 2 [kWh/year]**	**Total energy [kWh/year]**
Envelope and thermal bridges	-1170	-681	-1851
Internal walls and masses	-122	-274	-397
Window and solar	-911	-942	-1853
Mechanical supply air	-1370	-1428	-2797
Infiltration and openings	-183	-163	-346
Occupants	2107	2107	4215
Equipment	541	541	1082
Lighting	506	506	1012
Local heating units	888	621	1509

4.2 Simplified model

The energy usage for the different energy posts in the simplified model of ZEB Lab in IDA ICE are displayed in table 4.2. For the simplified model was only one zone per floor created, with the exception of the twin room. The reasons why energy usage varies for some of the posts such as DHW and lighting for the main and simplified model, is because the model floor area is different. Floor area occupied by internal walls are not included in IDA ICE, resulting in a larger model floor area for the simplified model since less zones are included.

Table 4.4: Energy usage for the simplified model of ZEB Lab.

Energy post	**Energy usage [kWh/year]**
Space heating	40 195
Ventilation heating	2574
Domestic hot water (DHW)	8723
Fans	4296
Pumps	107
Lighting	13 192
Technical equipment	14 180
Space cooling	0
Ventilation cooling	0
Total	83 267

4.2.1 Twin room

For the simplified model in IDA ICE was the two twin rooms merged together to one zone. The energy balance for merged twin room is shown in table 4.3. The values which are negative are losses in the zone and the positive values are supplied to the zone.

Table 4.5: Energy balance for combined twin room in simplified model of ZEB Lab.

Element of balance	**Energy for twin room [kWh/year]**
Envelope and thermal bridges	-1866
Internal walls and masses	-413
Window and solar	-1834
Mechanical supply air	-2804
Infiltration and openings	-398
Occupants	4214
Equipment	1089
Lighting	1019
Local heating units	1579

4.3 Altered solutions in twin room

The following paragraphs present the results regrading the altered solutions applied to the simplified model of ZEB Lab. This includes energy usage and temperature variations. The AHU in the third floor supplies air to the entire building. Therefore, the difference in energy usage related to the ventilation can not be shown on zone level and is displayed for the entire building in the results. For all the cases are the majority of parameters the same, with the exception of the specific measure applied to the twin room (opening of windows, amounts of PCM and altered occupancy).

The simulation period was set to be 1st of June - 31th of August. This was conducted in order to shorten the simulation time. Additionally, since most of the altered solutions are cooling measures to lower the temperatures during warmer periods, the largest effect occurs during Summer. For all the cases are the temperatures in the zone displayed during a warm working week (Monday-Friday) in Summer. The specific week is 5th of August - 9th of August 2019 in IDA ICE. The vertical grid lines in the figure shows every 6th hour, meaning each day consist of four vertical grid lines. The graphs start at 00 AM on Monday. This applies for all the following figures in section 4.3. Figure 4.2 shows the outside air temperature during that week.

Additionally, the direct normal irradiance and diffuse irradiance on a horizontal surface during the week are shown in figure 4.3.

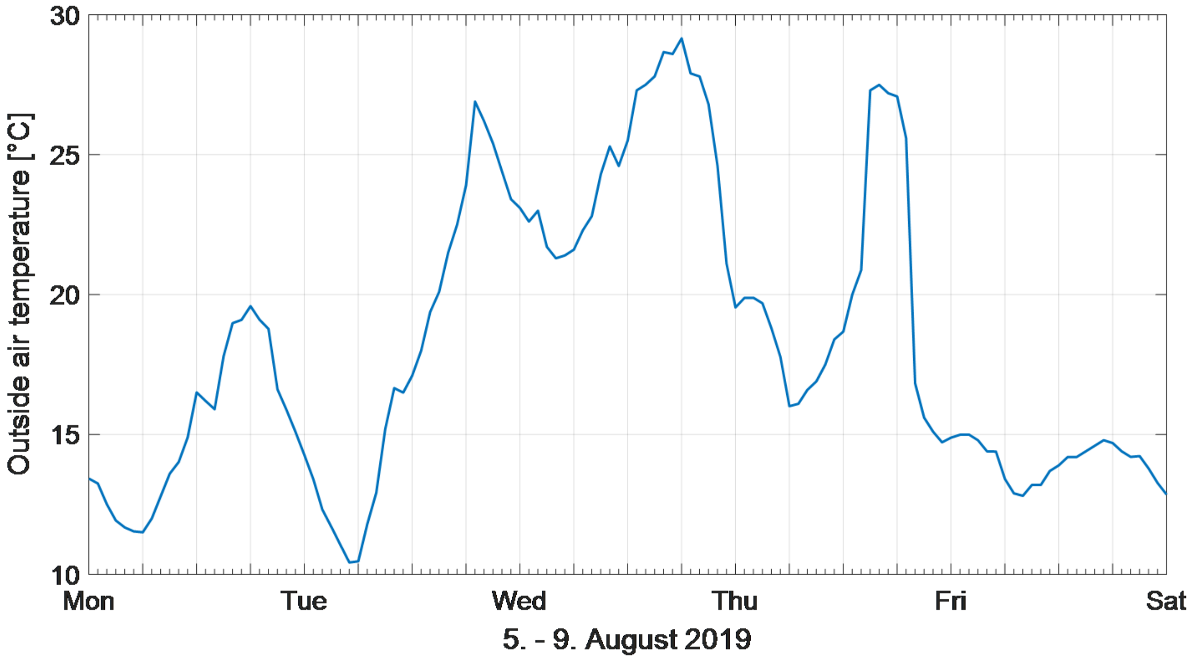

Figure 4.2: Outside air temperature variation for a week in Summer.

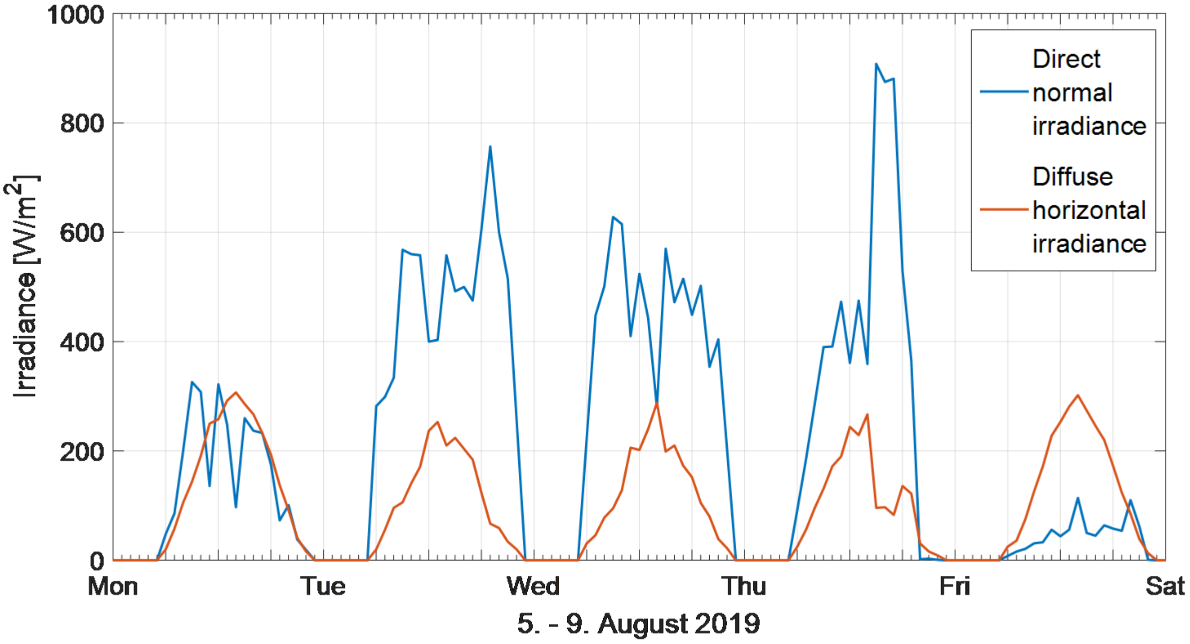

Figure 4.3: Direct normal and diffuse horizontal irradiance over a week in Summer.

4.3.1 Opening of windows

Three different opening controls of the windows in the twin room were simulated, which are listed below.

1. Motorized windows open according to PI temperature control (base model)
2. Motorized and manually windows open according to PI temperature control
3. No windows can be opened

Temperature

Figure 4.4 displays the operative temperature in the zone during a warm working week (Monday - Friday) in Summer. The blue line shows the temperature variation for case 1, the red line for case 2 and the green line for case 3. Case 1 and case 2 have approximately the same temperature variation, although this is not very visible in the figure. The vertical grid lines in the figure shows every 6th hour.

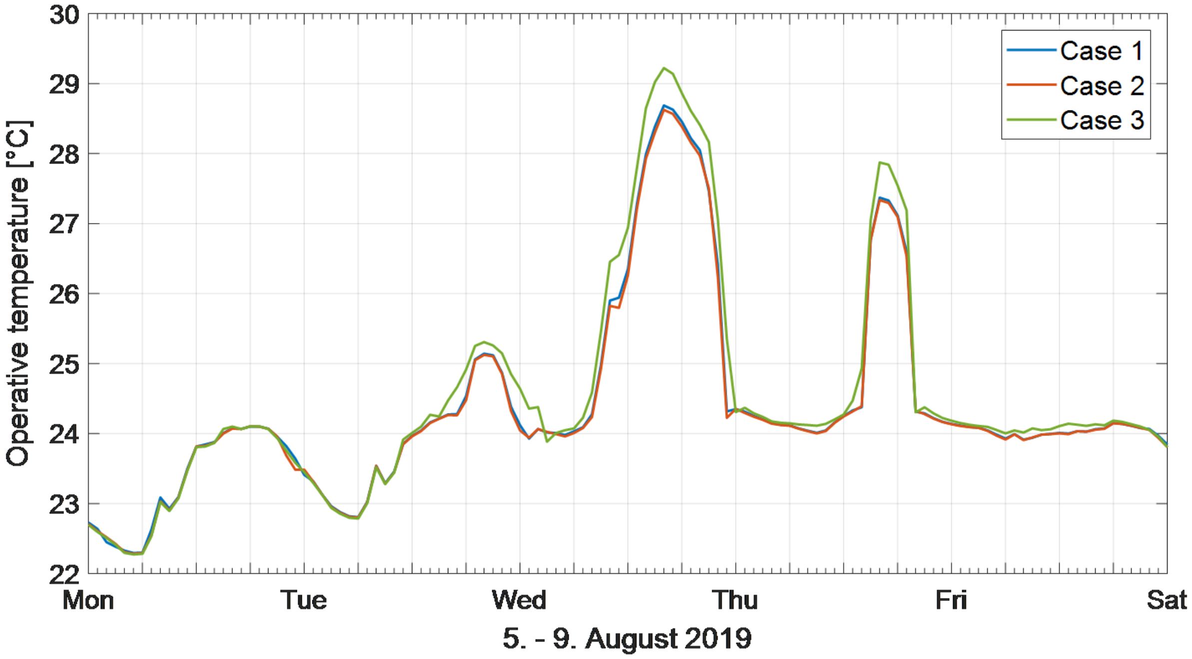

Figure 4.4: Temperature variation in the twin room for a week in Summer with different control opening of windows.

The average temperature and the maximum temperature for each case over the week is displayed in table 4.6.

Table 4.6: Temperatures for case 1, 2 and 3 over a week in Summer.

Case	Average temperature [°C]	Maximum temperature [°C]
1)	24.4	28.7
2)	24.4	28.6
3)	24.5	29.2

Energy

Table 4.7 shows the airborne net heat flows into the twin room through external walls and mechanical ventilation. Table 4.8 shows the airflow in the twin room, in/out through external walls and mechanical ventilation. The values are presented as an average over the specific week.

Table 4.7: Average airborne net heat flows into twin room for case 1, 2 and 3 over a week in Summer.

Case	Net heat inflow through external walls [W]	Net heat inflow from mechanical ventilation [W]	Total net heat inflow [W]
1)	-513	-417	-930
2)	-541	-394	-935
3)	-1	-839	-840

The energy usage for the AHU is displayed in table 4.9, in addition to the energy used for heating in the twin room. The values are presented as a total over the Summer (June, July and August). The opening control of windows in the twin room is the only parameter which was altered for the different scenarios, all other parameters are the same in each case.

Table 4.8: Average air flows in twin room for case 1, 2 and 3 over a week in Summer.

Case	**Outflow through external walls [m^3/h]**	**Inflow through external walls [m^3/h]**	**Mechanical inflow [m^3/h]**	**Mechanical outflow [m^3/h]**
1)	490	480	330	330
2)	571	561	299	299
3)	10	0	714	714

Table 4.9: Energy consumption for case 1, 2 and 3 over Summer.

Case	**Heating units in twin room [kWh]**	**AHU heating [kWh]**	**Fans [kWh]**
1)	0	0	1505
2)	0	0	1488
3)	0	0	1671

4.3.2 PCM in ceiling

Three different amounts of PCM in the twin room's ceiling were simulated. The different cases are listed below.

1. Motorized windows open according to PI temperature control (base model)
4. Case 1 with h_{PCM} = 0.005 m
5. Case 1 with h_{PCM} = 0.02 m
6. Case 1 with h_{PCM} = 0.1 m

Temperature

Figure 4.5 displays the operative temperature in the zone during a warm working week (Monday - Friday) in Summer. The blue line shows the temperature variation for case 1, the red line for case 4, purple for case 5 and the green line for case 6.

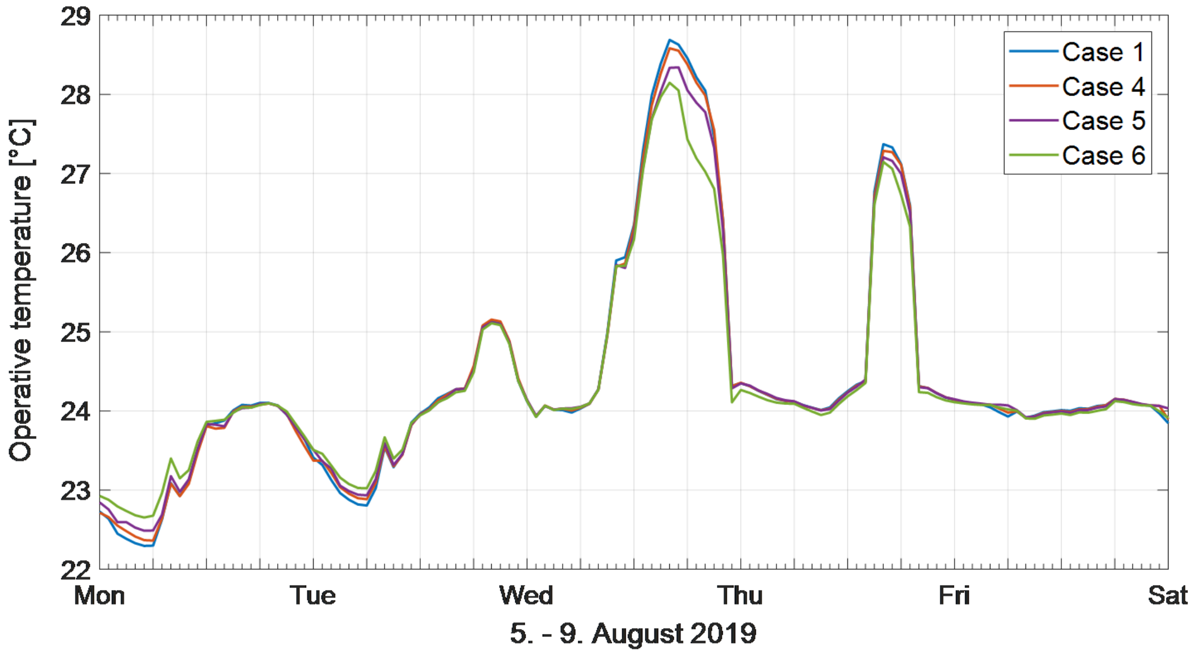

Figure 4.5: Temperature variation for a week in Summer with different amounts of PCM in ceiling.

The average temperature and the maximum temperature for each case over the week is displayed in table 4.10.

Table 4.10: Temperatures for case 1, 4, 5 and 6 over a week in Summer.

Case	Average temperature [°C]	Maximum temperature [°C]
1)	24.4	28.7
4)	24.4	28.6
5)	24.4	28.3
6)	24.4	28.1

Energy

Table 4.11 shows the airborne net heat flows into the twin room through external walls and mechanical ventilation. Table 4.12 shows the airflow in the twin room, in/out through external walls and mechanical ventilation. The values are presented as an average over that specific week.

Table 4.11: Average airborne net heat flows into the twin room for case 1, 4, 5 and 6 over a week in Summer.

Case	Net heat inflow through external walls [W]	Net heat inflow from mechanical ventilation [W]	Total net heat inflow [W]
1)	-513	-417	-930
4)	-500	-423	-923
5)	-487	-429	-916
6)	-457	-421	-878

Table 4.12: Average air flows in twin room for case 1, 4, 5 and 6 over a week in Summer.

Case	Outflow through external walls [m^3/h]	Inflow through external walls [m^3/h]	Mechanical inflow [m^3/h]	Mechanical outflow [m^3/h]
1)	490	480	330	330
4)	477	467	332	332
5)	445	436	330	330
6)	404	395	310	310

The energy usage for the AHU is displayed in table 4.13, in addition to the energy used for heating in the twin room. The values are presented as a total over the Summer (June, July and August). The amount of PCM in the ceiling in the twin room is the only parameter which was altered for the different scenarios, all other parameters are the same in each case.

Table 4.13: Energy consumption for case 1, 4, 5 and 6 over Summer.

Case	Heating units in twin room [kWh]	AHU heating [kWh]	Fans [kWh]
1)	0	0	1505
4)	0	0	1509
5)	0	0	1508
6)	0	0	1503

4.3.3 Altered occupancy pattern

The effect of altering the occupancy in the twin room is displayed in the following sections. Case 1 is the base model and case 7 is the base model with altered occupancy. Figure 4.6 displays the operative temperature in the zone during a warm working week (Monday - Friday) in Summer. The blue line shows the temperatures for case 1 and the red line for case 7.

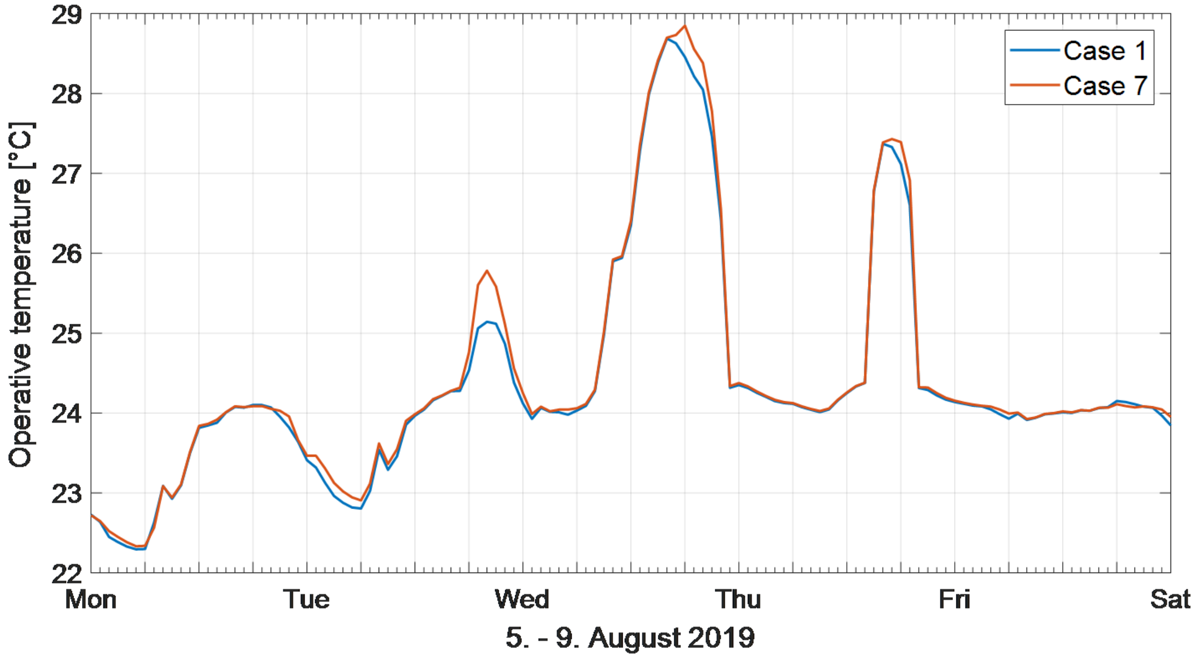

Figure 4.6: Temperature variation for a week in Summer with altered occupancy.

The average temperature and the maximum temperature for each case over the week is displayed in table 4.14.

Table 4.14: Temperatures for base model and base model with overtime over a week in Summer.

Case	**Average temperature [°C]**	**Maximum temperature [°C]**
1)	24.4	28.7
7)	24.5	28.8

The energy consumption for various elements in the building regarding case 1 and 7 is displayed in table 4.15, and the values are presented as a total over the Summer (June, July and August). The heat released from occupants into the twin room is also included in the table. Additionally, the heat released into the zone from technical equipment and lighting is modeled to be 100% of the energy consumption.

Table 4.15: Energy usage for base model and base model with overtime over Summer.

Energy post	**Energy used in base model [kWh]**	**Energy used with overtime [kWh]**
Heating in twin room	0	0
Tech.eq. in twin room	280	330
Lighting in twin room	262	340
AHU heating	0	0
Fans	1505	1516
Pumps	1	1
Energy post	**Energy released in base model [kWh]**	**Energy released with overtime [kWh]**
Occupants in twin room	1126	1209

4.3.4 Altered occupancy and opening of windows

Three different scenarios of opening controls of windows in combination with altered occupancy were simulated for the twin room, which are listed below.

7. Case 1 with altered occupancy
8. Case 2 with altered occupancy
9. Case 3 with altered occupancy

Temperature

Figure 4.7 displays the operative temperature in the twin room during a warm working week (Monday - Friday) in Summer. The blue line shows the temperature variation for case 7, the red line for case 8 and the green line for case 9.

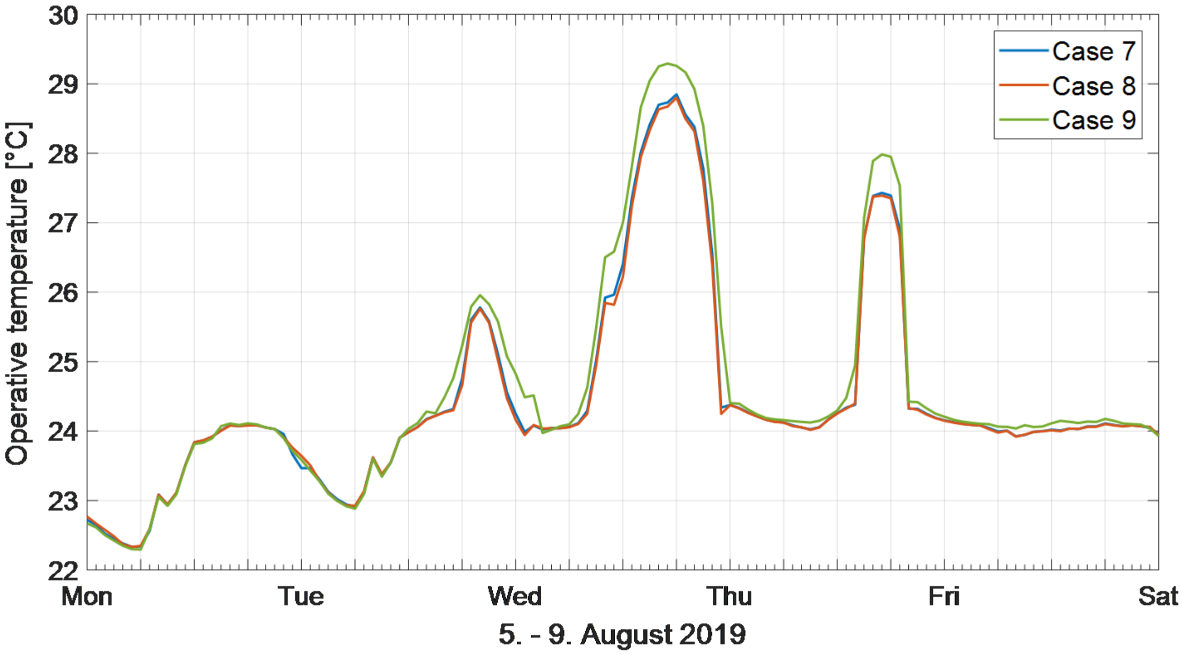

Figure 4.7: Temperature variation for a week in Summer with altered occupancy and different control opening of windows.

The average temperature and the maximum temperature for each case over the week is displayed in table 4.16.

Table 4.16: Temperatures for case 7, 8 and 9 over a week in Summer.

Case	Average temperature [°C]	Maximum temperature [°C]
7)	24.5	28.8
8)	24.4	28.8
9)	24.6	29.3

Energy

Table 4.17 shows the airborne net heat flows into the twin room through external walls and mechanical ventilation. Table 4.18 shows the airflow in the twin room, in/out through external walls and mechanical ventilation. The values are presented as an average over the specific week.

Table 4.17: Average airborne net heat flows into twin room for case 7, 8 and 9 over a week in Summer.

Case	Net heat inflow through external walls [W]	Net heat inflow from mechanical ventilation [W]	Total net heat inflow [W]
7)	-594	-429	-1023
8)	-626	-404	-1030
9)	-1	-918	-919

Table 4.18: Average air flows in twin room for case 7, 8 and 9 over a week in Summer.

Case	Outflow through external walls [m^3/h]	Inflow through external walls [m^3/h]	Mechanical inflow [m^3/h]	Mechanical outflow [m^3/h]
7)	582	572	346	346
8)	684	673	311	311
9)	11	0	813	813

The energy used in the AHU on building level is shown in table 4.19, in addition to the energy used for heating in the twin room. The values are presented as a total over the Summer (June, July and August). The opening control of windows and overtime in the twin room are the only parameter which were altered for the different scenarios, all other parameters are the same in each case.

Table 4.19: Energy usage for case 7, 8 and 9 over Summer.

Case	Heating units in twin room [kWh]	AHU heating [kWh]	Fans [kWh]
7)	0	0	1516
8)	0	0	1497
9)	0	0	1704

4.3.5 Altered occupancy and PCM in ceiling

Three different amounts of PCM in the ceiling in combination with altered occupancy were simulated for the twin room, which are listed below.

10. Case 4 with altered occupancy pattern
11. Case 5 with altered occupancy pattern
12. Case 6 with altered occupancy pattern

Temperature

Figure 4.8 displays the operative temperature in the zone during a warm working week (Monday - Friday) in Summer. The blue line shows the temperature variation for case 7, the red line for case 10, the purple line for case 11 and the green line for case 12.

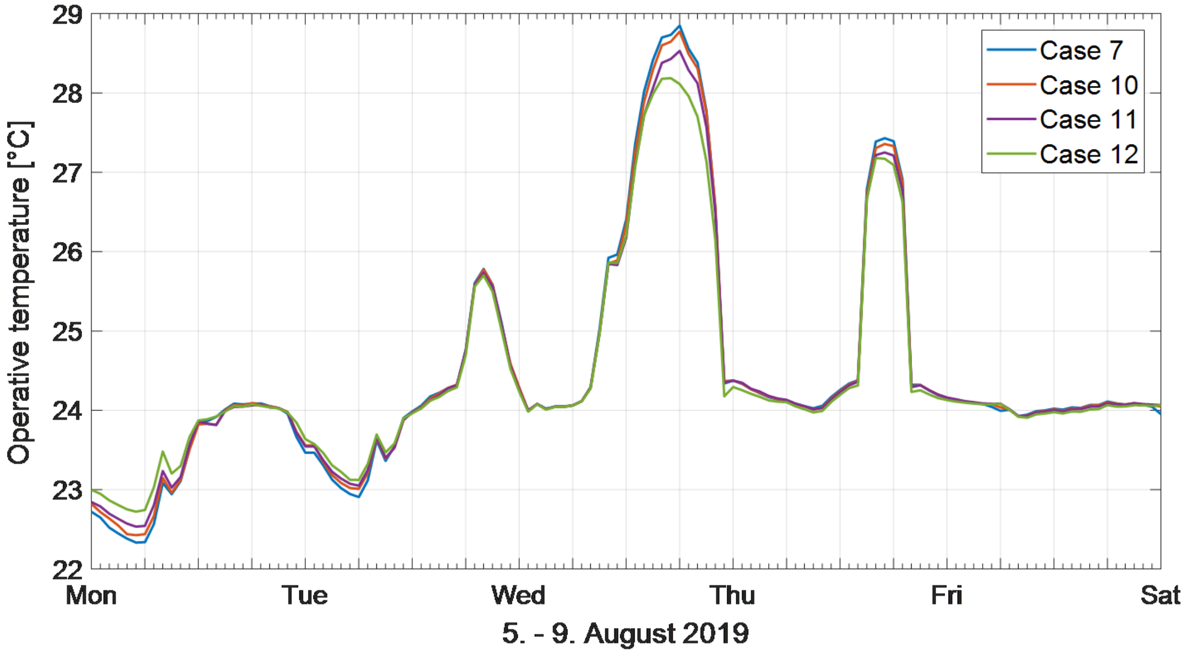

Figure 4.8: Temperature variation for a week in Summer with altered occupancy pattern and different amounts of PCM.

The average temperature and the maximum temperature for each case over the week is displayed in table 4.20.

Table 4.20: Temperatures for case 7, 10, 11 and 12 over a week in Summer.

Case	**Average temperature over the week [°C]**	**Maximum temperature [°C]**
7)	24.5	28.8
10)	24.5	28.8
11)	24.4	28.5
12)	24.4	28.2

Energy

Table 4.21 shows the airborne net heat flows into the twin room through external walls and mechanical ventilation. Table 4.22 shows the airflow in the zone, in/out through external walls and mechanical ventilation. The values are presented as an average throughout the specific week.

Table 4.21: Average airborne net heat flows into twin room for case 7, 10, 11 and 12 over a week in Summer.

Case	**Net heat inflow through external walls [W]**	**Net heat inflow from mechanical ventilation [W]**	**Total net heat inflow [W]**
7)	-594	-429	-1023
10)	-583	-434	-1017
11)	-571	-439	-1010
12)	-546	-429	-976

Table 4.22: Average air flows in twin room for case 7, 10, 11 and 12 over a week in Summer.

Case	**Outflow through external walls [m^3/h]**	**Inflow through external walls [m^3/h]**	**Mechanical inflow [m^3/h]**	**Mechanical outflow [m^3/h]**
7)	582	572	346	346
10)	570	559	348	348
11)	539	528	346	346
12)	484	473	324	324

The energy used in the AHU in building level is shown in table 4.19, in addition to the energy used for heating in the twin room. The values are presented as a total over the Summer (June, July and August). The amount of PCM in the ceiling and overtime in the twin room are the only parameters which were altered for the different scenarios, all other parameters are the same in each case.

Table 4.23: Energy usage for case 7, 10, 11 and 12 over Summer.

Case	**Twin room heating [kWh]**	**AHU heating [kWh]**	**Fans [kWh]**
7)	0	0	1516
10)	0	0	1519
11)	0	0	1517
12)	0	0	1513

Chapter 5

Discussion

This chapter will analyse and discuss the selected method and obtained result for this thesis, such as advantages, weaknesses and uncertainties. Additionally, simplifications and approaches which were conducted.

5.1 Building performance simulation

It was selected to use the software IDA ICE to conduct the various tasks of this master thesis. However, other BPS software may also be suited to perform the same procedures. Taking into account the information presented in section 2.6.1, as well as other relevant factors, the following can be concluded regarding using BPS for the ZEB Lab.

Firstly, SIMIEN was evaluated to not be comprehensive enough to represent a detailed modeling of the building and is therefore poorly suited of this purpose. Secondly, TRNSYS would require more workload since the software can not import AutoCad files. This can be seen as unnecessary usage of time considering the time limitation for this thesis. Another aspect to consider is the necessary competence and skills to operate the BPS software. Taking that into account, ESP-r might be unsuited considering the user does not have any knowledge of the software. The main advantage of IDA ICE compared to EnergyPlus is the visualisation of the building in 3D. However, it would require more in depth understanding of the different software and the various modeling possibilities of each to give a more extensively conclusion. Another thing to point out, is that this evaluation is based on the skills which the user inhabits.

5.2 The main model of ZEB Lab

The following paragraphs will discuss the main model, such as its appropriateness, advantages and weaknesses. Additionally, some adjustments and simplifications which were conducted, as it is not realistic to create an exact replica of a building in a BPS software.

5.2.1 Appropriateness, advantages and weaknesses

Previously had SIMIEN been used in the project to document the energy requirements in accordance with TEK17. IDA ICE has the possibility of more detailed modeling compared to SIMIEN, which results in a more accurate representation of the building ZEB Lab and all its technicalities. Accordingly, this will most likely result in more accurate results. An overall advantaged of creating a model in a comprehensive BPS tool, is that it enables the possibility of simulating the future research experiments which will take place at the ZEB Lab.

Specific values from the project have been used for the simulation model when suitable and appropriate. Values from SN/TS 3031:2016 were used when no specific data regarding the project were stated. As mentioned in section 2.1, SN/TS 3031:2016 has been withdrawn and replaced by SN-NSPEK 3031:2020. This took place after the work of this thesis had begun and SN/TS 3031:2016 was therefore used.

For this thesis were mainly four zones created for each floor by taken into account the effect of solar radiation. Several zones can be created in order to achieve the most detailed representation of the building. However, as previously mentioned in section 2.6.2, the amount of zones created does not greatly affect the results of the overall energy performance. Additionally, a drawback by creating a very detailed model is that results in a increase of the simulation time in IDA ICE.

Furthermore, there are many ways in which the creation of the model in IDA ICE could be developed. This depends on what the interest point of utilizing BPS is, for instance studying air flows, thermal environment, overall energy usage ect. An advantage of the model is the establishment of two individual zones for the twin rooms. This enables to investigate measures which are planned to be performed for these rooms in the future.

As described in section 3.1.6, the main staircase in the building will be used as extract for the ventilation. This was not modeled in IDA ICE, and the open stair case was included in the middle zone for each story seeing as the temperature will be approximately equal. Implementation of an open staircase as extraction for ventilation airflow could be included in further modeling of the ZEB Lab. However, it is not possible to model horizontal openings in IDA ICE. Moreover, when the building operates on natural ventilation will the extraction of air occur due to thermal buoyancy. If the stair case is modeled as a single zone, is it significant that temperature differences occurs within the zone in the simulation model.

Moreover, specification uncertainties are present for the model in some extent. Assumptions were made regarding setpoints for a few components in the building, since this has not been decided yet. An example is the setpoint for when the lighting should be dimmed in relation to the amount of daylight in the zone. The model developed in IDA ICE can in the future be adjusted and refined after the test operation for the ZEB Lab is done. In that way, the established setpoints can be implemented.

Furthermore, validation of the model in IDA ICE was not done since the building is still under construction. Validation of a simulation model is important in order to check if it is an accurate representation of the physical building. For further modeling should this be conducted, by comparing the energy usage from the simulation model in table 4.2 with the measured energy for the building. Firstly should as build documentation be obtained and compared to the model, which was developed based on available information from design documentation.

As previously mentioned, displacement ventilation is currently only limited to zones with a rectangular shape in IDA ICE. Most of the modeled zones does not have a rectangular shape and displacement ventilation was thus no included for these. Furthermore, PCM was not included in the model of ZEB Lab. At this moment, IDA ICE have the possibility to add PCM as a layer to a construction element, such as walls and roof. In this way, the PCM is used passively and responds to temperature changes in the zone. For the ZEB Lab, the PCM will be used actively. This is a weakness of the model, and is related to the modeling possibilities and knowledge for the selected BPS tool.

5.2.2 Approaches and simplifications

As mentioned in section 3.2.7, the two sloped walls was not modeled with this shape in IDA ICE. Instead was the walls modeled with an L shape and defined as external walls to account for the heat losses which will occur. This will most likely have a minor impact on the energy performance of the building. This is because the area towards the outside air is approximately the same, meaning that the transmission heat losses will be somewhat equal.

Furthermore, by using the function "connect to face" is the wall thermally connected to a selected facade of the building. This means that the orientation of the sloped walls in IDA ICE is different from the actual building. However, the difference is relatively small and at the most 25° deviation. The wall set towards north will experience slightly less solar exposure while the wall set towards east will experience more.

The PV panels was only modeled on the roof, and other programs can be used to simulate the energy production from PV panels separately, for example PVsyst. Hence, the total energy production from PV panels installed on the building will be larger then what is displayed in table 4.1.

5.2.3 Problems and observations

During the time of work several problems, challenges as well as observation related to IDA ICE occurred. This section will present some of them. Firstly, during the project assignment was the designed power for the heating system obtained form the system schematics for heating from the design documentation to the project and implemented into IDA ICE. This resulted in some illogical values. Therefore, the design power for each radiator were sized in IDA ICE by conduction a "heating load" simulation during the master thesis.

In SN/TS 3031:2016, the temperatures for office buildings are stated to be 21°C during operation hours and 19°C outside of this. However, when this was implemented in IDA ICE, the results displayed some unreasonable values. It resulted in a extremely high power demand when performing the "heating load" simulation in IDA ICE, which is the function used to size the heating system. This seemed very illogical and was thus not included in the model. Further work may be to investigate this closer. Moreover, this problem is is also related the level of competence and expertise about the software the user inhabits, which is a uncertainty to consider.

5.3 Future research

The section will present potential need for BPS for future research and development work planned to be conducted at the ZEB Lab. The building ZEB Lab will be used for research purposes and BPS can be a vital tool in that context. Several factor should be considered when selecting which BPS tool to utilize, such as, does the software have the ability to perform the set task.

Another software which has the possibility of modeling PCM as part of the energy system should be used instead, if analysis of PCM will be conducted in the future, since this was not included in the model.

Moreover, research regarding displacement ventilation can be problematical to perform for the areas on the west side of the building. This is because the displacement ventilation function is only limited to rectangular zone and the west external walls is not perpendicular with regard to the south external wall. Neither is the north-west wall with regard to the north wall.

On the other side, the developed model of ZEB Lab in IDA ICE can be a great foundation for further modeling and research, seeing as IDA ICE have many functions in the software. It is possible to merge and split zones in IDA ICE as the user sees fitting, which offer many investigation possibilities. For instance, the building ZEB Lab will be constructed so that the south facade on the second floor can be altered. This can be conducted without difficulty in the IDA ICE model, since the twin rooms were created as individual zones.

5.4 Altered solutions of ZEB Lab

As previously stated, the initial idea was to study the different research experiments which are planned to be carried out at the ZEB Lab for the model in IDA ICE. This was not conducted for this master thesis, but the developed model can be used for these research experiments in the future.

5.4.1 Simplified model

When conducting analysis of various altered solutions in the twin rooms, was the main model of ZEB Lab simplified. By studying table 4.2 and 4.4, the overall difference between the energy usage for main and simplified model is relatively moderate. Moreover, the difference between the energy balance for the twin rooms in table 4.3 and 4.5 are minor. Therefore, the results from the altered solutions in the simplified model can be expected to have the same outcome if the they were applied to the twin rooms in the main model. Moreover, this indicated that a simulation model can be simplified in a appropriate way if elements in a single zone are analysed.

Originally was the idea to apply the alternated solutions to twin room 1 and compare the outcome to twin room 2 (where no parameters were changed). Despite this, it was observed that the difference in energy usage for the two rooms were too large (see table 4.3). This is because twin room 1 has two external walls, whereas twin room 2 only has one, resulting in less transmission and infiltration losses. As a result, the twin rooms were merged together as one zone and several simulations were carried out instead. In that way, the different simulations were compared to each other. The same location and weather file was used for all simulations.

5.4.2 Opening of windows

By studying figure 4.4, it is clear that there is no significant difference between case 1 and 2 regarding the temperature over the selected week. In case 2, the total number of windows with temperature control are increased by six windows. Therefore, it can be concluded that this makes a relative small contribution in lowering the temperature. This can also be seen in table 4.6, where the temperature difference is almost negligible. If all the windows in the zone could be opened, the difference might be larger.

Moreover, a more notable difference can be observed between case 1/2 and 3 during the warmest days of the week: Tuesday, Wednesday and Friday. The maximum temperature during the week is increased by 0.5°C for case 3.

Furthermore, all the cases result in roughly the same temperatures for Monday and Friday. This is most likely due to the setpoint temperature for cooling (24°C) and the temperature regulated ventilation. For case 3 where all windows are closed will the ventilation supply more air in order to maintain the setpoint temperature. Whereas, for case 1 and 2 will the airflow through the windows contribute to remove heat from the zone, and thus the ventilation supplies less air. This is clear by studying table 4.8, where the mechanical airflow is twice the size for case 3 compared to case 2. This is because the ventilation is used more actively since it must compensate for the closed windows. This can also be observed in table 4.7. Consequently, case 3 result in a larger energy usage for the fans.

In table 4.9, the energy used for fans is increased by 10% for case 3 and decreased by 1% for case 2 compared to case 1. If the alternated solutions were applied to the entire building would the difference in energy usage probably be larger, since the energy used for fans is displayed on building level. Overall, the positive effect on both the thermal environment and energy usage of installing passive cooling measures are clear by studying the results from group 1.

5.4.3 PCM in ceiling

Figure 4.5 shows that the implementation of PCM in the ceiling reduces the temperature fluctuations, and the effect is more notable with increasing amount of PCM. This is due to the storage capacity, as the this will increase with increasing volume of the PCM, using on equation 2.1. Moreover, the difference in temperature is minor during the day on Monday, Tuesday and Friday. This is due to the ventilation and cooling setpoint (24°C), same as for group 1. In IDA ICE is VAV used first when both VAV and other means of cooling have been defined. Therefore, the temperature regulated ventilation will actively remove heat from the zone. Moreover, for Wednesday and Thursday when the ventilation and opening of windows are not sufficient enough to keep the temperature in the zone below 24°C, the effect of PCM is more prominent.

At the most, the installation of PCM reduces the maximum temperature by 0.6°C and the reduction in energy usage for the fans is almost insignificant. Moreover, an installation of PCM should also be evaluated from an economical perspective as well. This was not included in this report. Nonetheless, it can be assumed that the installation is more expensive compared to the savings it results in, considering the energy reduction is minor. The effect of installing PCM as a part of the wall could be included in a further study.

Case 4 and 5 shows some strange values regarding the mechanical ventilation and energy usage for fans. The overall air exchange in the zone are decreased from the base case, which were expected. Moreover, the total net inflow decreases with increasing PCM in the ceiling. However, the mechanical ventilation supply is the same for case 1 and 5, and a higher value is seen for case 4. During the work period were several variations of the model in IDA ICE simulated as knowledge and skills about the software improved. For instance, all the cases were first simulated with completely mixed ventilation. The results showed that both the mechanical and natural air exchange is the zone were reduced for all the cases with PCM. Therefore, it can be assumed that the displacement ventilation function affect the relation between the ventilation and opening of windows. This should be looked into further.

An uncertainty with the results, is the effect the surrounding areas have on the PCM. Since the PCM was added as a layer in the ceiling will the zone above the twin room also likely be effected. However, the extent of this was not investigated.

5.4.4 Altered occupancy

Analysing the results presented in chapter 4.3.3, it is clearly that the simulation of people working overtime have an effect on both the temperature and energy usage. In chapter 2, the presence and modeling of occupants were presented. The results in this thesis clarifies the effect modeling of occupants in a BPS software have on achieving realistic results. For the ZEB Lab it is likely that people will be present at the building beyond the time schedule in SN/TS 3031:2016. However, it is challenging to predict the load variation from occupants. The amount of people that will be working overtime will vary over the year and can be expected to be more notable close to deadline etc.

An uncertainty with the results, is in how great extent the presence of occupant affect the energy usage for technical equipment. Considering the load variation for technical equipment have the same pattern as heat released from occupants in SN/TS 3031:2016 (see figure 3.13), the relation between occupants and equipment could also be the same with overtime as well.

Altered occupancy and opening of windows

Several elements which are discussed in section 5.4.2 (opening of windows without overtime) also applies here. The three cases in group 3 have approximately the same pattern and effect as for group 1. Hence, case 8 where both manually and mechanical windows open according to PI temperature control, have the best results.

Altered occupancy and PCM in ceiling

Several elements which are discussed in section 5.4.3 (PCM in the ceiling without overtime) also applies here. The three cases in group 4 have approximately the same pattern and effect as for group 2. Hence, case 12 with the largest volume of PCM in the ceiling have the best results.

5.4.5 Uncertainties

An uncertainty related to all the simulated cases are the operation temperature. A heating setpoint of 19°C outside operation time was not included in the model due to unreasonable values. Therefore, the temperatures during nighttime might be lower than what is displayed in the results. However, this is a continuous error and it can be assumed that the relation between the different cases would be the same.

Chapter 6

Conclusion

The purpose of this master thesis was to establish a simulation model of the new building "ZEB Laboratoriet". This was conducted by utilizing the dynamic simulation software IDA ICE. Information about the building was acquired from the design documentation in order to create the model, and some simplifications and approaches were done when developing the model in IDA ICE. For instance, displacement ventilation was not included for most of the zones since it is limited to zones with a rectangular shape in IDA ICE.

The simulation model developed during this thesis can be used for the future research and development work planned to be conducted at the "ZEB Laboratoriet". However, this is dependent on whether the set tasks corresponds with the modeling possibilities in IDA ICE. Moreover, as build documentation must be obtained and compared to the input data for the model. Further on, validation of the model in IDA ICE should be conducted when the actual energy consumption in the building is measured.

Several alternations of the building design were simulated and analysed for two rooms in the building, the twin rooms. The results show that both cooling measures, windows with temperature regulation and PCM in the ceiling, have a positive effect on the thermal environment. Furthermore, simulation of people working overtime shows how the input values regarding occupancy in the building in a BPS tool affect the resulted energy usage.

The largest simulated volume of PCM result in the lowest maximum temperature, with a decrease of 0.6°C. Additionally, the negative consequences by installing windows which can never be opened in a room are clear, as the maximum temperature in the zone is increased by 0.5°C. Moreover, the energy usage was reduced for most of the cooling measures, but none resulted in a considerable reduction. An exception is energy usage for four cases with PCM, and the relation between air supply through windows and displacement ventilation should be analysed further.

To which extent an installation is economical beneficial is a factor to consider. Taking into account that PCM in ceiling results in minor energy reduction, it can be assumed that this would not result in cost savings. An uncertainty related to all the simulated cases are the operation temperature. However, considering this is a continuous error, it can be assumed that the results would display the same relation between the different cases.

Chapter 7

Further work

Further work related to building performance simulation of the "ZEB laboratoriet" may include the following:

- The developed model is based on design documentation and as built documentation should be obtained when available. Then, the model in IDA ICE can be adjusted if something has been altered in the construction process.
- When all the setpoints for the building is determined can the model in IDA ICE be adjusted with the correct values.
- After the test operation of the building is completed can the measured energy usage be compared with the result from IDA ICE. In that way can the model be evaluated, adjusted and validated.
- Investigate the effect of installing PCM in the walls of twin room.
- More detailed and extended modeling of the ZEB Lab in IDA ICE. For instance, inserting more zones.
- Consider using another BPS tool which has the possibility to include an actively used PCM-unit as a part of the energy system.
- Simulate the altered solutions which are to be installed in the building in IDA ICE when this is decided.

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Appendix A

Floor plans

The figures below show the floor plans of the ZEB Lab, in addition to the roof. The figures were obtained by communication trough emails with Hans Martin Mathisen September 2019.

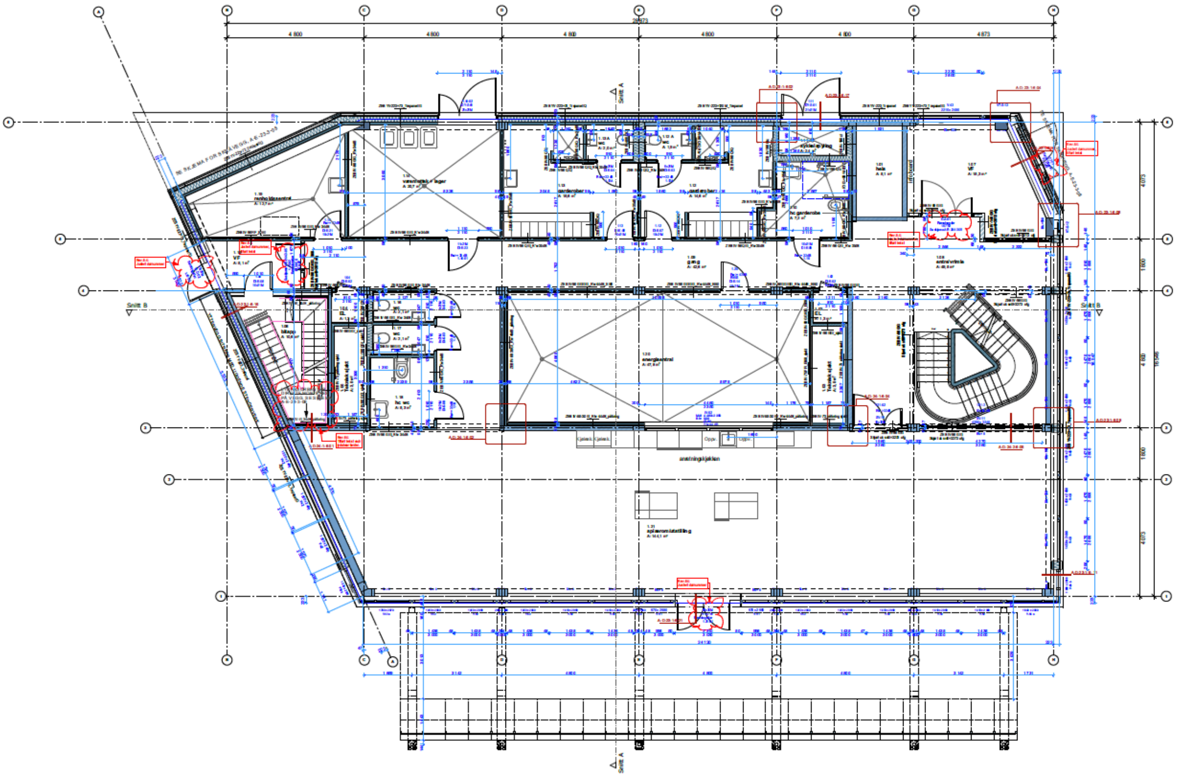


Figure A.1: Plan 1.

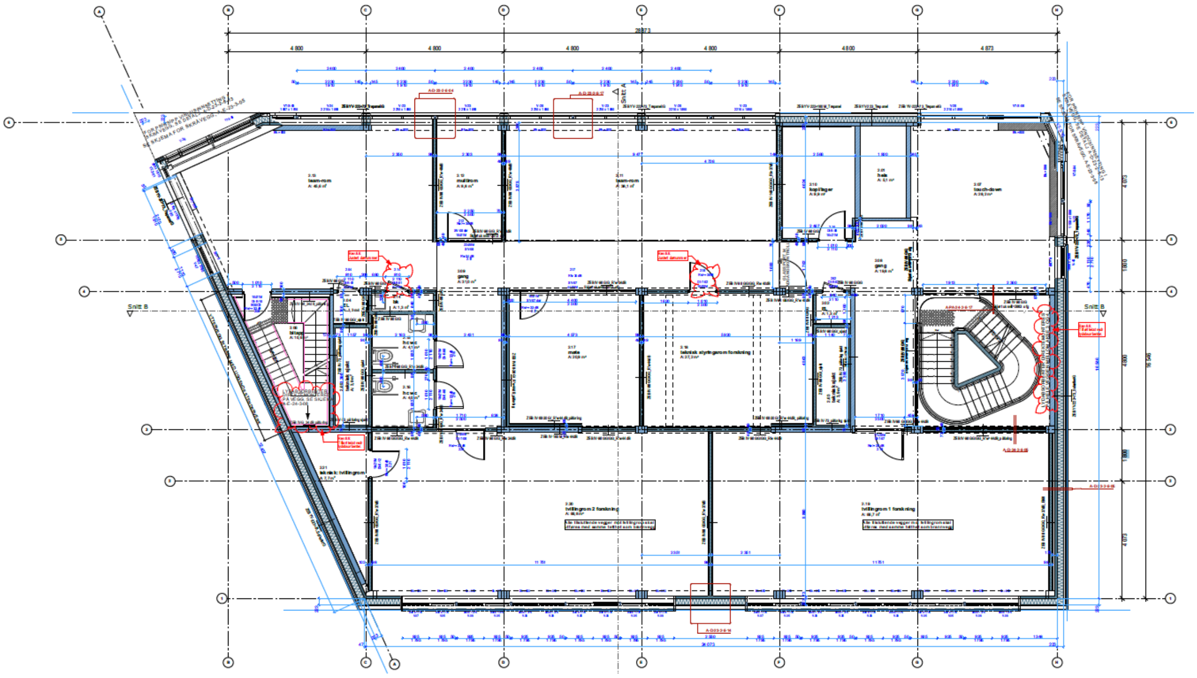


Figure A.2: Plan 2.

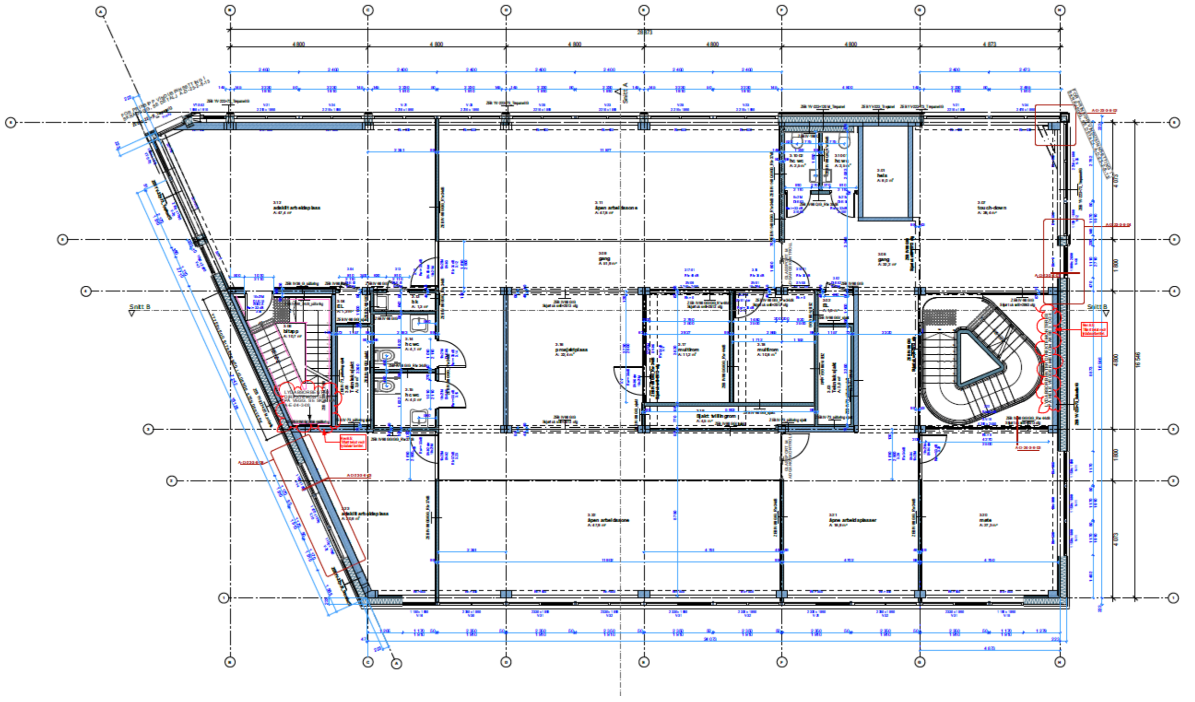


Figure A.3: Plan 3.

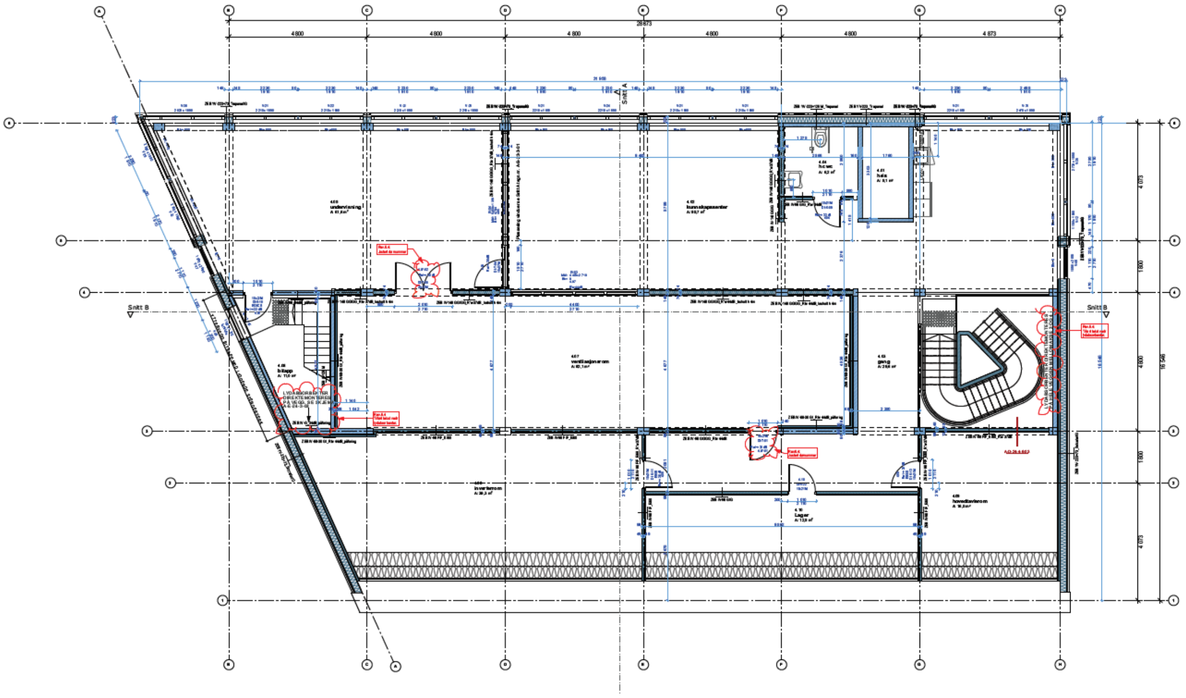


Figure A.4: Plan 4.

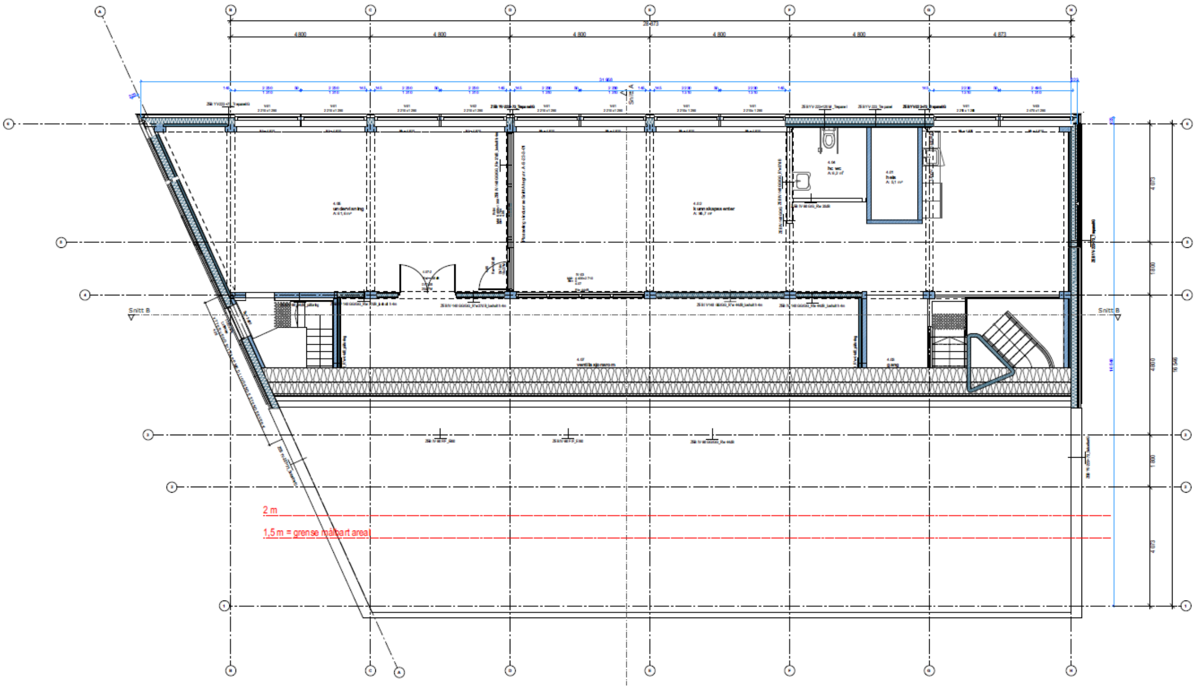


Figure A.5: Plan 4 upper part.

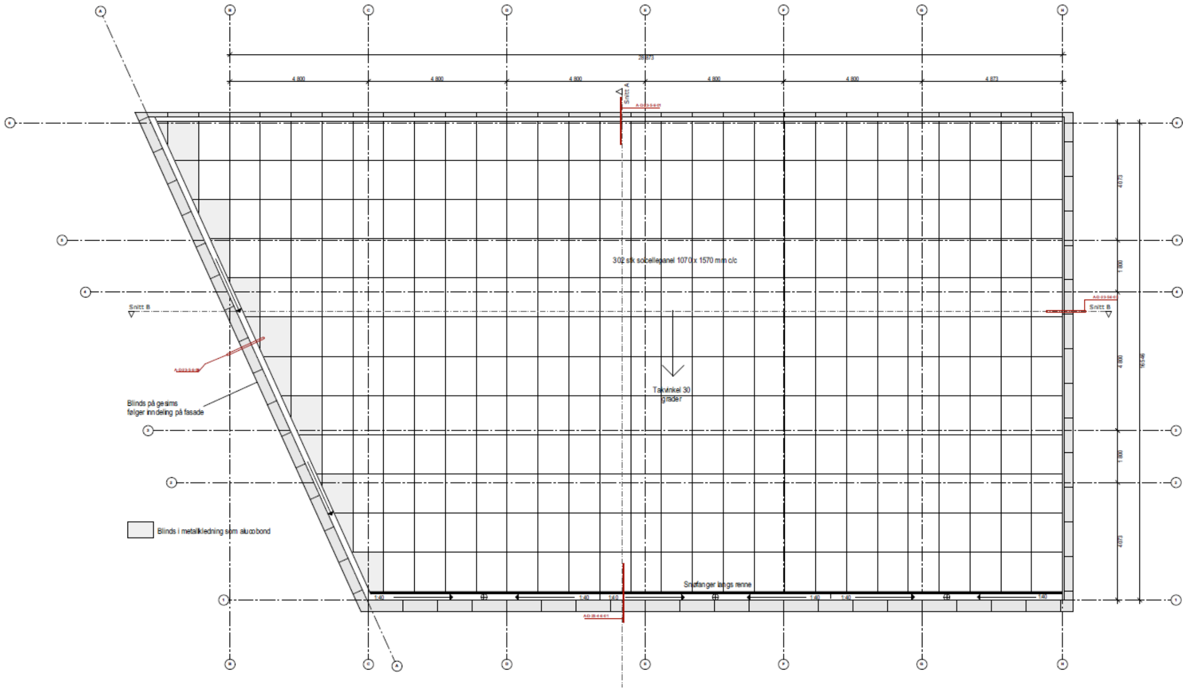


Figure A.6: Roof.

Appendix B

Facades

The following figures shows the facades, cross- and longitudinal section for the ZEB Lab. The figures were obtained by communication trough emails with Hans Martin Mathisen September 2019.

Figure B.1: The north facade.

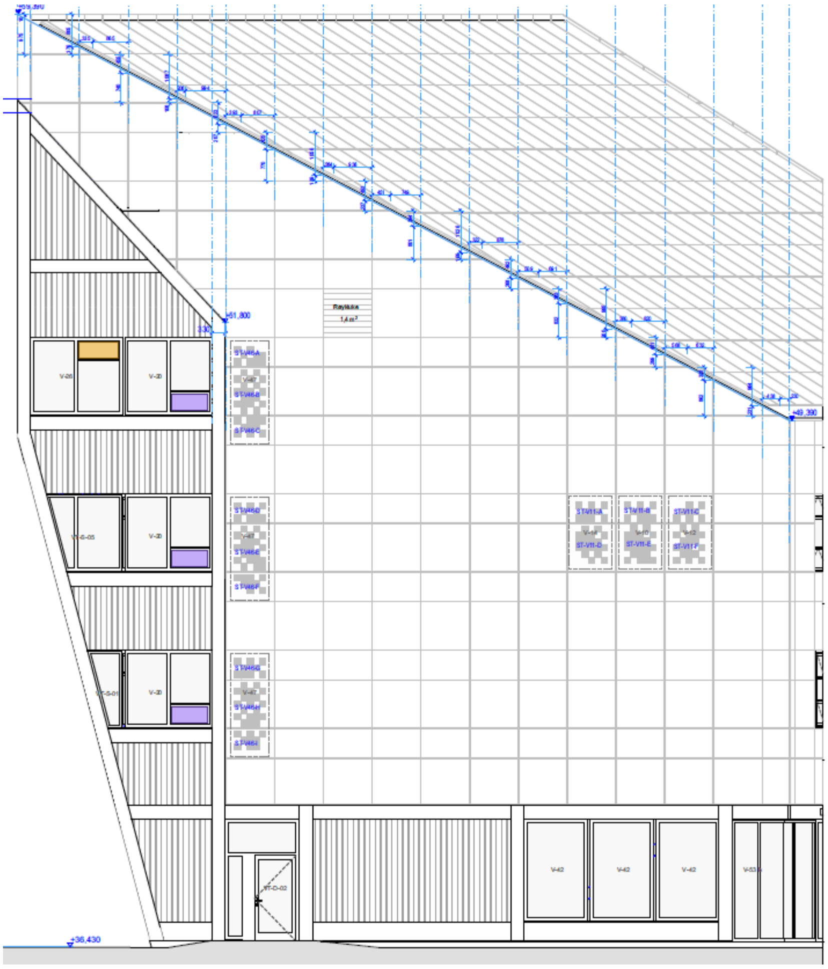


Figure B.2: The west facade.

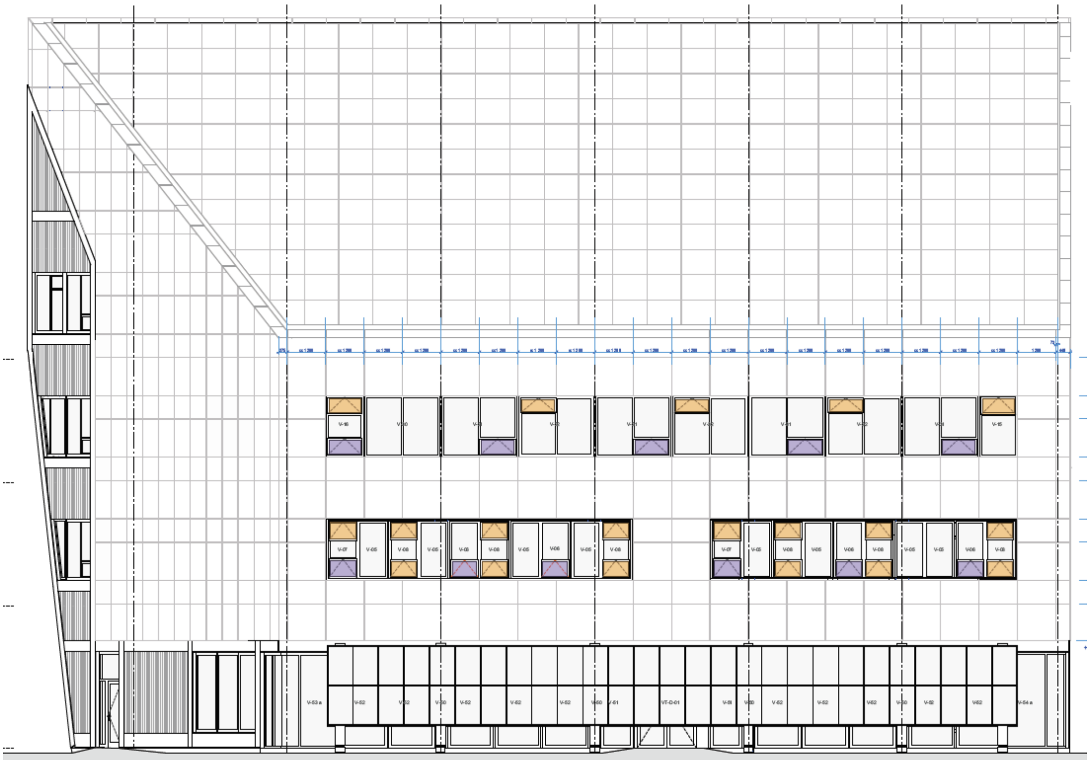


Figure B.3: The south facade.

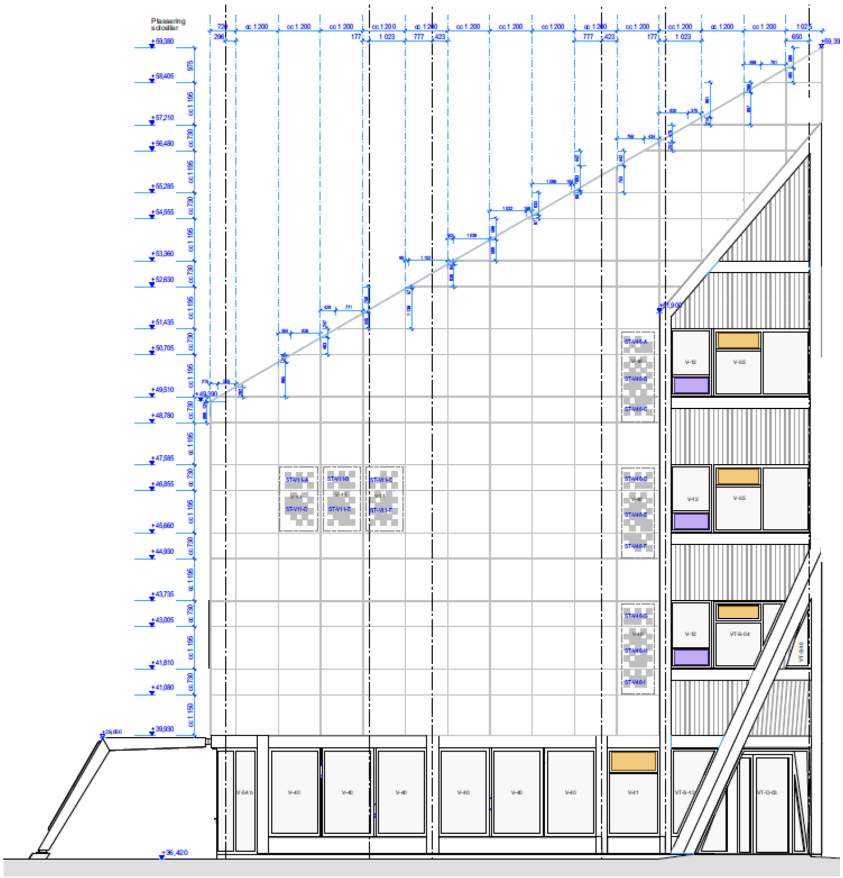


Figure B.4: The east facade.

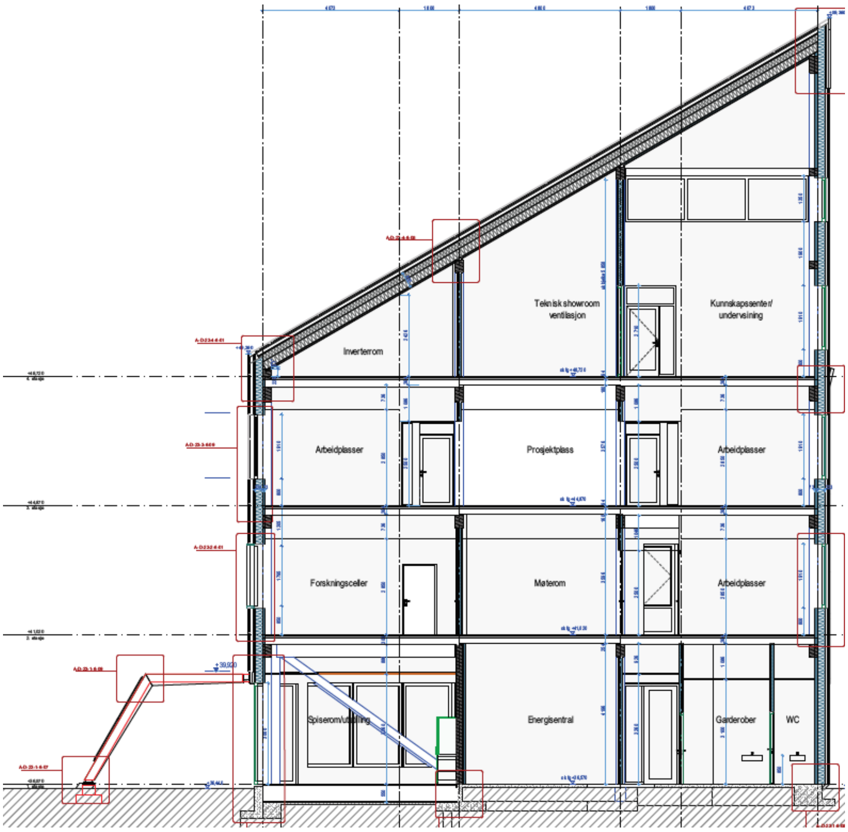


Figure B.5: Cross section of the building.

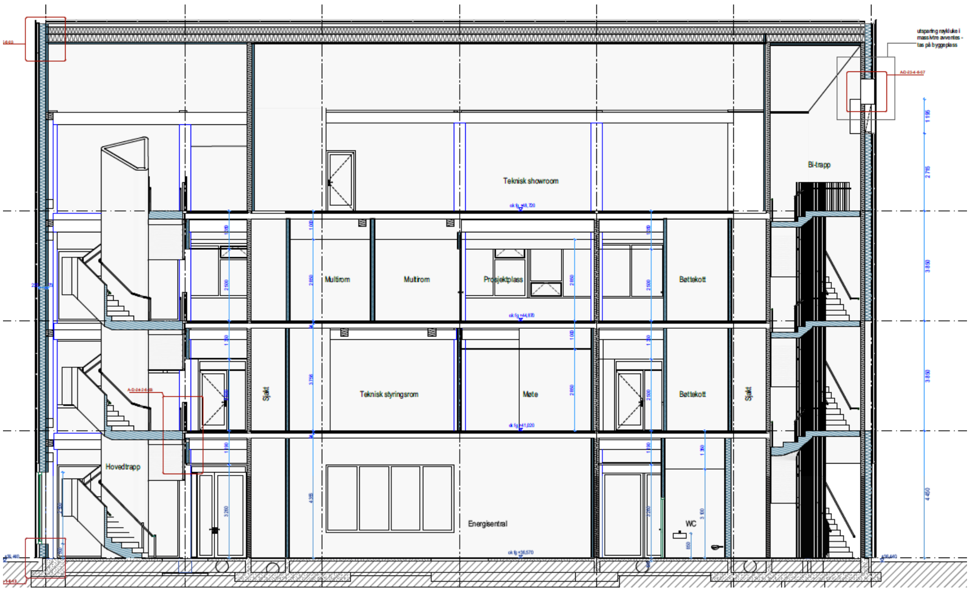


Figure B.6: Longitudinal section of the building.

Appendix C

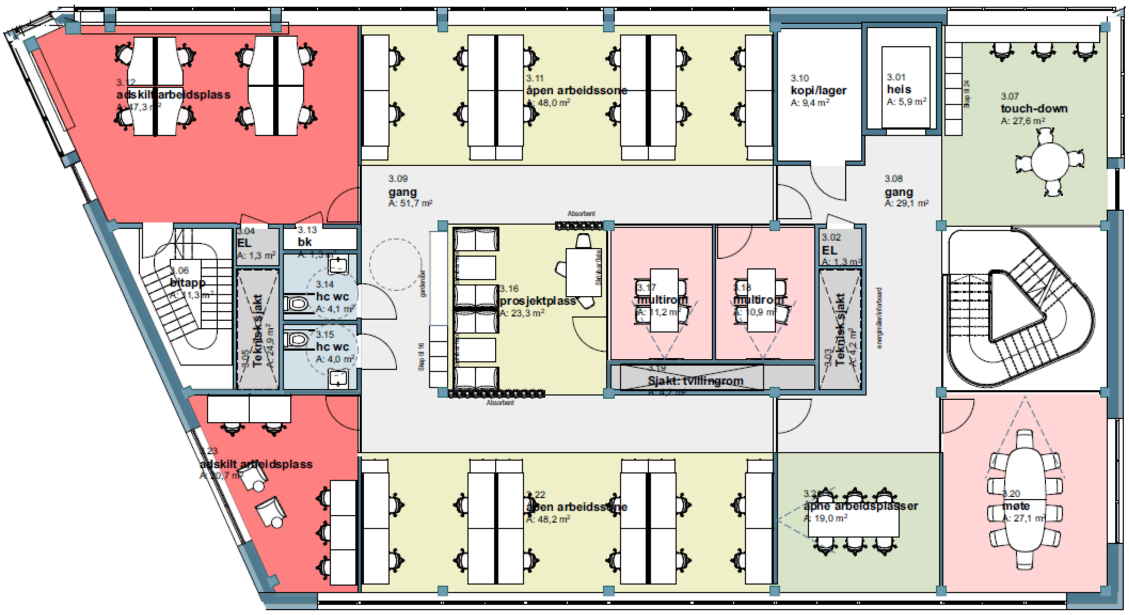
Furnishing plan

The following figures shows the furnishing plans for the ZEB Lab. The figures were obtained by communication trough emails with Hans Martin Mathisen September 2019.

Figure C.1: Ground floor.

37 arbeidsplasser, herav 2 testkontor
-Planlagt som "faste" arbeidsplasser, med personlig nærarkiv/oppbevaring
24 personlige skap

Figure C.2: First floor.



37 arbeidsplasser av ulik karakter, da ikke medtatt:
-Tilrettelagte plasser for arbeid i møterom, arbeids/lenestoler på fokus-sone, plasser i touch downsone, plasser i prosjektrom
40 personlige skap

Figure C.3: Second floor.

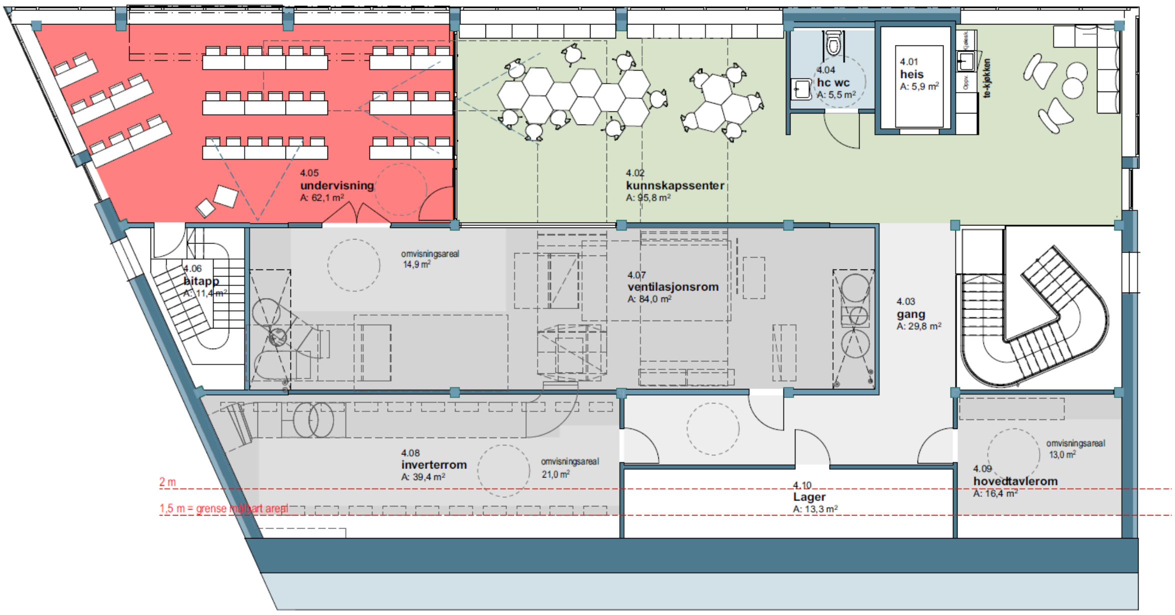


Figure C.4: Third floor.