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Performance evaluation of HVAC strategies for low-energy building retrofit

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and Process Engineering

EPT-M-2015-14

MASTER THESIS

for

Thea Marie Øygard Danielsen

Spring 2015

Performance evaluation of HVAC strategies for low-energy building retrofit

Evaluering av ytelsen til oppvarmings- og ventilasjons strategier i renoverte lav energi bygg

Background and objective

In the construction industry of today and of the future, there is a large focus on reducing the energy use in buildings. It is said that 80% of today's construction mass is to remain in 2050. In this sense, energy retrofit of existing constructions is necessary. Like new constructions, the rehabilitation will have to accept the demand for highly-insulated buildings, such as passive houses by 2015 or nearly zero-energy buildings (nZEB) by 2020. Even though the demands first and foremost apply to new buildings, similar demands will be included in future ambitions for rehabilitation of existing constructions.

The main goal of this master's thesis is to study investigate the indoor climate, the user comfort and efficiency when a building is renovated from a high-energy class (ex. "E" and "D") to a low-energy class (ex. "A" or passive house). A study of the challenges for HVAC systems in low-energy renovated buildings will be done as well a review of the HVAC development trend in the market. The HVAC strategy followed and the resulting indoor climate will be a central part of the problem. Investigations will be mainly based on a case study. The work is supported by *Hjellnes Consult.*

The following tasks are to be considered:

1. **Review** of the challenges for HVAC systems in building **renovated** to low-energy standards as well as of the HVAC development trend in the market.
2. Based on the **case study**, the HVAC strategy implemented in the renovation will be analyzed and its ability to obtain a satisfactory indoor climate (especially as regards ventilation).
3. Based on the case study, evaluate whether the focus on reducing the energy use in a building could potentially have an adverse **effect on the indoor climate**, with a focus on the psychological aspect through a survey (how the occupants experience the building/comfort).
4. Evaluate whether the results from the case projects can be **extended** other buildings.
5. As the work will be mainly performed at Hjellnes Consult, the student will make a **monthly comprehensive reporting** of her work progression to her supervisor.

Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Risk assessment of the candidate's work shall be carried out according to the department's procedures. The risk assessment must be documented and included as part of the final report. Events related to the candidate's work adversely affecting the health, safety or security, must be documented and included as part of the final report. If the documentation on risk assessment represents a large number of pages, the full version is to be submitted electronically to the supervisor and an excerpt is included in the report.

Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☐ Field work

Department of Energy and Process Engineering, 14. January 2015

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Preface

This work is a project on the performance of HVAC strategies for retrofitting of low-energy buildings, as a part of a masters degree at NTNU in Energy and Environmental Engineering, with a specialization in Energy and Indoor Environment. It was carried out in the spring of 2015 and was done in collaboration with the consulting engineer company Hjellnes Consult AS. The report studies the HVAC strategies in three different low-energy building retrofits, as well as the indoor environment and HVAC performance of the systems in the school building Stasjonsfjellet Skole in Oslo. The three case buildings were Fredrik Selmers vei 4, Grensesvingen 7 and Powerhouse Kjørbo. Hjellnes Consult were key to gain access and insight into the project documentation and other information on Stasjonsfjellet Skole. For Fredrik Selmers vei 4 and Powerhouse Kjørbo, Entra Eiendom were very helpful in providing information and insights. Similarly, Oslo Areal were highly accommodating with Grensesvingen 7. The work itself is meant for readers with a basic understanding of building physics and HVAC engineering.

Trondheim, 2015-06-10

Thea Marie Øygard Danielsen

Acknowledgements

In association with this work, I would like to thank the following people for their help. Firstly, to my NTNU supervisor, Laurent Georges, thank you for helping me and providing useful advice throughout the project. To my supervisor at Hjellnes Consult AS, Bjørn-Yngve Kinzler Eriksen, thank you for useful discussions, helpful insights and for following up on my work throughout the process. The whole idea behind this thesis came from Roar Smelhus from Hjellnes Consult, who supported me and inspired me to do this work in the first place, thank you for giving me this opportunity and for all your insights. Also, Henrik Ligaard Brynildsen, Ida Nordbotten Vågen, Marianne Algrøy and Marius Borg, in addition to many others at Hjellnes Consult, helped me both with information on Stasjonsfjellet Skole and with information and technical help on my IDA ICE model. This thesis would not have been possible without all of you. In addition to the Hjellnes Consult employees, thank you to Per Christian Holter from Heggelund og Koxvold AS Arkitekter MNAL who provided me with plenty of information on Stasjonsfjellet Skole. In order to see Stasjonsfjellet Skole and to perform a user survey on the employees, Pål Stette, the principal at the school, was of great help. From Entra Eiendom, Helge Stugård and Tom Riseth were highly accommodating and helpful in providing me the necessary information on Fredrik Selmers vei 4, and I am very grateful for our meeting and your cooperation. For Grensesvingen 7, Gunnar Moen from Oslo Areal and Asbjørn Mortensen from GK were insightful and helpful in providing me with both information and interesting perspectives on the project, and I am very grateful for it all. Although I already had the necessary information on Powerhouse Kjørbo from previous work, I would like to thank Tord Solvoll and Siri Steinbakk from Entra Eiendom for letting me use the information again and write about their interesting building. Lastly, I would like to thank Mie Fuglseth for her help with the report itself.

Summary

The work in this thesis is done to evaluate four different questions. A literature survey in addition to three case studies are first used to determine the challenges of HVAC systems in buildings renovated to low-energy buildings and the development trend in the market. The literature and case studies showed that client expectations and budget, policies and regulations, everything working as a whole, and a high level of occupant control were all challenges and important factors affecting the success of a construction project. The three case studies had various systems installed, including ground source heat pumps, air-to-water heat pumps, heat recovery in air handling units and solar screens to name a few. The choice of these, however, depended on the building characteristics and its environment.

The second part of the thesis evaluates firstly whether the HVAC systems in a school building, Stasjonsfjellet Skole, is able to achieve a satisfactory indoor climate, as well as whether the focus on reducing the energy use in the building has an adverse effect on the indoor climate. Through IDA ICE simulations of the building, in addition to a user survey, the HVAC systems were concluded to provide a somewhat sufficiently satisfactory indoor climate in the parts of the building, but not for every zone. Some of the zones had very high temperatures, daylighting levels and PPD levels. Furthermore, the users complained that the temperature in the building in general was too low. Although this was not consistent with temperature results from IDA ICE, the simulations showed a low RH level in the colder months of the year, which may cause discomfort for occupants even at moderate temperatures (Novakovic, et al., 2007). Furthermore, the generalization of the standards and regulations was concluded to result in the building having variable indoor climate levels from room to room, indicating that the generalized values are not adapted for the different requirements of the different rooms.

I addition to the conclusions the indoor climate is not completely satisfactory in the building, the focus on reducing the energy use was concluded to have an adverse effect on the indoor temperature. Although there had been improvements to the indoor environment in the building, the lack of cooling caused the building to be too warm in the summer months. Also, given that the temperature was too low for the users due to the low RH levels and varying between the zones, showed that demand control of the HVAC systems to save energy may have an adverse effect on the user comfort.

Lastly, the results and conclusions from the different case studies were evaluated as to whether they could be extended to other buildings. Although all buildings are different, similar school buildings may show similar results when the same systems are installed. Furthermore, the results and conclusions concerning the office buildings may be applied to other buildings as they are highly general. Although the solutions chosen will vary from building to building, the expectations and budget of the client, standards and regulations,

optimally interacting systems and a high level of occupant control will all be difficulties and important factors for any construction project, whether it is a retrofitted or new one. Also, the conclusions concerning the generalization of standards and regulations and a need for shading and cooling, although dependent on building characteristics, will be applicable to any building.

Sammendrag

Arbeidet i denne masteroppgaven er gjort for evaluere fire spørsmål. Først ble et litteraturstudie, i tillegg til tre case-studier, gjort for å bestemme utfordringene ved oppvarmings- og ventilasionssystemer når man rehabiliterer til lavenergibygg, samt utviklingstrenden i markedet. Litteraturen og case studiene viste at kundens forventninger og budsjett, standarder og forskrifter, at alt fungerer sammen som en helhet og et høyt nivå av brukerkontroll er utfordrende og viktige faktorer som påvirker suksessen til et prosjekt. De tre casestudiene hadde diverse systemer installert, inkludert grunnvarmepumper, luft-til-vannvarmepumper, varmegjennvinning i ventilasjonsaggregater og duker for solavskjerming for å nevne noen. Valget av disse avhenger dog av karakteristikkene til bygningen samt dets miljø.

Den andre delen av masteroppgaven evaluerer både hvorvidt oppvarmings- og ventilasjonssystemene i et skolebygg, Stasjonsfjellet Skole, er i stand til å oppnå et tilfredsstillende inneklima, i tillegg til hvorvidt fokuset på å redusere energiforbruket til bygget har en negativ effekt på inneklimaet. Gjennom IDA ICE simuleringer, i tillegg til en brukerundersøkelse, har oppvarmings- og ventilasjonssystemene blitt konkluder til å forsyne bygget med et noe tilfredsstillende innekllima i deler av bygget, men ikke for alle soner. Noen av sonene hadde veldig høye temperaturer, dagslysforhold og PPD-nivåer. Videre klagde brukerne på for lav temperatur i bygningen generelt. Selv om dette ikke stemte overens med resultatene fra IDA ICE, viste simuleringene en lav relativ fuktighet i de kaldere månedene av året, som kan forårsake at brukerne av bygget føler seg kalde til tross for en moderat innetemperatur (Novakovic, et al., 2007). Videre viste generaliseringen av verdiene fra standarder og forskrifter å ikke være tilpasset de ulike kravene de ulike rommene i bygningen stiller.

I tillegg til konklusjonene om at inneklimaet i bygget ikke er helt tilfredsstillende, ble fokuset på å redusere energiforbruket konkludert med å ha en negativ effekt på inneklimaet i bygget. Selv om inneklimaet var forbedret, viste mangelen på kjøling og solavskjerming seg å forårsake at bygningen ble for varm i sommermånedene. I tillegg viste det faktum at temperaturen i bygget var for lav i forhold til relativ fuktighetsnivå, og varierende mellom sonene, at behovsstyringen av ventilasjonen og oppvarmingen for å spare energi hadde en negativ effekt på brukerkomforten.

Til slutt ble resultatene og konklusjonene fra de ulike casene evaluert i forhold til hvorvidt de kunne gjelde for andre bygninger. Selv om bygninger er forskjellige, ble det besluttet at liknende skolebygninger vil vise liknende resultater når de samme systemtypene er installert. Videre vil resultatene og konklusjonene fra de tre kontorbyggene kunne videreføres da de er generelle. Selv om løsningene som velges vil være ulike fra bygg til bygg, vil forventningene og budsjettet til kunden, standarder og forskrifter, optimalt interaktive systemer samt et høyt nivå av brukerstyring være utfordringer og viktige faktorer

for ethvert byggeprosjekt. I tillegg vil konklusjonsn om generaliseringen av standarder og forskrifter, samt et behov for kjøling og solavskjerming avhengig av byggets karakteristikker, gjelde for alle bygninger.

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Chapter 1

Introduction

1.1 Background

In the construction market today, there is an increasing focus on reducing the building energy use. Although the demands for passive and low-energy buildings first and foremost apply to new buildings, rehabilitation of existing constructions will also have to take these demands into account. As the energy use for the HVAC systems in a building is high, reducing this energy post becomes vital to comply with the demands of the standards. However, it is questioned whether the reduced use of energy for the HVAC systems is affecting the indoor environment and the user comfort in these buildings.

1.2 Objectives

In this master's thesis, the main focus is put on the performance of the HVAC systems in rehabilitated low-energy buildings and whether the focus on reducing the energy need for these systems have an adverse effect on the indoor environment and user comfort of the buildings in question. The following tasks will be considered:

1. Review of the challenges for HVAC systems in buildings renovated to low-energy standards as well as of the HVAC development tend in the market
2. Based on a case study, the HVAC strategy implemented in the renovation will be analyzed and its ability to obtain a satisfactory indoor climate (especially as regards ventilation).
3. Based on the case study, evaluate whether the focus on reducing the energy use in a building could potentially have an adverse effect on the indoor climate, with a focus on the psychological aspect through a survey (how the occupants experience the building/comfort).
4. Evaluate whether the results from the case projects can be extended to other buildings.

1.3 Method and scope

In order to consider the tasks mentioned above, several methods are used, although the bulk of the work in this report is done through IDA ICE simulations.

The first task of reviewing the challenges and development trend in the market is mainly based on the study of three case studies, but also through a literature survey. Through presentation meetings with engineers and technical chiefs involved with each of the projects, Fredrik Selmers vei 4 and Grensesvingen 7 were investigated and are presented in this report. As is Powerhouse Kjørbo which was studied by the author in a previous project (no meeting was done in association with this thesis as the author was very familiar with the building from previous work). All three cases are office buildings that were finished in 2014.

In order to evaluate the second and third task, an elaborate study of a school building called Stasjonsfjellet Skole was done. The building was modeled and simulated in the simulation programme called IDA ICE, where the focus was on obtaining an as realistic model as possible. For the second task, the simulation results were used to evaluate the HVAC solutions' ability to obtain a satisfactory indoor climate. In addition to the simulation results, a user survey performed on the employees at the school was used to evaluate task three, concerning whether the focus on reducing the energy use in the building had an adverse effect on the indoor climate.

Lastly, all three case studies evaluated for task one, in addition to the case study for tasks two and three, were used to evaluate whether the results and conclusions could be extended to other buildings.

Although all four tasks are considered, the main focus has been on tasks two and three, with the IDA ICE model and simulations representing the bulk of the work performed.

1.4 Structure of the report

There are several parts and chapters to this report in order to answer all the tasks and objectives. Firstly, some background theory is presented in order to explain terminology and principles that may be unclear. Following, the first task of reviewing the challenges and development trend in building retrofit is studied, first through a literature survey in chapter three (including some background on the effectivity and effects of HVAC and ventilation systems) and then through a study of the three case studies in chapters four and five. The report then shifts focus onto the school building, Stasjonsfjellet Skole, starting with a general description of the school in chapter six, then followed by the user survey in chapter seven. The IDA ICE model of the building is then described and explained in chapter eight, followed by an explanation of the different simulation scenarios that were performed in chapter nine. Chapter ten presents and summarizes the simulation results, which are discussed in chapter eleven. Lastly, chapter twelve summarized the conclusions from the work as well as presenting suggestions for further work.

Chapter 2

Background Theory

As this report discusses different mechanisms for heating, ventilation and air conditioning (HVAC), it is assumed that the reader has some insight into relevant terms and principles. However, some supplemental terms and theory will be described here.

2.1 BREEAM NOR

BREEAM is a building certification tool that evaluates the environmental impact of a building and is the leading tool used in Europe (BREEAM NOR, n.d.). The Norwegian Green Building Council (2015) claims it is the best method in Norway for certification of sustainable buildings. BREEAM NOR is a version of BREEAM adapted to Norwegian conditions and was published in 2011 (Norwegian Green Building Council, 2015). From acquisition to delivery, increased motivation for considering sustainability and sustainable solutions in construction projects throughout the construction processes, is the main purpose of the BREEAM NOR classification (BREEAM NOR, n.d.).

BREEAM assigns points according to ten different categories:

- Energy
- Materials
- Innovation
- Management
- Water
- Waste
- Transport
- Health & Wellbeing
- Land Use and Ecology
- Pollution

(Norwegian Green Building Council, BREEAM NOR Technical Manual, 2012)

For each category, a certain amount of points are given and then added up to give an overall score (Norwegian Green Building Council, BREEAM NOR Technical Manual, 2012). The total score of points will then decide what kind of certificate the building will receive. The highest score will result in a BREEAM Outstanding certificate, followed by Excellent, Very Good, Good, Pass and Unclassified (Norwegian Green Building Council, BREEAM NOR Technical Manual, 2012). In order to obtain the highest scores, there are some points that have to be obtained, independent of the overall score (Norwegian Green Building Council, BREEAM NOR Technical Manual, 2012).

2.2 Building Management System (BMS)

According to Bernstein (2013), a Building Management System (BMS) allows for management, oversight, configuration, performance monitoring and visualization of the subsystems in a building.

2.3 CAV and VAV

In order to control the airflow rates provided to a room or zone there are two main methods, the constant air volume (CAV) and the variable air volume (VAV) method. With the CAV method, the air volume provided to the room is kept constant, while the air temperature is varied according to the need (Nilsson, P.-E., et al., 2003). In contrast to the CAV method, a VAV system alters the airflow rate provided according to the need, and keeps the temperature constant (Nilsson, P.-E., et al., 2003).

2.4 Clo

Clo is a unit describing the insulation value of materials, specifically the thermal resistance between the clothing and the surface of the skin (Novakovic, et al., 2007). The unit is either used itself, or it is given as m^2K/W, with the defined correlation of $1 \text{ clo} = 0.155$ m^2K/W (Novakovic, et al., 2007).

2.5 Displacement and mixing ventilation

There are two main ways of mechanically ventilating a room, by mixing ventilation or displacement ventilation. Mixing ventilation supplies air at a relatively high velocity and at room temperature through jets, creating approximately the same temperature and contamination conditions everywhere in the room (Nilsson, P.-E., et al., 2003). The air is supplied and extracted through diffusors placed preferably at ceiling level to avoid the zone of occupancy (Nilsson, P.-E., et al., 2003). In contrast to mixing ventilation, displacement ventilation is supplied to the room close to the floor and extracted at ceiling level (Nilsson, P.-E., et al., 2003). The air temperature is below the room air temperature, using a heat source in the room to create buoyancy forces that will make the air move slowly upward, bringing contaminants with it (Nilsson, P.-E., et al., 2003). For the supply air to achieve its flow pattern of slowly moving upward, it needs to be supplied at low velocities with a high cross sectional area of the supply air diffusor (Nilsson, P.-E., et al., 2003).

2.6 Comfort level of CO_2

According to Novakovic, et al. (2007), the level of CO_2 in the Norwegian outdoor air is around 350-450 ppm (parts per million). Furthermore, Novakovic, et al. (2007), a recommended CO_2 level for comfort is defined to be a maximum 1000ppm.

2.7 Comfortable Temperature

According to Arbeidstilsynet (1991), the operative temperature for light work to be 19-26°C, with an accepted 50 occupancy hours per year exceeding this temperature during summer conditions when the outdoor temperature exceeds 22°C. In NS-EN ISO 7730:2005 (Standard Norge, 2006) they suggest two operative temperature intervals, for three different comfort categories, for design criteria for classrooms. These intervals are as listed below:

- Category A, summer: 24.5 ± 1.0
- Category A, winter: 22.0 ± 1.0
- Category B, summer: 24.5 ± 1.5
- Category B, winter: 22.0 ± 2.0
- Category C, summer: 24.5 ± 2.5
- Category C, winter: 22.0 ± 3.0

(Standard Norge, 2006)

2.8 Fanger's comfort indices

Professor P.O. Fanger has defined two indexes for comfort, namely PPD and PMV (Novakovic, et al., 2007). According to Novakovic, et al. (2007), the Predicted Mean Vote, PMV, indicates on a seven point scale the thermal feeling of the occupants. The Predicted Percentage of Dissatisfied, PPD, gives an approximate percentage of a larger group of people who will be dissatisfied with the thermal conditions in a room (Novakovic, et al., 2007). In NS-EN ISO 7730:2005 (Standard Norge, 2006), a range for recommended PPD and PMV levels are given for three different categories. The best category, category

A, defines PPD $< 6\%$ and $- 0.2 < \text{PMV} < 0.2$, while category B is defined as PPD $< 10\%$ and $-0.5 < \text{PMV} < 0.5$ (Standard Norge, 2006). The third category, category C, has the values PPD $< 15\%$ and $-0.7 < \text{PMV} < 0.7$ (Standard Norge, 2006).

2.9 IDA Indoor Climate and Energy (IDA ICE)

IDA Indoor Climate and Energy (IDA ICE) is a building simulation program delivered by EQUA Simulation AB. According to EQUA Simulations AB (2014), "IDA ICE is an innovative and trusted whole-year detailed and dynamic multi-zone simulation application for study of thermal indoor climate as well as energy consumption for the entire building.". The program allows the user to build a model of a building and perform detailed simulations on the behavior of the building, its systems and its surrounding environment.

2.10 Lost working hours due to under or overheating

A parameter that the IDA ICE simulation program can yield is the lost working hours due to under or overheating. According to EQUA Simulation AB (2015), this parameter is calculated by summing up the lost work per occupant, which is defined as a loss of 0.02 percent per degree above 30°C or below 15°C. EQUA Simulation AB (2015) further explain that the occupants are defined to work with 100% efficiency when the temperature is between 20°C and 25°C, and that it decreases linearly at temperatures beyond this interval.

2.11 Lux

As a measure of the strength of a lighting source, the unit "lux" is used (Novakovic, et al., 2007). $1 \text{ lux} = 1 \text{ lumen/m}^2$, where lumen is the same as the luminous flux (Novakovic, et al., 2007).

2.12 met

Depending on a persons activity level, met defines the heat gain from a person per m^2 body surface, defined as $1 \text{ met} = 58.15 \text{ W/m}^2$ (Novakovic, et al., 2007).

2.13 Relative Humidity (RH) comfort level

According to Novakovic, et al. (2007), the relative humidity can vary from 20% to 70% without affecting the occupants comfort sensation significantly.

2.14 SIMIEN

SIMIEN is a dynamic simulation program delivered by ProgramByggerne. There are seven types of simulations in the program:

- Dimensioning summer conditions
- Dimensioning winter conditions
- Evaluation against regulations
- Passive house/ low-energy
- Profitability of measures
- Whole year simulation
- Energy certification

(ProgramByggerne, n.d.)

The program is mainly used for energy simulations and to determine whether a building complies with the relevant standards and regulations.

2.15 Abbreviations

In order to clarify abbreviations that are used in the report, the following list will link abbreviations used with the correct term.

ACH - Air Changes per Hour
AHU - Air Handling Unit
DHW - Domestic Hot Water
PMV - Percentage Mean Vote
ppm - parts per million
PPD - Predicted Percentage Dissatisfied
RH - Relative Humidity
SFP - Specific Fan Power

Chapter 3

Literature survey

In the following, studies performed by Ma, et al. (2012), Cao, et al. (2014) and by Chidiac, et al. (2011) are used to describe factors affecting the efficiency of building retrofit. Also, the difficulties engineers and architects face when retrofitting are discussed. Furthermore, types of retrofit measures that are available and used are listed, with a background in descriptions and studies done by Xing, Hewitt and Griffiths (2011) and Ma, et al. (2012). Lastly, the performance of HVAC strategies and their effects on the users, with a focus on ventilation, is discussed based on studies performed by Cao, et al. (2014), Kosonen and Tan (2004) and Barlow and Fiala (2007).

When it comes to building retrofit, Ma, et al. (2012) identified six influential factors; client resources and expectations, building specific information, human factors, retrofit technologies, policies and regulations and other uncertainty factors. As it is up to the client to determine what the goals and scope of the project are, their resources and expectations will determine the retrofit technologies that are used (Ma, et al., 2012). Regulations and policies provide minimum requirements and subsidies (Ma, et al., 2012), but Ma, et al. (2012) also argue that the effectiveness of the building retrofit depends on building specific information and on human factors. Although there are many factors affecting the success of the retrofit, it will all initially depend on the goal and scope of the project, which in every case will be determined by the client.

In addition to these influential factors, Ma, et al. (2012) list several difficulties regarding building retrofit. Essentially, the challenges concern the choice of energy conservation measures, which is a multi-objective optimization problem (Ma, et al., 2012). As no building is the same, the optimal choice of energy conservation measures will differ from building to building, making it necessary to make a thorough investigation of different options before making a choice (Ma, et al., 2012). Cao, et al. (2014) argue that the choice of the most efficient ventilation strategy is difficult for engineers to make due to the high level of required information, which may not always be available (such as occupancy and internal gains). Furthermore, both Ma, et al. (2012) and Chidiac, et al. (2011) agree that the efficiency of energy conservation measures/energy retrofit measures is not the sum of all measures chosen, but dependent on the interactivity between them.

With an increasing focus on energy conservation, there are several measures that can be taken to reduce the energy demand of a building. In *Zero carbon buildings refurbishment - A Hierarchical pathway*, Xing, Hewitt and Griffiths (2011) discuss several refurbishment techniques, including insulation materials, lighting sources, heating sources such as solar thermal, biomass heat pumps and district heating, ventilation strategies and microgeneration. Regarding alternative, renewable energy sources, Ma, et al. (2012) also name solar hot water, solar photovoltaics (PV), geothermal and wind energy as some alternatives for energy supply of buildings. There are, in other words, many options and choices to reduce the energy demand of a building, but the choice of solutions should be made based on the building itself and the local opportunities.

Although there are many options for retrofit measures, the effects on the users of a building is of extreme importance. In a study performed by Cao, et al. (2014) it was found that the performance of the different ventilation strategies depends on the task of the strategy in question. However, Kosonen and Tan (2004) claim that with higher ventilation rates, the amount of people dissatisfied with the indoor air quality is reduced. Although higher ventilation rates may be preferable, the building itself may set restrictions as to duct sizes and ventilation possibilities, making an optimal solution difficult to implement. However, in a study performed by Barlow and Fiala (2007) it was found that allowing the occupants of office buildings to actively adapt to the indoor environment, through opening of windows and controlling external shading, was highly recommended. Barlow and Fiala (2007) argue that engineers and architects need to increase their focus on the occupants of the building to "include intelligent adaptive opportunities within their refurbishment strategies.".

The literature shows that there are several factors that make retrofitting buildings challenging, although it usually starts with the willingness and budget of the client (Ma, et al., 2012). Ma, et al. (2012) also pointed out that policies and regulations are of high importance when retrofitting to low-energy buildings, as they both set requirements and can provide subsidies. The options are many, but what retrofit measures to choose should depend on the budget of the project and on the building and its available opportunities (Ma, et al., 2012). Also, selecting which energy conservation measures to implement in a building is challenging and it is important to thoroughly investigate different options before making a choice (Ma, et al., 2012). It is also important for the set of solutions that are chosen to work as a whole (Ma, et al., 2012, and Chidiac, et al., 2011). From the studies (Cao, et al., 2014, Kosonen and Tan, 2004 and Barlow and Fiala, 2007) it is clear that here is no doubt that the HVAC solutions in a building affect the comfort of its occupants, as that is their whole purpose. However, their effects and performance will depend on their purpose (Cao, et al., 2014). Furthermore, Barlow and Fiala (2007) have emphasized the importance of allowing the occupants to control factors that affect their comfort.

Chapter 4

Case Studies

4.1 Introduction

In order to establish the challenges, as well as what kind of solutions are used in the Norwegian market today, when retrofitting HVAC systems to low-energy buildings, three case buildings have been studied. The buildings and their HVAC solutions are presented here, before the next chapter discusses and summarizes the discoveries made.

4.2 Fredrik Selmers vei 4

Figure 4.1: Fredrik Selmers vei 4

4.2.1 Background

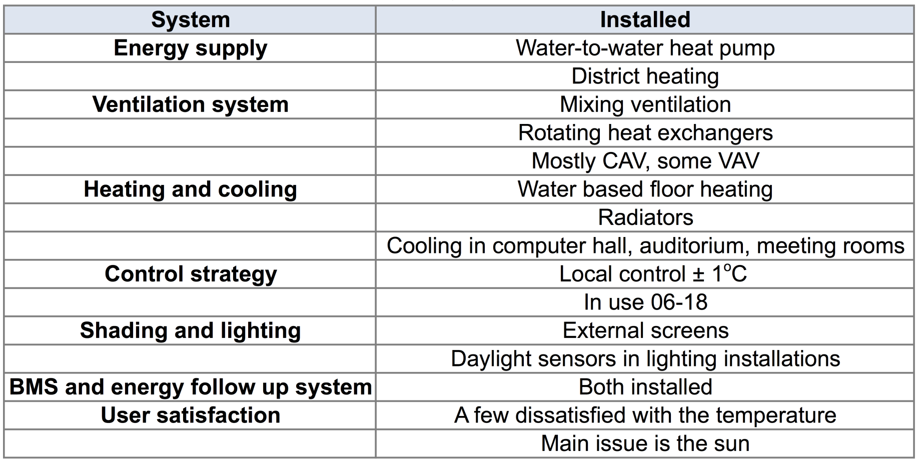
The first building that is presented is the office building Fredrik Selmers vei 4. Unless otherwise specified, the information presented here is based on a presentation meeting with Tom Riseth and Helge Stugård from Entra Eiendom in Oslo, the 16th of March 2015 (Riseth and Stugård, 2015).

Fredrik Selmers vei 4 is an office building owned and run by Entra Eiendom. The building is situated at Helsfyr in Oslo, and currently houses Skatteetaten. The building was originally built in 1982 (FutureBuilt, 2015), but recently underwent a rehabilitation process that was finished in November 2013 (Entra, n.d.). According to FutureBuilt (2015) there are five blocks that are connected by new floors, which has reduced the thermal bridges and increased the floor area. The facade of the building has been changed, and now gives a quite different impression, consisting of 95% recycled aluminum (FutureBuilt, 2015). Although keeping the facade may have released less greenhouse gases, the financial support from Enova did not allow for it to be kept, due to its poor insulation properties (FutureBuilt, 2015). The image above shows the new facade as well as the connection between two of the blocks.

Fredrik Selmers vei 4 not only complies with the Norwegian passive house standard, NS 3700/NS 3701, and energy class A, but it has also received a BREEAM Very Good classification. With the Helsfyr metro station and bus stop being only a couple minutes walking distance away and proper facilitation for cycling and electric car parking, the building has gained many points for alternative transportation.

The systems installed in the building are tabulated in table 4.1 below, and the further explained in the following text.

Table 4.1: Table of installed systems in Fredrik Selmers vei 4



System	Installed
Energy supply	Water-to-water heat pump
	District heating
Ventilation system	Mixing ventilation
	Rotating heat exchangers
	Mostly CAV, some VAV
Heating and cooling	Water based floor heating
	Radiators
	Cooling in computer hall, auditorium, meeting rooms
Control strategy	Local control ± 1°C
	In use 06-18
Shading and lighting	External screens
	Daylight sensors in lighting installations
BMS and energy follow up system	Both installed
User satisfaction	A few dissatisfied with the temperature
	Main issue is the sun

4.2.2 Energy Supply

The building's energy supply are to come from district heating (30%) and from a water-to-water heat pump that takes advantage of condenser heat from a cooling system (70%) in a computer hall (FutureBuilt, 2015, and Stugård and Riseth, 2015).

4.2.3 Ventilation system

Stugård and Riseth (2015) described the ventilation system in the building to be based on mixing ventilation, with some transfer air devices in the meeting rooms and project rooms. In most parts of the building the air is supplied on a CAV basis, but meeting rooms and project rooms have VAV controlled by CO_2 sensors, with a set point of 800 ppm. On each floor there are three pressure controlled VAV dampers, two on the supply side and one on the exhaust side.

According to Stugård and Riseth (2015), the air handling units have rotating heat exchangers, recycling much of the heat from the exhaust air. When the outside temperature reaches 5°C, the pump for the heating coil stops, making the heat exchanger and a radiator system take care of the heating demand.

4.2.4 Heating and cooling

In our meeting, Stugård and Riseth (2015) described the heating system to be based mostly on water based floor heating and radiators. Furthermore, there is installed street heating in 1100 m^2 outside the building, in the entrance area and the loading docks. In the building there is cooling installed in the computer hall and a few local cooling points in some meeting rooms in addition to a cooling fan coil with local control in the auditorium. The heating devices are supplied with hot water at 55°C, leaving at 35°C. The water is preheated by the heat exchanger from the computer hall cooling system, then heated up to the desired temperature by district heating.

To regulate the indoor temperature, an outdoor-temperature compensation curve is used, and when the outdoor temperature reaches 8°C, all heating is unnecessary and shut off. Stugård and Riseth (2015) explained that as the building holds 1000 users and 20 showers in a basement gym, the need for domestic hot water (DHW) is quite high. In the summer months, they claimed, this is the only heating demand, supplied by district heating.

4.2.5 Control Strategy

As previously mentioned, the ventilation system is mainly a CAV system with a set supply air temperature. However, for local control, the users are able to adjust the temperature up or down 1°C. As most of the users are placed close to each other in an office landscape, very local temperature differences are not possible (if two people have a set point temperature of 22°C, the person between them cannot set the temperature to 21°C).

The building is assumed to be in use between 06 and 18, with an overtime switch available for use outside this time interval.

4.2.6 Shading and lighting

Stugård and Riseth (2015) explained that the biggest problem for comfort in the building was the sun. For this, they explained, there are external screens installed, that are either lowered automatically by use of a sensor on the roof, or by the users themselves. The sensor is set to lower the screens at 45/50 klux. For lighting, the lamps in the building have daylight sensors, which increase their lifetime.

4.2.7 BMS and energy follow up system

In order to control and supervise the different systems in the building, there is an elaborate BMS system in place. From here, the air handling units and heating system can be controlled, in addition to the system allowing for control of the local sensors and the sun screens. According to Stugård and Riseth (2015) there is, in addition to the BMS-system established an energy follow up system, which logs data on the energy use from 170 sensors throughout the building. From here, the energy use of the building can easily be supervised.

4.2.8 User Satisfaction

According to Stugård and Riseth (2015) from Entra, the users of the building are very satisfied with the new systems. A few people are dissatisfied with the indoor temperature, but the main issue with the building is the sun. Although there are external screens installed for shading, it has been the biggest problem for comfort.

4.3 Grensesvingen 7

Figure 4.2: Grensesvingen 7

4.3.1 Background

The second building presented is the office building Grensesvingen 7. Unless otherwise specified, the information presented here is based on a presentation meeting with Gunnar Moen from Oslo Areal and Asbjørn Mortensen from GK in Oslo, the 27th of March 2015 (Moen and Mortensen, 2015).

Grensesvingen 7 is a building owned by Oslo Areal housing the public entities Undervisningsbygg (7th and 8th floor) and Miljødirektoratet (3rd to 6th floor). On the first floor of the building, each of them have their own gym, with the second floor having a shared cafeteria (and partly housing Undervisningsbygg).

According to Moen and Mortensen (2015), for everything in the building to function as planned, it was absolutely necessary for all surfaces to be correct. This way, cold downdraft is completely prevented, and the building walls form a tight shell.

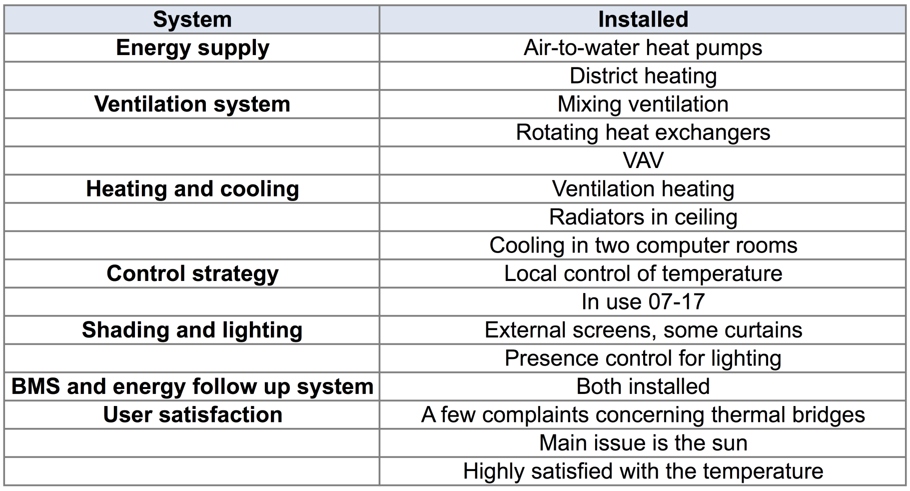
Originally, the external walls of the building were of red brick, as can be seen in the image above. These have been reused in the external walls of the first seven floors, which has resulted in these floors not being passive due to thermal bridges. As the eigth floor does not have any red brick walls, this floor complies with the passive house standard. The thermal bridges were practically inevitable, but as using the brick was more important, the sacrifice of passive standard on the whole building was made. To reduce heat loss and for noise cancellation the ceiling of the basement car park has been insulated as part of the rehabilitation.

The main goal of the rehabilitation of the building was to achieve BREEAM Excellent standard. This has been a controlling factor throughout the process, deciding everything down to what materials to use.

In order to reduce energy use in the building, the users are not permitted to charge their electrical equipment outside office hours. Furthermore, the motion sensors in the ventilation diffusers ensure that when there is no one present, screens, lamps and other electrical equipment is turned off (except hard drives etc. that risk losing data).

The systems installed in the building are tabulated in table 4.2 below, and then further described in the following text.

Table 4.2: Table of installed systems in Grensesvingen 7



System	Installed
Energy supply	Air-to-water heat pumps
	District heating
Ventilation system	Mixing ventilation
	Rotating heat exchangers
	VAV
Heating and cooling	Ventilation heating
	Radiators in ceiling
	Cooling in two computer rooms
Control strategy	Local control of temperature
	In use 07-17
Shading and lighting	External screens, some curtains
	Presence control for lighting
BMS and energy follow up system	Both installed
User satisfaction	A few complaints concerning thermal bridges
	Main issue is the sun
	Highly satisfied with the temperature

4.3.2 Energy Supply

The energy supply of the building is based on two 300 kW air-to-water heat pumps placed on the roof of the building. As there were already district heating installed in the building, this is used for top-up heating.

4.3.3 Ventilation system

In each of the eight floors of the building there are two air handling units, with combined heating and cooling batteries. For ventilation control, there are branch dampers, but no dampers locally. The supply air diffusers measure and control the following parameters:

- Supply air volume
- Heating demand
- Presence - movement sensor affects the ventilation
- Temperature
- Reports to the air handling unit - when three or more diffusers require more air, the air handling unit will increase the air flow rate

These diffusers are supplied by Lindinvent and hang under the ceiling, as shown in the image below, providing air by mixing ventilation with a very carefully calculated throw length. They are disk shaped, and with the spread pattern and sensors built into the diffusers, they are of the more expensive kind. However, Oslo Areal wanted the best system possible, not necessarily the cheapest. Considering the amount of technology built into the one unit, the price may not in total be that much higher than normal.

Figure 4.3: Air diffuser and radiators

By using the presence/motion sensors and temperature sensors in the diffusers, the ventilation air flow is VAV controlled. Furthermore, all meeting rooms have CO_2 controlled VAV. The exhaust air is led back to the air handling unit through central extract units hidden in the suspended ceiling. Here, the insulation is removed creating an opening for the air to be extracted. The air handling units are equipped with rotating heat exchangers for heat recovery. The system is dimensioned for a supply air flow rate of 10 m^3/hm^2. The ventilation normally runs at 10-15 m^3/h as a minimum, with a minimum of 35 m^3/h when there are people present. At night, the system reuses 100% of the exhaust air.

4.3.4 Heating and cooling

The building is solely heated by the ventilation air, except for a few conventional radiators in an annex. For top-up heating there are some electrical radiators placed in a suspended ceiling along the outer facade. These are shown in the image above, being the two white squares on either side of the circular air diffusor in the ceiling. For heating control, the room regulators control the supply air temperature by using the average temperature.

For the two computer rooms there is constant local cooling, supplied by an 80kW cooling machine. Also, the ventilation system will cool when necessary.

4.3.5 Control Strategy

The use-time of the building is set to be from 7 to 17. If the motion sensors in the diffusers notice more than two people present before or after this time, the appropriate air handling unit will start. When there are no people present, the air handling unit will shut off and recycle the air. Locally, the users can adjust the set point temperature through the ventilation and also with the top-up radiators.

In the technical rooms and wherever relevant there are clocks and measuring instruments visible and easily readable for the janitor to be able to follow up on every part of the system on a daily basis. This daily control has been very important to Oslo Areal, who wish for the janitor to maintain and control the building thoroughly.

4.3.6 Shading and lighting

For shading, there are indoor curtains. In areas where it is needed, there are external screens controlled by sensors on the roof. These are not user controlled, which has proven to be a problem. Also, there are screens on surrounding buildings that interfere with the sensors and which are troublesome for the users in the building.

The lighting system in the building is controlled by presence sensors. When the building was being designed, LED lighting was fairly expensive, making the payback time too long for it to be an option. Now, however, when the building is finished, the payback time would have been sufficiently short.

4.3.7 BMS and energy follow up system

As in Fredrik Selmers vei 4, Grensesvingen 7 is also equipped with both a BMS system and an energy follow up system.

4.3.8 User Satisfaction

The complaints from the building concerns thermal bridges and sun issues. Otherwise, the users are highly satisfied with the indoor environment, including noise levels. The systems are also working well.

4.4 Powerhouse Kjørbo

Figure 4.4: Staircase in the centre of Powerhouse Kjørbo (Nordang, 2014)

4.4.1 Backgroud

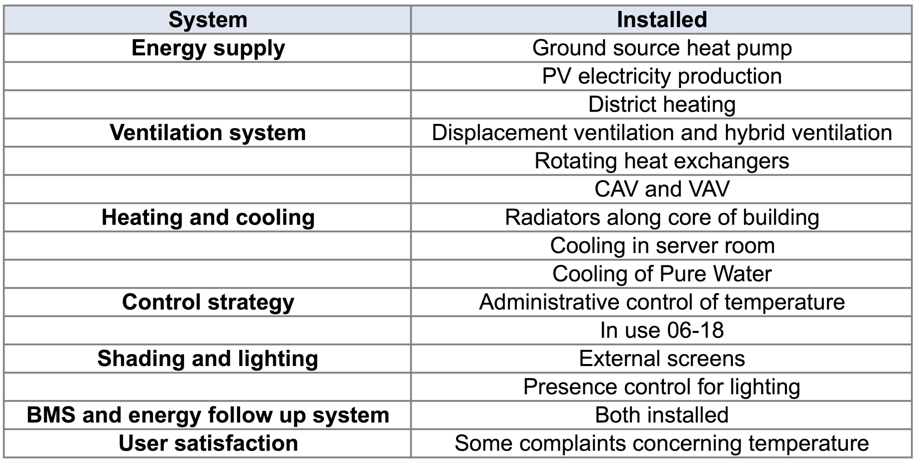
Lastly, the office building Powerhouse Kjørbo is presented. As the author was highly familiar with the building from previous work, no meeting was arranged for this building. Unless otherwise specified, the following information is in stead based on the information presented in the project report "Ventilation for a Zero Energy Building" (Danielsen, 2014).

Powerhouse Kjørbo is an office building owned by Entra Eiendom, located in Sandvika, Bærum. It was originally built in the 1980s, but was taken into use in the autumn of 2014 after being retrofitted. There are two buildings, attached by a staircase, which make up Powerhouse Kjørbo. The buildings are called building four and building five, and have four and three floors, respectively. The building is, according to Danielsen (2014), a life cycle energy positive building.

Being an energy positive building, Powerhouse Kjørbo has accomplished the remarkable classification of BREEAM Outstanding. In order to accomplish this, the lifetime of the materials and the energy use for their production had to be reduced to minimal levels.

The systems installed in the building are tabulated in the table below, and then further described in the following text.

Table 4.3: Table of installed systems in Powerhouse Kjørbo



System	Installed
Energy supply	Ground source heat pump
	PV electricity production
	District heating
Ventilation system	Displacement ventilation and hybrid ventilation
	Rotating heat exchangers
	CAV and VAV
Heating and cooling	Radiators along core of building
	Cooling in server room
	Cooling of Pure Water
Control strategy	Administrative control of temperature
	In use 06-18
Shading and lighting	External screens
	Presence control for lighting
BMS and energy follow up system	Both installed
User satisfaction	Some complaints concerning temperature

4.4.2 Energy Supply

Powerhouse Kjørbo is meant to, in its lifetime, produce more energy than the building itself needs. This is done through electricity production from PV cells on the roof of the building and on a part of the garage roof, as well as by using a ground source heat pump. The heat pump collects heat from energy wells located close to the building and takes advantage of surplus energy from the computer server room. As top-up heating, the building is supplied with district heating. The heat pump is not only able to cover 100% of the buildings heating demand, but also the cooling need.

4.4.3 Ventilation system

The ventilation system in Powerhouse Kjørbo is based on CAV and VAV displacement ventilation. The air is supplied centrally through diffusers strategically placed along the core of the building, as well as in the corner of the cell offices along the external walls. In the center of the building (building four) there is a staircase, used as an exhaust air shaft, with exhaust fans placed at the top. The air is then led back through the air handling unit and out of the building.

The air handling unit has both a heating and a cooling battery, a rotating heat exchanger and the option for re-using the air. The main reason why the building uses so little energy, is that the air handling unit is supplying air at a very low pressure, allowing the fans to run at very low rpms (rotations per minute). This reduces the energy need of the air handling unit significantly. When it is not raining and there is no need for heat recovery, hybrid ventilation is possible by opening hatches placed above the central staircase and windows on the top floor of the building. It is also possible to provide free cooling through the system.

In order to demand control the ventilation of the building, there are temperature and CO_2 sensors placed strategically in the building. The supply air temperature is given by an exhaust temperature compensation curve. The temperature in the zones is decided by an outdoor temperature compensation curve with corrections for the set point temperature. The set point temperature for the zone varies between them, so as to comply with the different demands. The CO_2 set point is set to 650 ppm in all zones, but with an override function for the user.

The cell offices in the building are ventilated by CAV, but in meeting rooms and the landscape areas, there is a VAV system.

4.4.4 Heating and cooling

In order to heat Powerhouse Kjørbo, there are radiators placed along the core of the building. These radiators are supplied with heat from the heat pump. The temperature in the zones are adjusted by using the temperature sensors mentioned earlier. In the cooling season, the radiators will be turned off and the cooling battery in the ventilation will supply the necessary temperature reduction.

The heat pump is also designed to ensure cooling for the computer server room, as well as cooling of Pure Water. The latter is a water purifying system, that provides drinking water to the building.

4.4.5 Control strategy

The temperature and ventilation air flow rates are controlled through the sensors that measure CO_2 levels and temperatures. However, although the users are not able to adjust the temperature in the zone, it is possible for an administrator to adjust the temperature set point for a larger area.

The building is set to be in use from 06 to 18, but with an overtime switch, for use when necessary.

4.4.6 Shading and lighting

The shading system in the building is based on screens that are activated both automatically and can be overridden by the user.

The main lighting solution is based on a DALI system, adjusting the lighting according to daylight and presence. In the central core areas and along the staircase in building four, there are LED lights as leading lights and to illuminate the corridor. Elsewhere, there are conventional downlights installed.

4.4.7 BMS and energy follow up system

As in the other buildings, Powerhouse Kjørbo is equipped with a BMS system for technical system control and for logging of data (such as temperatures and pressure levels that are measured by the sensors). Also, they have an energy follow up system which measures and logs the different energy uses of the building.

4.4.8 User satisfaction

According to Rådstoga (2014), the occupants of Powerhouse Kjørbo are highly satisfied with the building and its indoor environment, although there have been a few complaints regarding the temperature in the building.

4.5 Summary and conclusion

For all three buildings, several systems and installations were applied, indicating a trend of solutions that are used. The following installations were mutual for all three case studies:

- Heat pump
- District heating
- Rotating heat exchanger in air handling units

- Some level of VAV controlled ventilation
- Radiators for heating, although of various types
- Occupancy control with specified use times
- External screens for solar shading
- Both a BMS and an energy follow up system

As all these installations were the same for the three buildings that were studied here, it can be concluded that they are typical solutions used in the market today.

Chapter 5

Solutions and challenges

All three case studies that were presented in the previous chapter are successful projects. They all achieved their target classifications and they all claim to be satisfied with the results. The following will evaluate some of the key aspects as to what make these buildings successful as well as what the challenges associated with them were.

High owner involvement

The most important reason why these buildings perform the way they do, may have to do with the involvement of the owners. From the meetings with both Entra Eiendom and Oslo Areal it was clear that both owners have taken an interest and played important roles in order to achieve the ratings and quality that these buildings represent. The concepts of building environmentally friendly buildings are increasing in popularity and desirability, however these buildings are all built by entities that have a special interest and willingness to spend the resources that it takes to achieve them. This willingness and these expectations of the owners was also pointed out in the literature to be an important factor for a building to be successfully retailed (Ma, et al., 2012). If the owner only cares about the budgets and does not see the bigger picture and the value in investing in optimal solutions, then it is likely that the buildings presented here would not be what they are today.

Standards as limitations

In both Fredrik Selmers vei 4 and Grensesvingen 7, using the existing facade was seen as a better solution than keeping it. However, in Fredrik Selmers vei 4 they decided to change it in order to obtain financial support from Enova, while they in Grensesvingen 7 decided to keep the existing red brick facade and subsequently loose a potential passive house classification. This indicates that the standards and regulations are not always compatible with the best and most optimal solution for rehabilitation of buildings. They are, however, important factors influencing the retrofitting of buildings, as was pointed out by Ma, et al. (2012).

Everything needs to work together

When meeting with Oslo Areal, one thing was made very clear. For the solutions in the building to work the way they were intended to, every single surface of the building facade has to work perfectly. If a window is wrongly installed or dimensioned or if a wall behaves differently than predicted, the whole system will be affected. This claim was supported by the literature in the studies done by Ma, et al., (2012) and Chidiac, et al. (2011). In order to achieve this, it is of high importance that everyone involved in the project and in constructing the building pay attention to detail. This level of control throughout the project becomes essential for everything to work together and can be quite challenging.

High level of occupant control

Achieving an appropriate and satisfying indoor environment is not easy. However, a trend is seen also in this aspect for the buildings studied here. They all provide high levels of user control of thermal conditions, as well as some provide control of shading devices. In the literature, this was emphasized as an important aspect for occupant comfort by Barlow and Fiala (2007). There will always be some people who complain about the temperature in a building, but by providing some level of user control, the complainants may be fewer. In Fredrik Selmers vei 4 the users can change the temperature up or down 1°C. The temperature can also be controlled by the users in Grensesvingen 7, while in Powerhouse Kjørbo, the temperature is not controlled locally, but can be changed by an administrator for larger areas. In addition to temperature control, the screens in both Fredrik Selmers vei 4 and in Powerhouse Kjørbo can be controlled by the users. Allowing for such high levels of occupant control may be a challenge, but it is also an occurring trend in the three buildings studied here.

Chapter 6

Stasjonsfjellet Skole

For a detailed study, the retrofitted part of a school building called Stasjonsfjellet Skole was considered. By doing several simulations on the building in the indoor climate and energy simulation program IDA ICE, the HVAC systems in the building and their ability to obtain a satisfactory indoor climate were evaluated. The simulation results in addition to a user survey performed on the employees on the school, were used to determine whether the focus on reducing the energy use of the building had adverse effects on the indoor climate.

6.1 General background

The information presented on the building and which forms the basis for the IDA ICE model has been collected from the project documentation, from engineers and from an architect involved in the project itself. Unless otherwise specified, the information that is not obtained by the author through the user survey or the simulation results is collected from these unpublished sources.

The background of the building is found from the technical description of the building. According to this the school is located at Stovner in Oslo, and it consists of one new and one old, retrofitted building. For the analysis here, only the old, retrofitted building is considered and will be described in the following. The building was constructed in 1982, then with a gross internal area (GIA) of 3400m^2. After the retrofitting, the building has a GIA of 4081m^2. As the building is a school building, it holds 340 pupils in total (for both the new and retrofitted building) according to the technical description. According to the principal of the school, there are 33 employees working in the school (Stette, 2015). The goal of the project was to reduce the energy use of the building by 50%. Before the the retrofitting of the building, the energy use of the building was on average 144.1 kWh/m^2 per year for the last three years. The technical description of the building also claims that according to SIMIEN calculations, the energy delivered to the building was 162.3 kWh/m^2 per year and the net energy demand was 160.2 kWh/m^2 per year. With the measures that were planned to be implemented and the passive house calculation in SIMIEN, the new energy demand was calculated to be 74 kWh/m^2 per year. The delivered energy to the building was calculated to be 55.6 kWh/m^2 per year from the passive house calculation method, and 65 kWh/m^2 per year after the energy certification calculation method. These calculations were, according to the technical description, done in SIMIEN.

6.2 Technical installations

According to the documentation, the building energy supply is provided by eight boreholes supplying heat for a ground source heat pump. For top-up heating an electrical boiler is installed. To heat the building both heated ventilation air at a constant 19°C is supplied, in addition to a water based radiator system. Both the heating batteries in the six air handling units and the water for the radiators is heated by the heat pump. The radiators, which are meant to lift the temperature from the 19°Cs from the ventilation air to the set point of 21°C, are placed under the windows along the facades of the building or along the internal walls. The exact placement, size and effects of the radiators are shown in the drawings in appendix N. As this is a school building, the classrooms do not have any means of local control of the temperature, although there are some level of control installed in the offices. The radiators are meant to allow for some adjustments from the occupant. There is no cooling or shading installed in the building, except for some light curtains. Also, over the west-facing wall of the A wing the roof continues past the external wall, shading this facade and some of the outdoor area around it. This can be seen in figure 8.1 in chapter 8.

Chapter 7

User survey

7.1 User Survey - Method

In order to establish whether the focus on reducing the energy use in Stasjonsfjellet Skole had had any adverse effects on the indoor environment, the staff and teachers in the building answered a user survey. In total, there were 33 employees in the building (Stette, 2015), of which 24 answered the survey. Of the 24 who answered, 13 were women and 11 were men. The survey was made as easy to understand and as descriptive as possible, and can be seen in appendix A. The questions and method (using scaling for most of the answers) in the survey were inspired by those in an example provided by Natasa Nord (2015). The questions deemed relevant were adapted by the author in cooperation with the school principal, Pål Stette, to make them suit the building and the level of insight of the school employees. The survey itself was answered in written form, during a common meeting held by Stette. It was he who oversaw the process, while the author collected the answer sheets when the meeting was over.

As the group of people that answered the survey was a mixture of teachers and administrative staff members, some of the questions would not be applicable to all. Therefore, it is highly expected for some to answer "Do not know" on some questions.

7.2 User Survey - Results

The results presented here are those considered most relevant. A complete overview of the answers can be seen in appendix B.

7.2.1 Women

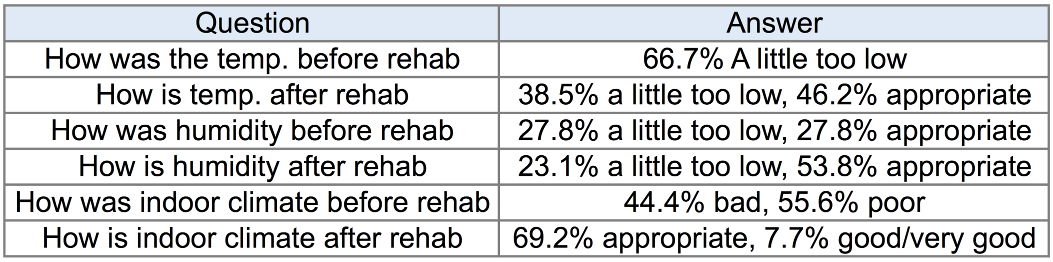
As could be expected, the survey yielded varying results. However, some trends were seen in the answers.

For the women, 9 out of the 13 (69%) had been present and had knowledge of the building before the rehabilitation took place. In calculating the percentages for the questions concerning the conditions before the retrofitting took place, this has been accounted for by only taking these 9 into account. Below the different results are presented and discussed.

Temperature, humidity and indoor climate

Table 7.1 below lists the different questions and most relevant results concerning the temperature, humidity and indoor climate in the building.

Table 7.1: Temperature, humidity and indoor climate



Question	Answer
How was the temp. before rehab	66.7% A little too low
How is temp. after rehab	38.5% a little too low, 46.2% appropriate
How was humidity before rehab	27.8% a little too low, 27.8% appropriate
How is humidity after rehab	23.1% a little too low, 53.8% appropriate
How was indoor climate before rehab	44.4% bad, 55.6% poor
How is indoor climate after rehab	69.2% appropriate, 7.7% good/very good

From the results in table 7.1 above, it is shown that the majority, 66.7%, found the temperature to be a little too low before the rehabilitation of the building took place. After, as many as 38.5% of the women still found the temperature to be a little too low. However, the highest percentage of opinions of 46.2% found the temperature to be appropriate.

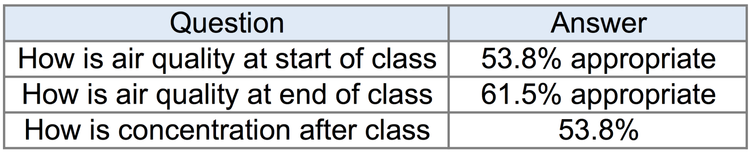
When it comes to the humidity in the building, only a few had an opinion, saying that it was either a little too low (27.8%) or appropriate (27.8%). After rehab, however, as many as 53.8% women found the humidity to be appropriate, and 23.1% found it to be a little too low.

Regarding the indoor climate, 44.4% found it to be bad, and 55.6% thought it was poor before rehabilitation. However, afterwards as many as 69.2% of the women found the indoor climate to be appropriate. As only 7.7% had answered good and one very good, it can be assumed that the women find the indoor climate to be fine, but not perfect, after rehab.

Effects on concentration and over time

The questions and answers concerning the effects on concentration over time are listed in table 7.2 below.

Table 7.2: Effects on concentration over time



Question	Answer
How is air quality at start of class	53.8% appropriate
How is air quality at end of class	61.5% appropriate
How is concentration after class	53.8%

The table shows that majority of the women considered the air quality at the beginning and the end of class to be appropriate and that their ability to concentrate is appropriate after class, indicating that it does not get worse with time. However, as the amount of time spent in a class room varies and the occupants have a break after as little as 45 minutes, it is likely that the short time interval that the room is in use at a time results in a better indoor environment.

User friendliness

When it comes to the user friendliness of the ventilation and heating systems, the questions and answers are listed in table 7.3 below.

Table 7.3: User friendliness of the heating and ventilation system

Question	Answer
How do you find the user friendliness of ventilation system	23.1% bad, 15.4% appropriate, 53.8% do not know
How do you find the user friendliness of heating system	23.1% bad, 15.4% appropriate, 46.2% do not know

Table 7.3 shows that when it comes to the user friendliness of the control of the ventilation and heating systems, the majority answered that they did not know, and a few found it to be bad. Only 15.4% found it to be appropriate. As some of the women, specifically those working in the offices, have more control than the women working in the classrooms it is likely that those who do not have control wish to have it.

Noise and lighting

In table 7.4 below, the questions and answers concerning the noise and lighting in the building are listed.

Table 7.4: Noise and lighting

Question	Answer
How do you find the sound/noise level of the ventilation system	38.5% appropriate, 38.5% very good
How did you find the lighting before rehab	88.9% appropriate
How do you find the lighting after rehab	84.6% appropriate

The noise levels from the ventilation system does not seem to bother the women, as 38.5% found it to be appropriate and 38.5% answered very good.

When it comes to lighting, the results from the survey indicate that it has been improved a little, as can be seen from the results in table 7.4, but as there were some that had not experienced the lighting before rehab, it is likely that the same people answered the same, with the "new" employees finding the lighting to be appropriate after rehabilitation.

Tiredness and overall satisfaction

The questions and answers concerning tiredness and overall satisfaction are listed in table 7.5 below.

Table 7.5: Tiredness and overall satisfaction

Question	Answer
Did you get tired at the end of class before rehab	55.6% no
Do you get tired at the end of class now	69.2% no
Were you satisfied with the indoor climate before rehab	100% no
Are you satisfied with the indoor climate now	76.9% yes
Do you think the indoor climate has improved	76.9% yes

Almost all the women either did not know or did not get tired at the end of class neither before nor after rehabilitation of the building. However, as as many as 100% of the women were not satisfied with the indoor climate before the rehabilitation, but now 76.4% women are, it is safe to say that the rehabilitation did improve the indoor climate of the building.

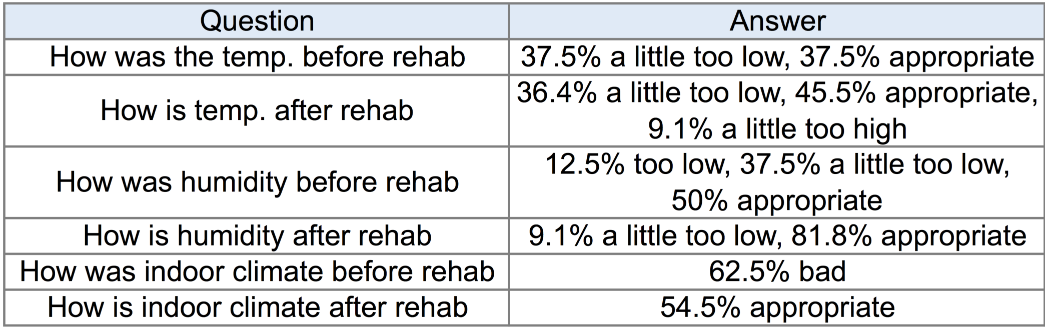
7.2.2 Men

Of the 11 men who answered the survey, only 3 were not present before the rehabilitation took place, while the remaining 8 (72.7%) had experience with the building before rehab. In calculation of the following percentages, this has been accounted for by only taking these 8 into account.

Temperature, humidity and indoor climate

The questions and corresponding answers concerning the temperature, humidity and indoor climate in the building are listed in table 7.6 below.

Table 7.6: Temperature, humidity and indoor climate



Question	Answer
How was the temp. before rehab	37.5% a little too low, 37.5% appropriate
How is temp. after rehab	36.4% a little too low, 45.5% appropriate, 9.1% a little too high
How was humidity before rehab	12.5% too low, 37.5% a little too low, 50% appropriate
How is humidity after rehab	9.1% a little too low, 81.8% appropriate
How was indoor climate before rehab	62.5% bad
How is indoor climate after rehab	54.5% appropriate

Of the men present before rehabilitation, as many as 37.5% found the indoor temperature to be a little too low and 37.5% found it to be appropriate. Although, after the rehabilitation, as many as 36.4% still found the temperature to be a little too low, and 45.5% found it to be appropriate. There were only 9.2% who thought the temperature was a little too high.

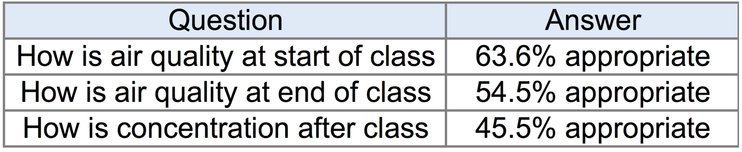
Regarding humidity in the building before rehab, 50% found it to be appropriate, 37.5% thought it was a little too low and 12.5% thought it was too low. Now, after rehab, as many as 81.8% of the men find the humidity to be appropriate and only 9.1% find it to be a little too low.

When it comes to the indoor climate before rehab, the 62.5% of the men found it to be bad before rehab, while after rehab a majority found it to be appropriate.

Effects on concentration and over time

In table 7.7 below, the questions and corresponding answers concerning the air quality and its effect over time are listed.

Table 7.7: Effects on concentration over time



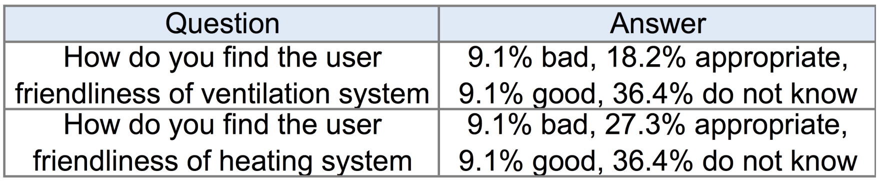
Question	Answer
How is air quality at start of class	63.6% appropriate
How is air quality at end of class	54.5% appropriate
How is concentration after class	45.5% appropriate

There appeared to be a very low percentage of the men who found the air quality to get worse at the end of class, indicating that the analysis done on the answers from the women applies to the men as well. A lot of the men seem to be content and happy with their ability to concentrate after class, supporting this assumption.

User friendliness

Below the questions and answers concerning the user friendliness of the heating and ventilation systems are listed in table 7.8.

Table 7.8: User friendliness of the heating and ventilation system



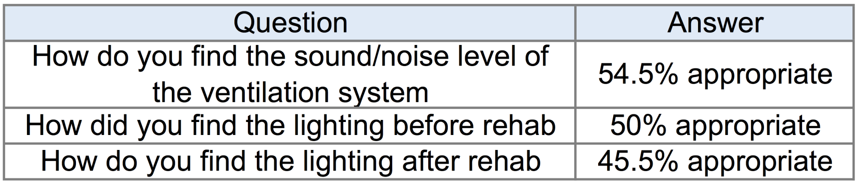
Question	Answer
How do you find the user friendliness of ventilation system	9.1% bad, 18.2% appropriate, 9.1% good, 36.4% do not know
How do you find the user friendliness of heating system	9.1% bad, 27.3% appropriate, 9.1% good, 36.4% do not know

Of the men, only 9.1% answered that the user friendliness of the ventilation and heating system was bad. Some found it to be good or appropriate, while most answered that they did not know. Compared to the response from the women, this may indicate that the local control may be desirable, but not as much for the men as for the women.

Noise and lighting

In table 7.9 below, the questions and relevant answers concerning the noise and lighting in the building are listed.

Table 7.9: Noise and lighting



Question	Answer
How do you find the sound/noise level of the ventilation system	54.5% appropriate
How did you find the lighting before rehab	50% appropriate
How do you find the lighting after rehab	45.5% appropriate

The results show that as for the women, the noise level does not seem to bother the men. Also, regarding the lighting levels, it seems that the men answered very similarly to the women, and that it can be concluded that the lighting is appropriate and has not changed as the building has been rehabilitated.

Tiredness and overall satisfaction

The questions and answers concerning tiredness and overall satisfaction are listed in table 7.10 below.

Table 7.10: Tiredness and overall satisfaction

Question	Answer
Did you get tired at the end of class before rehab	37.5% yes
Do you get tired at the end of class now	9.1% yes, 72.7% no
Were you satisfied with the indoor climate before rehab	87.5% no
Are you satisfied with the indoor climate now	72.7% yes
Do you think the indoor climate has improved	54.5% yes, 36.4% do not know

The table shows that 37.5% of the men answered that they got tired at the end of class. After rehab, however, only 9.1% still got tired at the end of class and as many as 71.7% did not.

Of the eight people who had experience with the building before the rehabilitation, as many as 87.5% were not satisfied with the indoor climate. After rehab, as many as 72.7% of the men are satisfied with the indoor climate, 54.5% thinking it has improved and 36.4% do not know.

Other comments

In addition to the answers presented above, there were some comments made by the participants of the survey. When asked if there were any particular rooms that had a worse indoor climate than others, the following were mentioned:

- Computer lab (Zone 126) (3 women, 3 men)
- Workroom teachers (Zones 175 and 198) (3 women)
- Bandroom (Zone 10)(2 women)
- Toilets 1st floor (2 women)
- Classrooms in 1st floor (1 woman)
- Carpenting room (Zone 23) (1 woman)
- Computer lab (Zone 120) (1 woman)
- Food and heath (Zone 155) (1 woman)
- Gym (Zone 37) (1 woman, 1 man)
- Personnel room (Zone 189) (1 man)

The number of men or women who mentioned the different rooms are listed in brackets. Although some of the rooms were only mentioned by one person, it may be as relevant as the others, as not all teachers use all the different rooms of the building. However, it is quite clear from the number of people having mentioned the computer lab in zone 126 that this is a zone that does not have a good indoor climate.

In addition to being asked if any rooms in particular had a bad indoor climate, the teachers were asked if they had any other concerns or comments regarding the indoor climate. Although not too many had anything to add to the survey, a few mentioned the temperature in the building as being a problem. Except for one man, they all were concerned that the temperatures were too low. In particular, three comments were quite informative. The first were: "Students think it is too cold in the classrooms. I do not notice this. BUT I notice it when we are having personnel meetings. Then I am sitting still and get colder. Many of us are cold after communal time". Two others mention that the temperature also varies quite a bit, and is different between rooms at the same time. In the workroom for teachers (assuming they mean zones 175 and 198 as these are facing the south and southwest respectively) it was commented on as the temperature being very high when the sun is shining.

In addition to commenting on the temperature not being appropriate, one woman added that the ventilation and heating systems can only be controlled by one person who is not always present.

Chapter 8

Model Description

In order to study the indoor environment and the energy use of Stasjonsfjellet Skole the simulation programme IDA ICE (Indoor Climate and Energy) version 4.6.1 was used to model and simulate the building. A complete and as realistic a model as possible was made in order to make the simulation results as close to the real life situation as possible. The model was made based on information found in the project documentation and information provided by the engineers and architect involved. However, as some of the input data was unavailable, some assumptions and approximations have been made. The following will explain what values and estimates that have been used in this IDA ICE model.

8.1 Shape and physical description

The building and its three wings, A, B and C is shown in figure 8.1 below. The roof over the west wall of the A wing continues on past the wall, shading the facade underneath. This is indicated by the line parallel and next to this wall in the figure below. The shape of the building is also shown here.

Figure 8.1: Building shape and shading roof

Wing A refers to the north wing, wing B the south wing and wing C the west wing. The A wing only has one floor, while the B and C wings have two floors. On the roof of wings A and C there are also two technical rooms. In order to create the correct geometry and room division of the building, the blueprints, section drawings and facade drawings of the building were used as a base on which the building body and zones were drawn. Although IDA ICE allows for an .ifc file to be used as a base for a model, the .ifc file for this building did not work. In stead, a .dwg file was used as a drawing base. The blueprints can be found in appendix C. The roof of the building was made using the blueprint of the roof, section drawings and facade drawings. The section drawings can be found in appendix D and the facade drawings in appendix E. As the geometry of the roof was quite challenging to recreate, a few simplifications were made, but none that will have a major impact on the simulations. The simplifications done involved defining one height of the roof where it is flat (over the hallways in wing B), so that it became one flat surface in stead of five segments of slightly different heights.

8.2 Global Data

The following describes the *Global Data* in the IDA ICE model, which is default values and general descriptions applying to the whole building.

8.2.1 Location, holidays and shading

As the building is located at Stovner in Oslo, the location and climate defined in the model had two choices. These were either Gardermoen or Frogner. As neither location were exactly the same as Stovner, the closest climate was chosen to be Gardermoen. This was confirmed by a Norwegian climate guard (Mamen, 2015), who was consulted to establish which of the two locations that would have a similar climate and weather as Stovner. The area around the building has previously been described as surrounded by dwellings and trees, making it natural to choose a suburban wind profile. Since the buildings is a school building, it will not be in use all times of the year. By using the public calendar for schools in Oslo (Oslo Kommune Utdanningsetaten, 2012) and the holiday calendar of the school itself (Stasjonsfjellet Skole, n.d.), the holidays of the building was found and defined as shown in appendix F. However, the holidays were defined differently for the two main simulation scenarios that will be explained in the next chapter.

8.2.2 Defaults

Elements of Construction

The default values for the elements of construction in the building were defined based on drawings and descriptions provided by the architect. The U-values and thicknesses that were used were the values provided and found in the documentation, but the density and specific heat were set to values of default materials defined in the program. The values are tabulated in appendix G. As no internal door construction or glazing description was available, they were both set to default properties. For the internal door construction this involved using wall construction, while the glazing was set to 3 pane glazing, clear, 4-12-4-12-4. External doors were defined as windows, as they had a high percentage of glazing installed.

Generator Efficiencies

The generator efficiencies were all set to be electric with default values. The default values were:

- Heating: COP = 1
- Cooling: COP = 3
- Domestic hot water: COP = 1

Energy meters and Other

The energy meters were not changed, but under ”Other”, the zone model fidelity was chosen to be Climate. This was because the intention for the simulations were to find information on both the indoor climate and on the energy parameters of the building. This results in a need to use the most detailed model where possible. However, the Climate fidelity is only possible for rectangular zones, making all non-rectangular zones use the Energy fidelity.

Site shading and orientation

As the building is located in a clearing and immediately surrounded by trees, with dwellings beyond them, no shading objects were inserted into the model. If it had been possible, some trees would have been added, but as trees do not shade as densely as a building, such an approximation did not seem accurate enough. However, the orientation of the site was defined as 295 degrees, so that it was positioned as shown in figure 8.2 below:

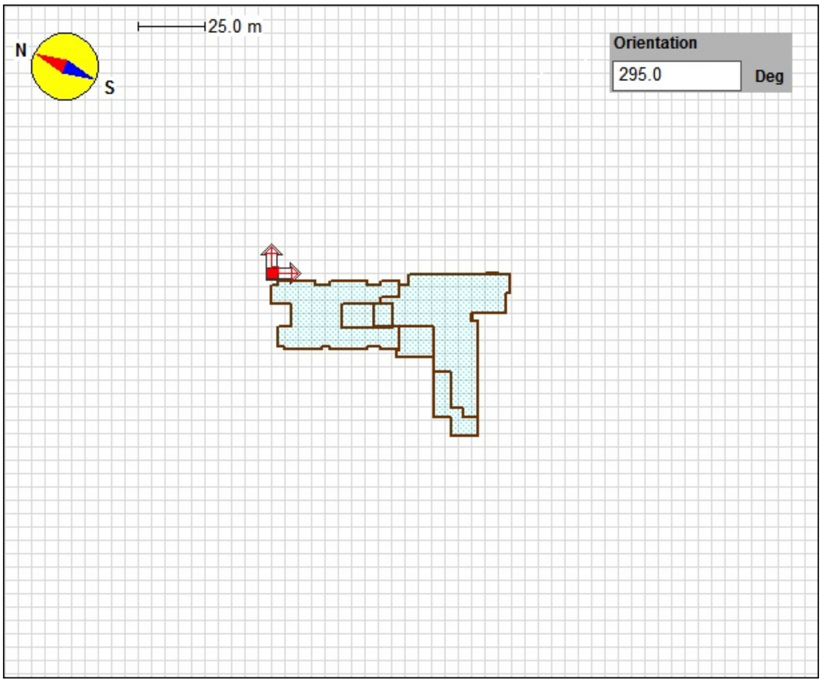


Figure 8.2: Orientation of the building

Thermal bridges

Based on calculations and documentation from the engineers, the thermal bridges were given *typical* or better values, as can be seen in appendix J.As there were no balconies, the balcony value was set to an arbitrary value. Furthermore, the external doors were assumed to have approximately the same value as the windows as they were not given a specific value in the documentation. The external slab/internal wall was also not found, and therefore set to a *typical* value of 0.04 W/mK. Although the building is meant to be of passive house standard, it only meets the requirements of a low-energy building with the total envelope area value of 0.04 W/m^{2}K. The passive house criteria is 0.03 W/m^{2}K (Standard Norge, 2012).

Ground Properties

The ground properties are chosen based on values from the calculations done by the engineers. The ground underneath the floor is defined as 3.2 m of sand/gravel. The calculation documents refer to NS 3031 table B.8 (Standard Norge, 2014), giving the sand/gravel a heat conductivity of 2.0 W/mK. The density and specific heat are set to default values.

In contrast to the ground properties, the calculation documents say that the ground layers outside basement walls are of mountain properties, with a heat conductivity of 3.5 W/mK (Standard Norge, 2014). Furthermore, these walls have different layers than the other external walls. Therefore, the ground layers outside the basement walls are defined as 0.20m of concrete, 0.15m of expanded polystyrene and 4.2m of mountain properties. The concrete and polystyrene are given heat conductivities of 2.5 W/mK and 0.037 W/mK respectively. The density and specific heat are given default values to similar materials.

Infiltration, extra energy and system parameters

As the building is known to be close to passive, the air tightness is defined as 0.6 ACH at a 50 Pa pressure difference (Standard Norge, 2012). This is used to define the infiltration in the building, using wind driven flow. Due to the building being in a clearing with trees and dwellings relatively close to it, the pressure coefficients are auto filled with a semi-exposed profile. Furthermore, there have not been defined any extra energy or losses, nor have the system parameters been edited. This is because there are no good reasons to make changes to these variables, so they are set to default.

8.2.3 Plant

The plant is designed to include the following components:

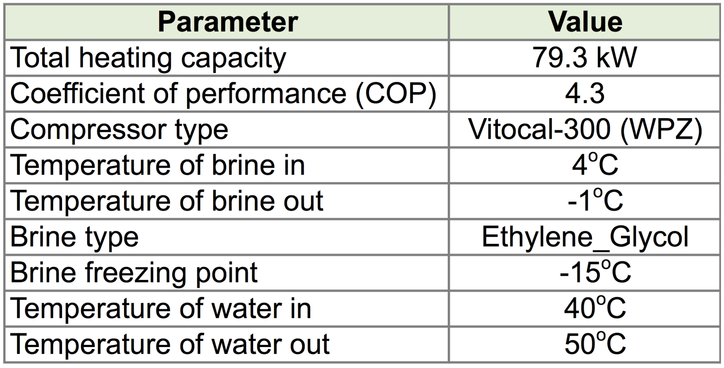
- Base heating: Brine-to-water heat pump
- Ground heat exchange: Ground source borehole loop
- Top up heating: Generic electricity heater
- Hot storage: Generic hot water tank
- Cold storage: Cold water tank

The system form created by the engineers, describing the plant and its connections, can be found in appendix K.

Heat Pump

The heat pump that was used in the building was delivered by Novema Kulde AS, of the type WRL 400X. The details of the heat pump are shown in the table below:

Table 8.1: Heat pump characteristics



Parameter	Value
Total heating capacity	79.3 kW
Coefficient of performance (COP)	4.3
Compressor type	Vitocal-300 (WPZ)
Temperature of brine in	4°C
Temperature of brine out	-1°C
Brine type	Ethylene_Glycol
Brine freezing point	-15°C
Temperature of water in	40°C
Temperature of water out	50°C

The compressor type was chosen because it closely resembled the actual compressor used (both being scroll compressors). Furthermore, the brine type used in the actual heat pump was R410a. This was not an option in IDA ICE, but as the COP and temperatures were overridden, the choice should not be of too great concern.

Ground source borehole loop

To supply the base heater, ground source borehole loops were included in the plant. There were eight loops of 200m depth.

Generic Electricity Heater

The generic electricity heater was given a maximum capacity of 210W, with a COP of 1. The energy carrier and energy meter were given default parameters being electricity for both.

Generic hot water tank and generic cold water tank

The volume of the generic hot water tank was chosen to be 1 m^3 from the system description. As there was no cooling installed in the system (apart from the possibility of installing a cooling loop from the boreholes), the generic cold water tank was given a volume of 0.1 m^3. As all the other input values were unknown, they were set to default for both tanks.

Distribution system

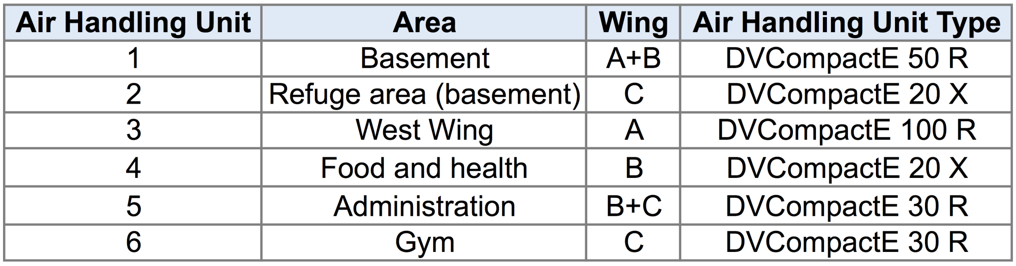
To heat the building, the heat pump supplied hot water to the air handling units and to a radiator system in the rooms. For the radiators, the room supply temperature set point was set to follow an ambient temperature compensation curve, with the set points <-15°C:50°C>, <0°C:40°C> and <15°C:30°C>. The air handling units had a supply temperature set point of 50°C. The pump pressure head was found in the system description to be 30.3kPa. The pump efficiency and shut off ambient temperature were set to default values.

Although no cooling was installed, values had to be assigned to the cold water tank and cold distribution system. Apart from giving the pressure head the same value as for heating, namely 30.3 kPa, the different values for the cold distribution system were set to default.

8.2.4 Air handling units

The project documentation describes six different air handling units (AHU) in the building, each supplying different areas in the building. The area supplied by each, as well as the type of AHU, is shown in table 8.2 below:

Table 8.2: Air Handling Units



Air Handling Unit	Area	Wing	Air Handling Unit Type
1	Basement	A+B	DVCompactE 50 R
2	Refuge area (basement)	C	DVCompactE 20 X
3	West Wing	A	DVCompactE 100 R
4	Food and health	B	DVCompactE 20 X
5	Administration	B+C	DVCompactE 30 R
6	Gym	C	DVCompactE 30 R

The six air handling units are all delivered by Systemair and are dimensioned for the worst case scenario. Four of them have a rotating heat exchanger and the other two a cross flow heat exchanger. The heat exchanger type is indicated by the last letter under ”Air handling unit type” in table 8.2, with X meaning cross flow and R meaning rotating heat exchanger. However, there is no choice of heat exchanger type in the IDA ICE program. In the model, all six air handling units are built up the same way. The air comes into the AHUs, enter a heat exchanger, then there is a fan installed before a heating coil. On the exhaust side, the air comes in to the heat exchanger, through the fan and out. The schematic is described in the figure below:

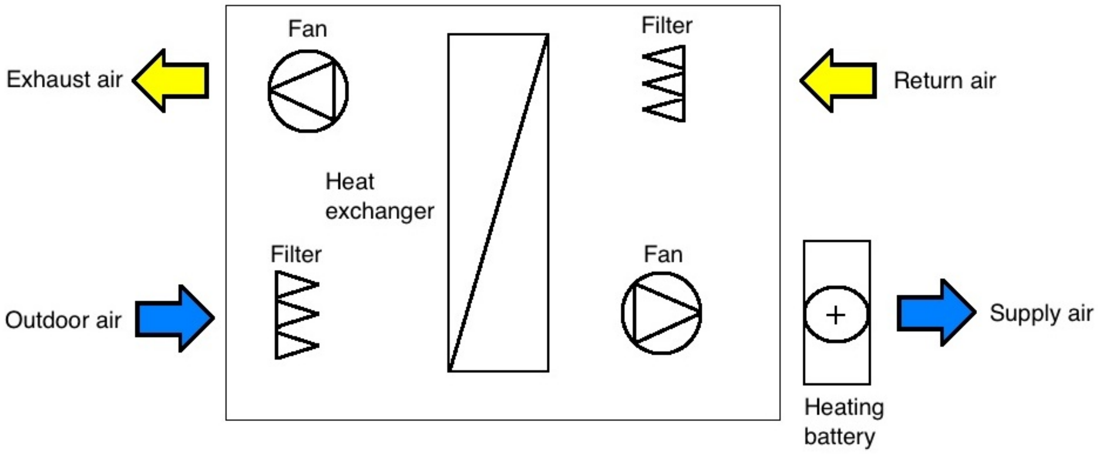
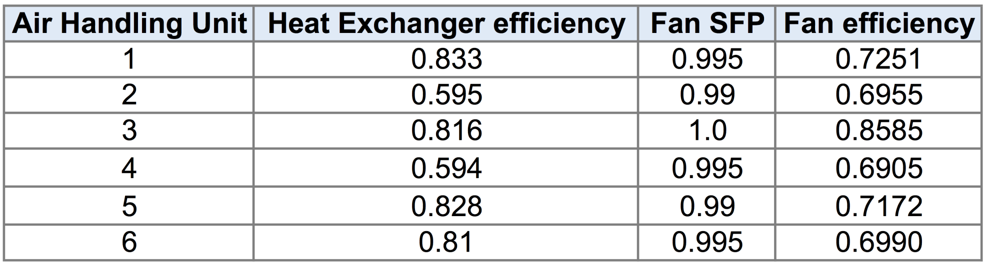


Figure 8.3: Air handling unit description

The supply air temperature is to be kept at a constant 19°C. Therefore, the heating batteries are chosen to be size free so they can take in the constant temperature signal. The fans in the air handling units are set to operate at 100% from 07 to 17, and at 20% otherwise and during weekends and holidays. The heating batteries are set to default values. The first default value is an air side effectiveness that is set to 1, since the batteries are said to be size free with a given temperature drop on the liquid side. The other sets the liquid side temperature drop of the heating coil. From the project documentation, the heating coil is known to have a temperature drop of 20°C, which is the same as the default value.

The efficiencies of the heat exchangers in the different AHUs were given in the product description, but the efficiency and SFP for the fan had to be calculated. By adding up all the pressure drops internally and externally in the AHU (given in the product description) and dividing the total on the total SFP of the AHU the efficiency was found (assumed to be the same for both fans). The SFP per fan was assumed to be approximately the same, so the total SFP (given by the product description) was divided by two. The calculations can be seen in detail in appendix L. For each AHU, the resulting values are listed below:

Table 8.3: Air Handling Units



Air Handling Unit	Heat Exchanger efficiency	Fan SFP	Fan efficiency
1	0.833	0.995	0.7251
2	0.595	0.99	0.6955
3	0.816	1.0	0.8585
4	0.594	0.995	0.6905
5	0.828	0.99	0.7172
6	0.81	0.995	0.6990

For the fans, the air temperature is estimated to be a constant 1°C and the VAV part load performance is unknown and therefore set to be unlimited. The choice of energy meter was set to default, being auxiliary HVAC. The heat exchanger is given the default minimum leaving temperature of 1°C.

8.2.5 Zones

Zone templates

When inserting zones into the building some templates were used. However, as the building was meant to be as realistic as possible, each zone had to be edited after it had been created. The different templates that were used were:

- Classroom
- Toilet/changing room/shower
- Hallway
- Office
- Other - multipurpose room
- Technical room
- Cupboard/storage/IT services

There were several values used in all zone templates. The values used are tabulated in appendix M, with the class room template as an example. The table in the appendix also indicates which values that were changed for each specific zone, and which were different for each template. The background for the value is also shown. As the building is meant to be close to passive, the lighting and equipment values were defined as 1 unit per m^2 and then the correct W/unit in order to make it comply with the passive house standard, NS 3701:2012.

For each zone, the position of the occupant in the room had to be defined. This was set to be in the middle of the room.

Zone approximations

As some of the rooms were not as interesting to study in detail, the corresponding zones were made to include more than one room. This was also in some places done in order to get the geometry of the roof as correct as possible. The rooms naturally had to be located next to each other, and they had to get their ventilation air from the same air handling unit. Wherever rooms were combined, all the relevant zone parameters were adjusted to include the correct area and room specific values. The rooms types that were combined into zones were:

- Toilets, changing rooms and showers
- Hallways
- Elevator and ventilation shafts were combined with the most convenient adjacent zone
- Storage rooms
- Hallway, cupboard, storage and IT services

The geometry in and around the library area also made it necessary to divide the originally open hallways and library into three zones, with openings in the walls where the three zones met. As the basement had a different shape than the first floor, making the roof of the basement inconsistent with the roof of the building, the toilet, shower and changing room zone, as well as the storage zone, in the basement had to be divided into two. The zones are shown in the figures below, with the combined zones in the basement and the library zones in the first floor highlighted in red:

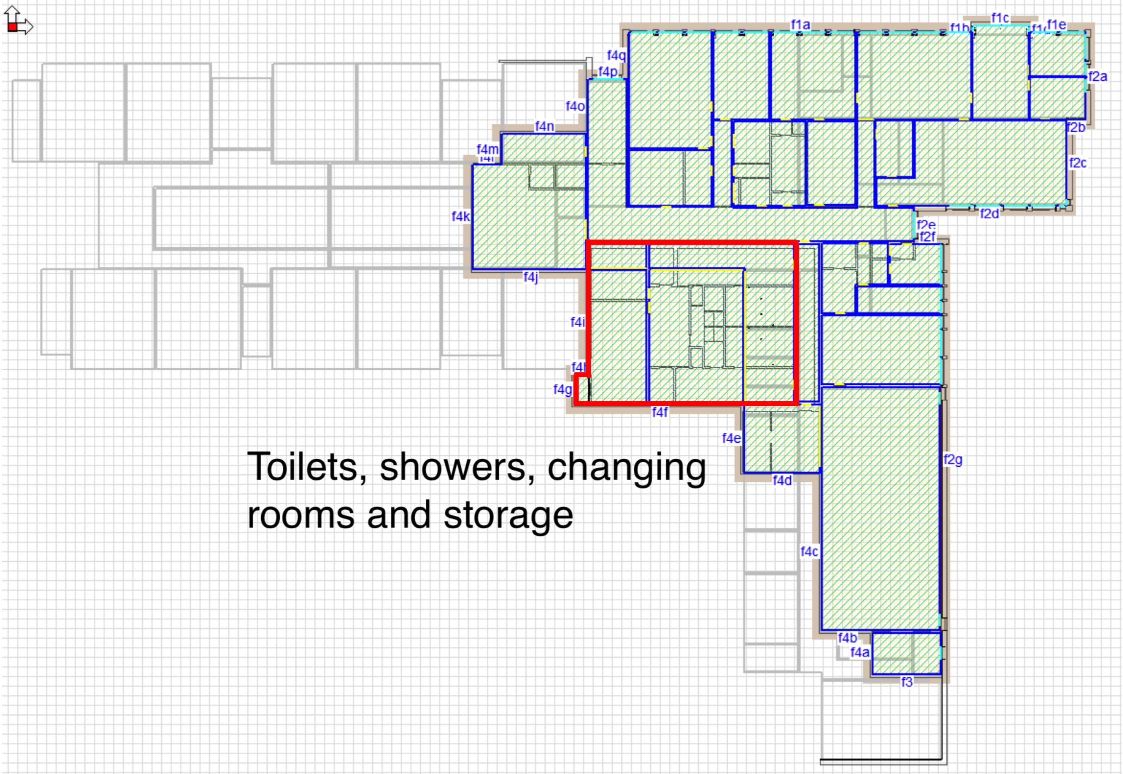


Figure 8.4: Zones in the lower level

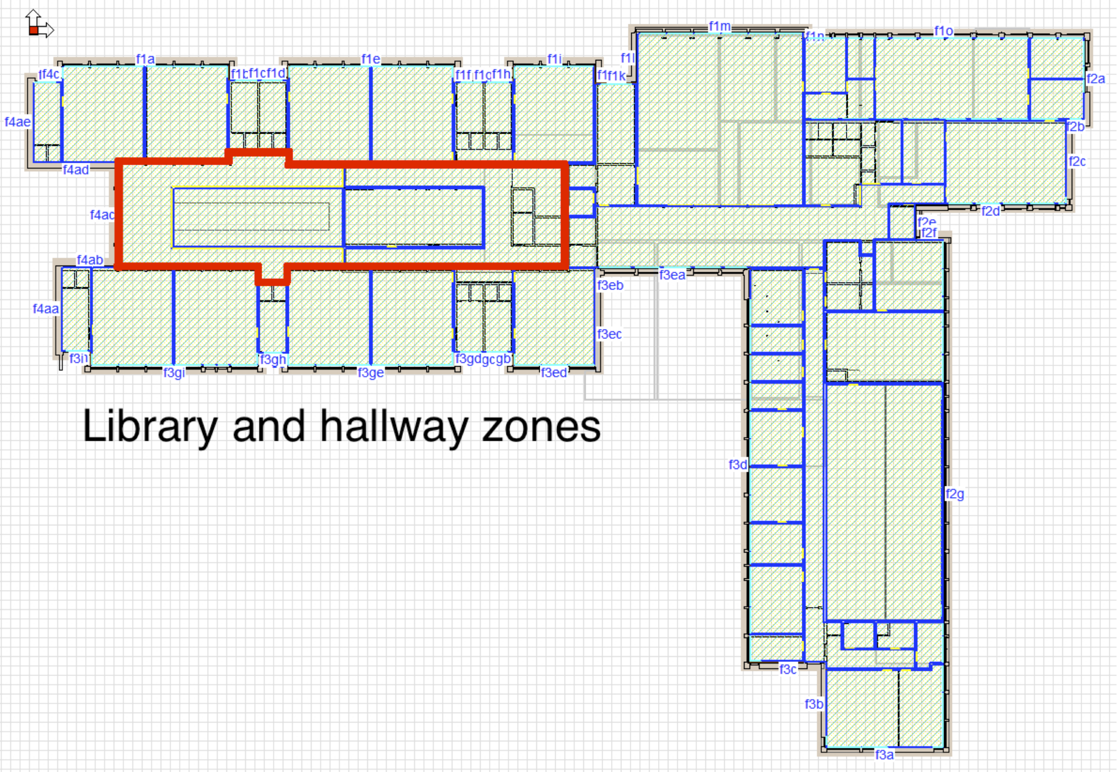


Figure 8.5: Zones in the lower level

Zone specific values

Although zone templates were used when making the different zones, each one of the zones were changed to get ensure that the correct values were modeled. Which values that were changed is illustrated by color in appendix M. In addition to changing the values in the zone, the doors, windows and radiators were placed in the correct position and with the correct geometry according to the blueprints, section drawings, facade drawings and the radiator drawings found in appendices C, D, E and N, respectively. The different types of windows that were used are listed in appendix H, and are differentiated according to the wings they were used in. The same applies for the external doors, which you can find in appendix I. As indicated in the table in appendix M, the room height was changed locally in each zone, according to the different drawings in appendices C, D and E. This was because some zones had a suspended ceiling and in others the ceiling went up to the roof. Where there was a suspended ceiling, the room height was set to the original value of 2.7m, but the ceiling was changed to have an internal construction called *Internal floors1 - suspended ceiling*, if the zone was in the basement, and to have an external construction called *Roof - Stasjonsfjellet - suspended ceiling* elsewhere. These were the same as the default constructions, but with and added 1m air gap in order to make up for the air gap that would have been present with an actual suspended ceiling. Please note that this is an approximation, as there would be several other effects of having an actual suspended ceiling, but IDA ICE does not allow for the inclusion of such ceilings at this point.

In addition to the values that were defined in the zone templates, the furniture in the room had to be changed for each zone. By using the estimated number of people in the classrooms from the air flow rate forms and a furnishing drawing (of a different building) in MagiCAD, the furniture was estimated to be as realistic as possible. Furthermore, the daylighting levels were defined for each zone, based on the activities it was meant for (Novakovic, et al., 2007).

The air flow rates were specific for each room/zone, and were found using the project documentation. In addition to the air flow rate, the specific air handling unit, whether VAV or CAV was installed in addition to supply and return air for CAV (if applicable) were defined for each specific zone.

In addition to all the different values mentioned, the zone specific values for occupants (number of occupants, schedule, activity level and clothing level) for each zone is defined in appendix O.

Chapter 9

Simulation Scenarios and Criteria

For this study, two main scenarios were considered. For both scenarios, the model itself was built up to be as realistic as possible. This involved using all information available to create a model of the building the way it was designed and meant to be. However, some settings were changed for the two scenarios. In addition to studying two different model scenarios, the effects of different installations and settings for each of the two scenarios were also studied. The two scenarios, and sub-scenarios, will be presented here.

9.1 Scenario one - Normative Scenario

For the normative scenario, some of the settings and set points were set to the values that were used in SIMIEN simulations from the project documentation and from NS 3031:2014 Beregning av bygningers energiytelse. Metode og data (Standard Norge, 2014). The conditions were:

- 100% occupancy
- 7 weeks of summer holidays (emphasized in yellow in appendix F) (Standard Norge, 2014)
- 1 week of Christmas holidays (emphasized in yellow in appendix F) (Standard Norge, 2014)
- 10 hours for occupancy in all areas and zones for 5 days per week (Standard Norge, 2014)
- Set point temperatures, throughout the year, being 21°C during occupancy and 19°C at all other times (Standard Norge, 2014)
- An average number of people per m^2 (see calculation and description below)
- Even equipment and lighting units. These were set to be 1 unit/m^2 and 4 W/unit equipment and 4,5 W/unit for lighting, in order to get the standard values (SIMIEN files and Standard Norge, 2012).

This scenario is used for comparison against the SIMIEN report that was made for the project by the project designers.

Although rooms such as hallways and storage rooms are not considered to have equipment in them, the model had to include equipment also here, to get the correct units/m^2. The number of people per m^2 were decided by multiplying the total floor area in the building with 12 W/m^2, which is the standard value from NS 3701:2012 (Standard Norge, 2012). This was then divided by 100 W/person (Novakovic, et al., 2007), which yielded a total number of people that had to be in the building. This number were then divided by the total area of the occupied zones. This resulted in a number of people per m^2. Lastly, this number was then multiplied with the area in each occupied zone, to assign a specific number of people to that zone. The calculation can be seen below:

Total floor area: 3 882.74 m^2
Heat gain from people: 12.0 W/m^2
Heat gain per person: 100 W/person (Novakovic, et al., 2007)
Total floor area of occupied zones: 2292.63 m^2

Total heat gain: 3 882.74 m^2 × 12.0 W/m^2 = 46592.88 W

Total number of people: $\frac{46592.88W}{100W/person} \approx$ 466 people

Number of people per m^2: $\frac{466people}{2292.63m^2} \approx \underline{0.2033 \text{ person/m}^2}$

In addition to the Normative scenario, there were six different effects that were simulated. These different settings and installations were:

- External shading
- Internal curtains
- No internal gains
- Reduced occupancy to 60%
- Occupants positioned close to the windows
- Cooling batteries installed in the AHUs

The 60% occupancy was chosen based on information from Hans Martin Mathisen (2015), who explained that through a study of two schools in Trondheim it had been found that the occupancy was approximately 50%. After discussing with the engineers in Hjellnes Consult AS, however, it was decided to increase it to 60%.

9.2 Scenario two - Actual use

The second scenario was designed to be comparable to the results and feedback from the user survey and to compare the actual versus the project designed energy use and indoor environment. Although the model was the same, some conditions were changed to make the use of the building as realistic as possible. The conditions in this scenario were:

- All holidays, including bank holidays, for 2014 (assuming that the teachers and staff are using the building the week before the school year starts)
- Reduced set point temperature during the summer holidays (15°C) in order to remove any heating demand
- Real time schedules for each classroom and specific purpose room (appendix P)
- Schedule for all other rooms set to the normal working hours of 8 to 16 (according to Stette (2015))
- Reduced occupancy to 60% (explained as for the Normative scenario)
- 100% internal gains except occupants
- Equipment divided between zones that include equipment (see explanation below)

The holidays for this scenario were defined as listed in appendix F. These dates were based on information from both the school website, concerning holidays (Stasjonsfjellet Skole, n.d., *Ferier og fridager*) and from the municipality (Oslo Kommune Utdanningsetaten, 2012). The schedules for the classrooms and specific purpose rooms were based on those available from the school website (Stasjonsfjellet Skole, n.d., *Timeplaner for Stasjonsfjellet Skole*).

The equipment in the building was assigned to the different zones. In zones such as the computer labs and the Food and Heath room, the equipment was given an approximate value based on the design of the room. The heat gain from stoves/ovens was inserted into the zone, but it was not deducted from the total amount of heat gain from the equipment in the building. However, the heat gain from the computers assumed to be in the room was added up and deducted from the total amount of heat gain from equipment in the building. The remaining heat gain was then divided by the total area of the zones (including computer labs) with equipment in them, in order to get a standard heat gain per m^2. This was then multiplied with the specific area in each zone. This was calculated in the following way:

Total floor area: 3 882. 74 m^2
Heat gain from equipment: 4.0 W/m^2
Heat gain from computers: 20 units × 150 W/unit = 3000 W (150 W/unit: estimate

from values given by Novakovic et al. (2007))
Total floor area of zones with equipment: 2 466.12 m^2

Total heat gain from equipment: 3 882.74 m^2 × 4 W/m^2 = 15 530.96 W
Remaining heat gain from equipment: 12 530.96 W
Heat gain from equipment per m^2: $\frac{12530.96W}{2466.12m^2} \approx \underline{5.081\ W/m^2}$

With one unit/m^2 × 5.081 W/unit in the model, the result becomes 5.081 W/m^2.

For the Actual scenario, three different effects were studied. They were:

- External shading
- No internal gains
- 100% occupancy

The results from all these simulation scenarios are presented and discussed in the next chapter.

Chapter 10

Simulation results

The different simulations yielded many results. In the following, the results considered most important are presented and analyzed.

10.1 Simulation Results and Analysis of Scenario One - Normative

In this section the results from the Normative simulation, as well as the results of the different effects that were simulated, are analyzed.

10.1.1 Normative Analysis

Energy

The Normative scenario resulted in an energy use for the building of 71.7 kWh/m^2, which is below the preliminary estimated energy demand that was calculated with the passive house calculation in SIMIEN, as a goal for the project, being 74 kWh/m^2. Below the delivered energy overview and the monthly delivered energy is shown in table 10.1 and figure 10.1.

Table 10.1: Delivered energy overview

		Delivered energy		Demand	Cost	
		kWh	kWh/m^2	kW	Kr	Kr/m^2
🟨	Lighting, facility	45238	11.7	18.1	38497	9.9
🟩	Equipment, facility	25123	6.5	8.09	21382	5.5
🟦	Electric cooling	0	0.0	0.0		
	Energy pumps	228	0.1	0.36	194	0.0
	Energy fans	62170	16.0	29.49	52906	13.6
	Total, Facility electric	132759	34.2		112979	29.1
	Total	132759	34.2		112979	29.1
□	Equipment, tenant	14656	3.8	6.63		
□	Heating, tenant	133358	34.4	396.2		
	Total, Tenant electric	148014	38.1		0	0.0
🟩	CHP electricity	0	0.0	0.0		
	Total, Produced electric	0	0.0		0	0.0
	Grand total	280773	72.3		112979	29.1

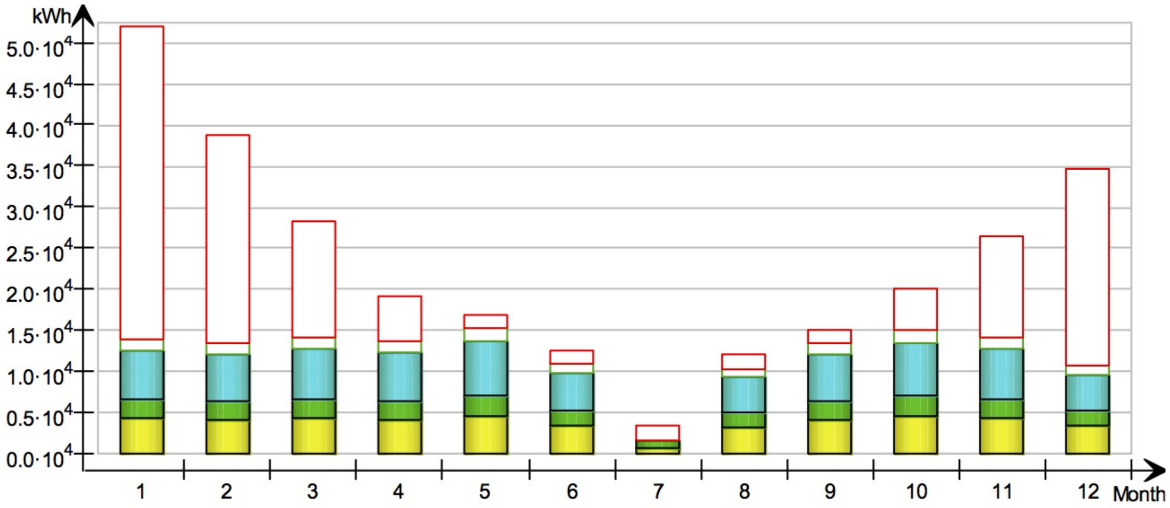
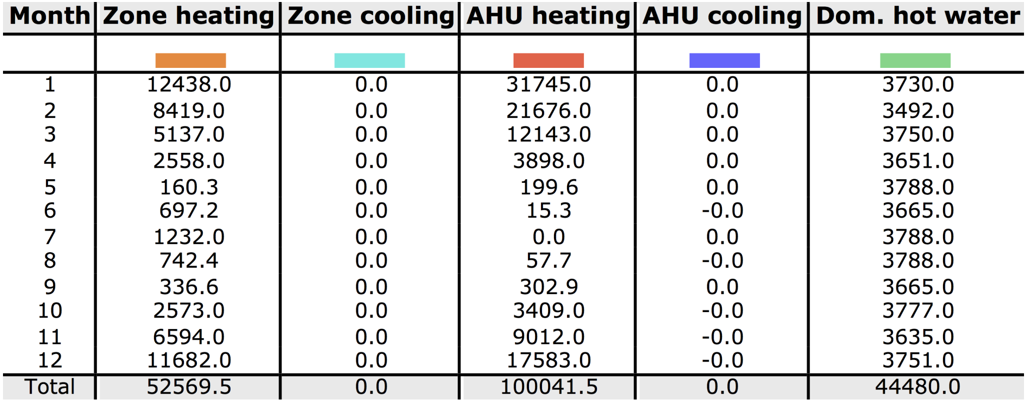


Figure 10.1: Monthly delivered energy

As the delivered energy overview indicates, approximately half of the energy demand is associated with the heating demand in the building. The second largest energy demand is the energy for the fans, with the energy for lighting being the third largest post. For a building in the cold Norwegian climate, the heating will naturally have a high demand.

This is also clear from the graph showing the monthly delivered energy, with the energy demand being highest in the cold winter months, and very low in the warm summer months. Below is a table showing the used energy in the building.

Table 10.2: Used Energy



Month	Zone heating	Zone cooling	AHU heating	AHU cooling	Dom. hot water
	🟧	🟦	🟥	🟦	🟩
1	12438.0	0.0	31745.0	0.0	3730.0
2	8419.0	0.0	21676.0	0.0	3492.0
3	5137.0	0.0	12143.0	0.0	3750.0
4	2558.0	0.0	3898.0	0.0	3651.0
5	160.3	0.0	199.6	0.0	3788.0
6	697.2	0.0	15.3	-0.0	3665.0
7	1232.0	0.0	0.0	0.0	3788.0
8	742.4	0.0	57.7	-0.0	3788.0
9	336.6	0.0	302.9	0.0	3665.0
10	2573.0	0.0	3409.0	-0.0	3777.0
11	6594.0	0.0	9012.0	-0.0	3635.0
12	11682.0	0.0	17583.0	-0.0	3751.0
Total	52569.5	0.0	100041.5	0.0	44480.0

The ventilation air temperature is set to be a constant 19°C. As the set point temperature for when the building is in use is 21°C, the supply air temperature will take care of most of the heating demand, with the radiators rising the temperature the last two degrees. This results in the heating need for the ventilation air (AHU heating) to be much higher than that of the radiators (zone heating). In table 10.2 above, the energy used for AHU heating is clearly much higher in the colder months, while the radiators have a higher demand when the outdoor temperature is higher, and presumably closer to 19°C. The heating demand for domestic hot water (DHW) is also quite high, but the by far highest total over the year is the AHU heating and the zone heating demand. As there is no cooling installed in the building, there is naturally no cooling energy demand.

Ground heat

According to the results from the Normative simulation, the amount of ground heat that is utilized for the whole year is 59 131 kWh, which is only 44.3% of the total delivered energy for heating. From the project documentation, the SIMIEN passive house evaluation showed that the borehole heat pump is meant to supply both this building with 90% of the total necessary heating demand, in addition to supplying the new building that is not considered here. It would therefore be expected that the amount of energy delivered by the heat pump to this building alone should be much higher. Something may therefore be wrong with the heat pump either in the IDA ICE model or in the SIMIEN calculations.

Building comfort and work loss results

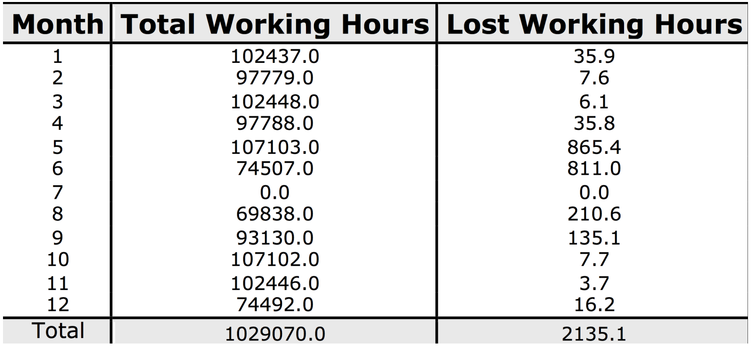
The building comfort reference indicates three measures for building comfort. These are:

- Percentage of hours when operative temperature is above 27°C in worst zone
- Percentage of hours when operative temperature is above 27°C in average zone
- Percentage of total occupant hours with thermal dissatisfaction

For the first measure, the result for the Normative scenario was 13%. On average for all zones however, the percentage of hours with operative temperature above 27°C was only 1%. Although the percentage was very much lower on average, the percentage of total occupant hours with thermal dissatisfaction was as high as 6%. As 27°C is a quite high temperature in the first place, these three values indicate that there is a significant cooling need in the building.

The indication for a cooling need is strengthened by the amount of lost working hours due to under or over heating, which are listed below:

Table 10.3: Working hours lost



Month	Total Working Hours	Lost Working Hours
1	102437.0	35.9
2	97779.0	7.6
3	102448.0	6.1
4	97788.0	35.8
5	107103.0	865.4
6	74507.0	811.0
7	0.0	0.0
8	69838.0	210.6
9	93130.0	135.1
10	107102.0	7.7
11	102446.0	3.7
12	74492.0	16.2
Total	1029070.0	2135.1

From October to March the lost working hours are not too many, but especially May and June have very high numbers of hours lost. Apart from July, August and June are the two months with the least amount of working hours. This indicates that June is a very bad month compared to the others.

AHU - temperature

According to the IDA Indoor Climate and Energy 4.0 manual (EQUA Simulation AB, 2009), the set point temperature in the air handling unit sets the temperature of the air when it exits the AHU. When the air reaches the terminal, however, it will have gained or lost heat. The supply air temperature given by the simulation results therefore shows the temperature of the air when it reaches the zones. The graph below shows the temperatures in AHU 3 (the trends were the same for all air handling units).

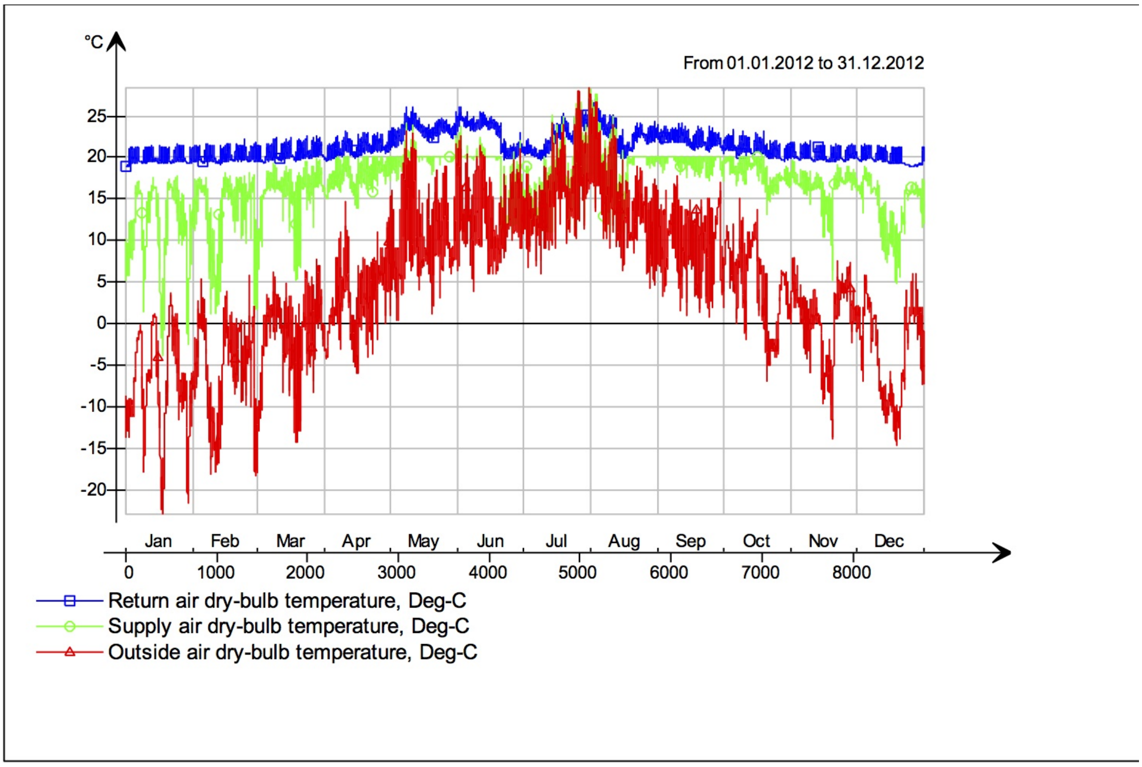


Figure 10.2: Temperatures in air handling units

The graph indicates that the supply air to the zones is quite low in the heating season, due to a high temperature loss in the system. Although only default values for the loss in the distribution system are used, this could be a high loss for a passive house.

AHU - air flows

For all air handling units except AHU4, the supply air flows are approximately the same throughout the year. To illustrate these air flows, the air flow diagrams for AHU3 and AHU4 are shown below:

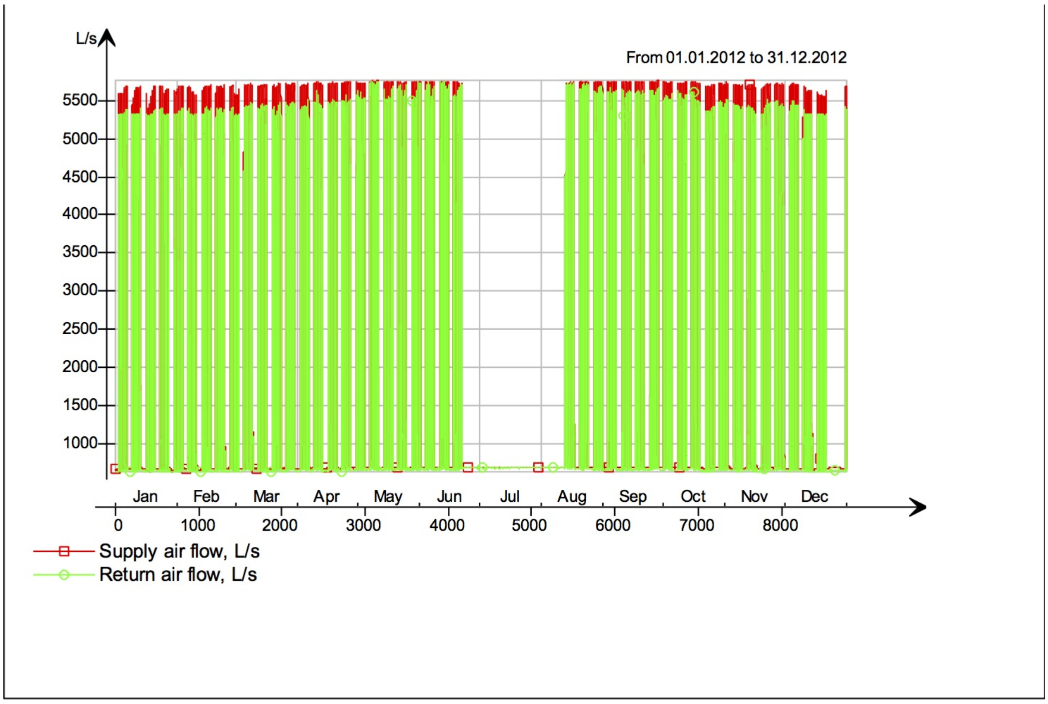


Figure 10.3: Air flow in air handling unit three

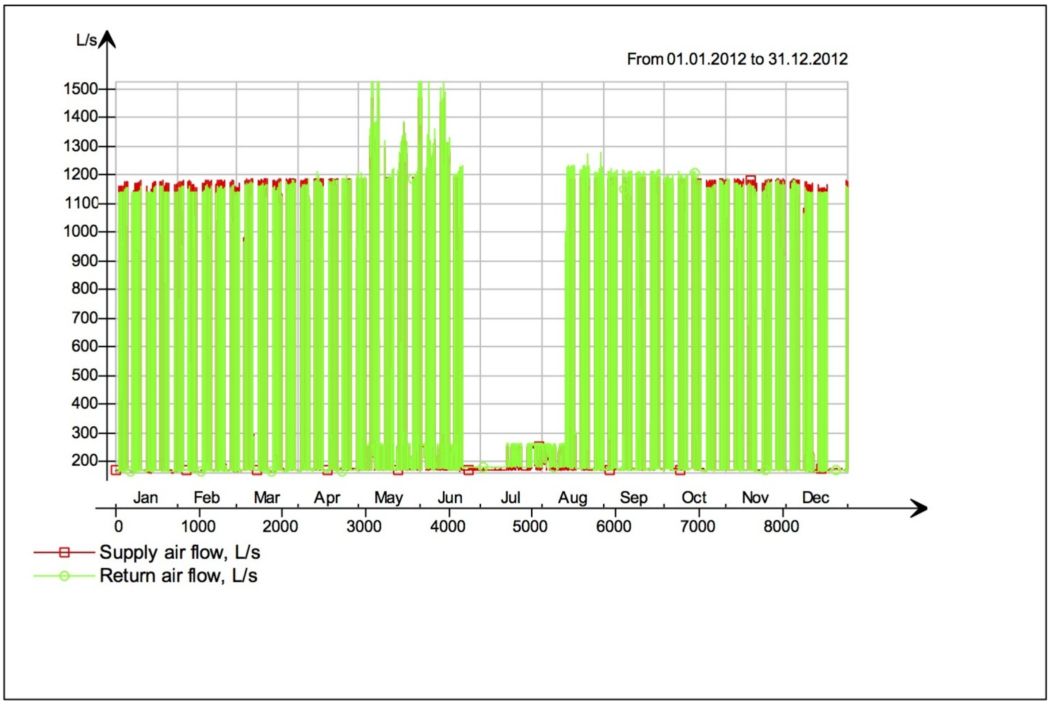


Figure 10.4: Air flow in air handling unit four

In the weekends and the holidays, the air flows are naturally only at a minimum. There is a relatively small increase in air flows in the warmer months, increasing from mid-April and then decreasing as the autumn progresses. Considering the cooling effect of an under-tempered air flow, this is not surprising. Although there is no cooling in the building, the outdoor air may be cooler than the indoor air for some periods of time in those months, resulting in natural cooling.

Although the ventilation in the building is based on balanced ventilation, all AHUs except AHU 4 have a higher supply air flow than return air flow. This can be due to the exfiltration of air from the building and because there is some air transfer between the zones.

AHU - heating, heat recovery, cool recovery

Another feature of the air handling units that is of high interest is the heat recovery. As the heat recovery efficiency was set to 78%, a lot of the energy from the return air could be used to preheat the supply air. For the different air handling units, the heat recovery as a percentage of the total heating in the respective air handling unit is listed below:

- AHU1: 87.3%

- AHU2: 80.9%
- AHU3: 86.3%
- AHU4: 88.9%
- AHU5: 87.1%
- AHU6: 86.4%

From the percentages, it is clear that a high efficiency in the heat recovery is important to reduce the energy demand of the ventilation of any building. With a low efficiency, much less energy would be required to be supplied through the heating coil in order to be able to provide the same supply air temperature. Although there is no cooling installed in the building, the heat exchangers in the air handling units will have a cooling effect. From the results report, the air handling units are shown to have a specific amount of cooling recovery in some months, indicating that in these months the supply air has a cooling effect. For air handling units AHU3, AHU4 and AHU5 this only occurs in July, while in AHU1, AHU2 and AHU6 it happens in June, July and August. Only AHU2 has some cooling recovery also in May.

Indoor climate in selected zones

To evaluate the indoor climate in the building, some selected zones are considered. The zones are chosen based on their characteristics and locations in the building. In each zone, the following aspects are considered:

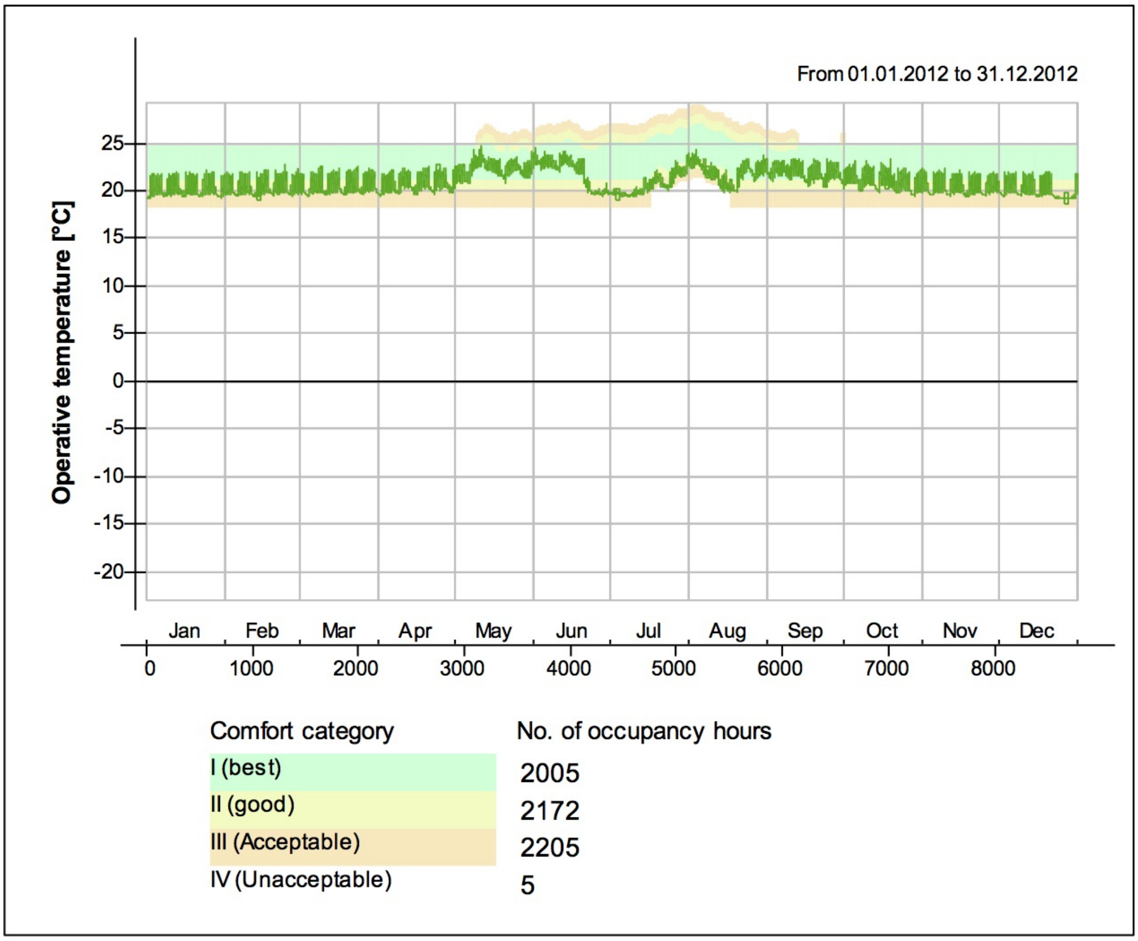
- Air flow in zone
- Thermal comfort
- Indoor air quality
- Fanger's comfort indices
- Daylighting

Zone 111 - Classroom, south-west side

Although classroom 119 has two external walls, it was discovered that there had been an error with the settings in this zone, making it necessary to choose a different one on the southwest side of the A wing. Therefore, as a representative room, zone 111 was chosen.

In the zone, the inflow and outflow through the internal and external walls is quite low throughout the year, varying between 0 and 10 L/s. During occupancy, the ventilation supply and return air is at maximum air flow rate, of 278 L/s, while when there are no people present, the air flow is reduced to the minimum level of 22 L/s.

The thermal comfort in the zone is shown in the graph below:



Comfort category	No. of occupancy hours
I (best)	2005
II (good)	2172
III (Acceptable)	2205
IV (Unacceptable)	5

Figure 10.5: Zone 111: Thermal comfort

In May/June the temperature is at approximately 23-24°C. Furthermore, the temperature reaches approximately 22°C during the weekdays of the colder months of the year.

Below the graph of the air age, the CO_2 level and the relative humidity is shown:

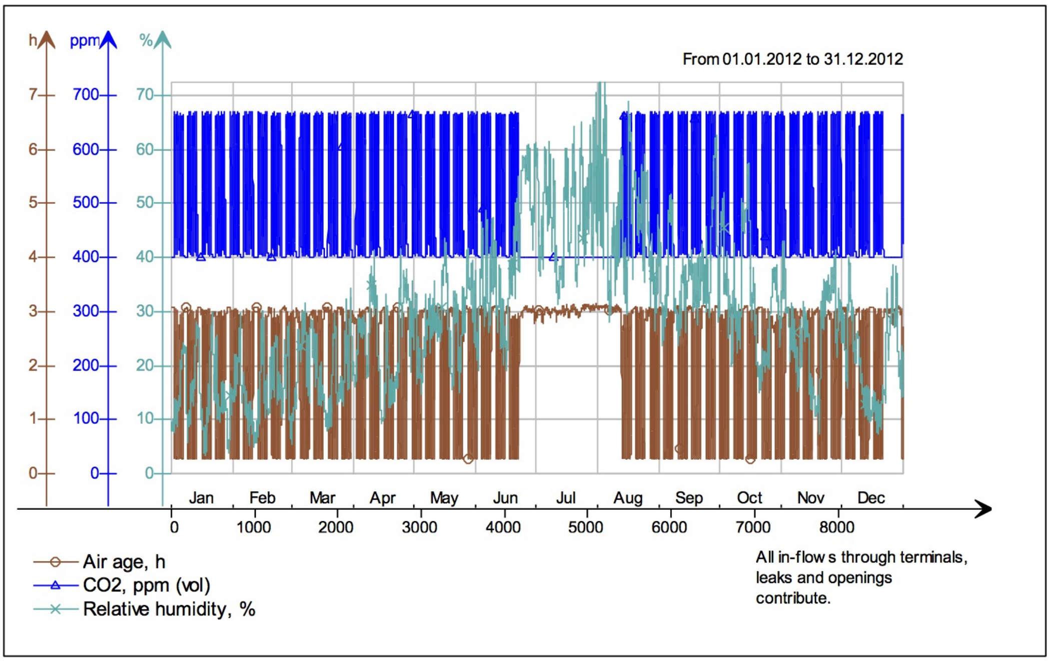


Figure 10.6: Zone 111: Indoor Air Quality

According to the graph above, the CO_2 level is kept below the the set point (750ppm) at 650ppm, and the air age during occupancy is at approximately 0.3 which is below the passive house requirements (Standard Norge, 2012). However, the relative humidity is a little high in late July/early August. As it passes 70%, it may be uncomfortably high for the users in this period (Novakovic, et al., 2007). Also, except for mid June to mid October, the RH drops below 20%, which may be uncomfortable and cause irritation to the occupants (Novakovic, et al., 2007).

To evaluate the comfort in the building, Fanger's comfort indices are shown over the course of the year in the graph below:

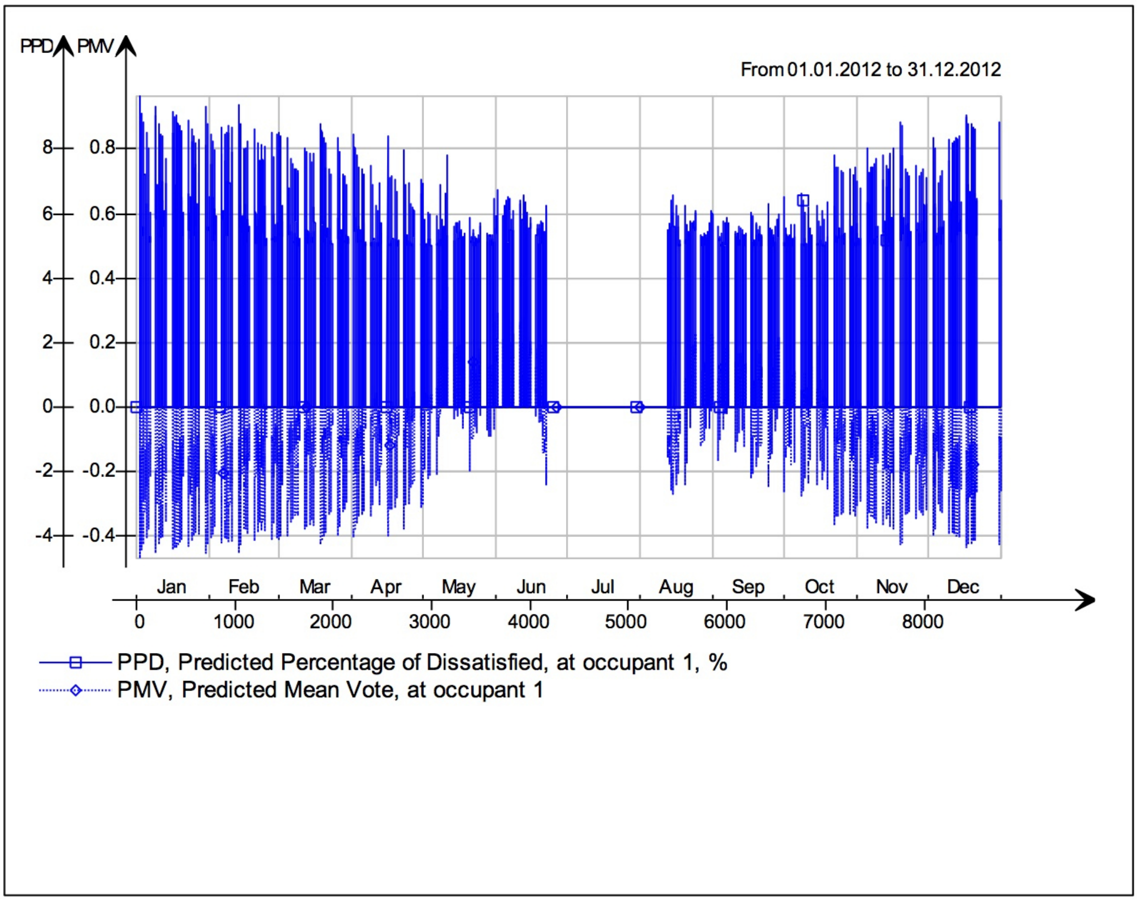


Figure 10.7: Zone 111: Fanger's Comfort Indices

As the PPD and PMV levels never pass 9% and -0.5 respectively, they indicate that more than 90% and 95%, respectively are satisfied with the indoor environment.

Lastly, the daylight level in the zone is shown in the following graph:

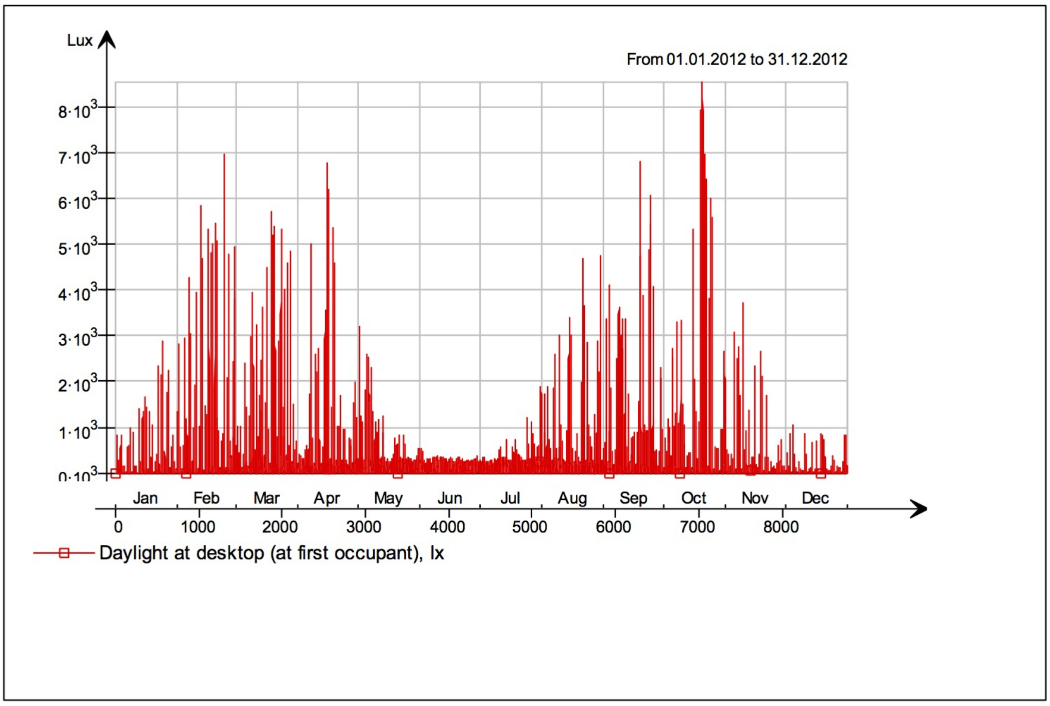


Figure 10.8: Zone 111: Daylighting

As this zone faces southwest, the variation through the year is as expected. Considering that the lighting requirement for tasks of high accuracy is 2000 Lux (Novakovic et al., 2007), the levels in the zone are at times quite high and additional shading may be required by the occupants (even though there is a roof overhang in place).

Summary

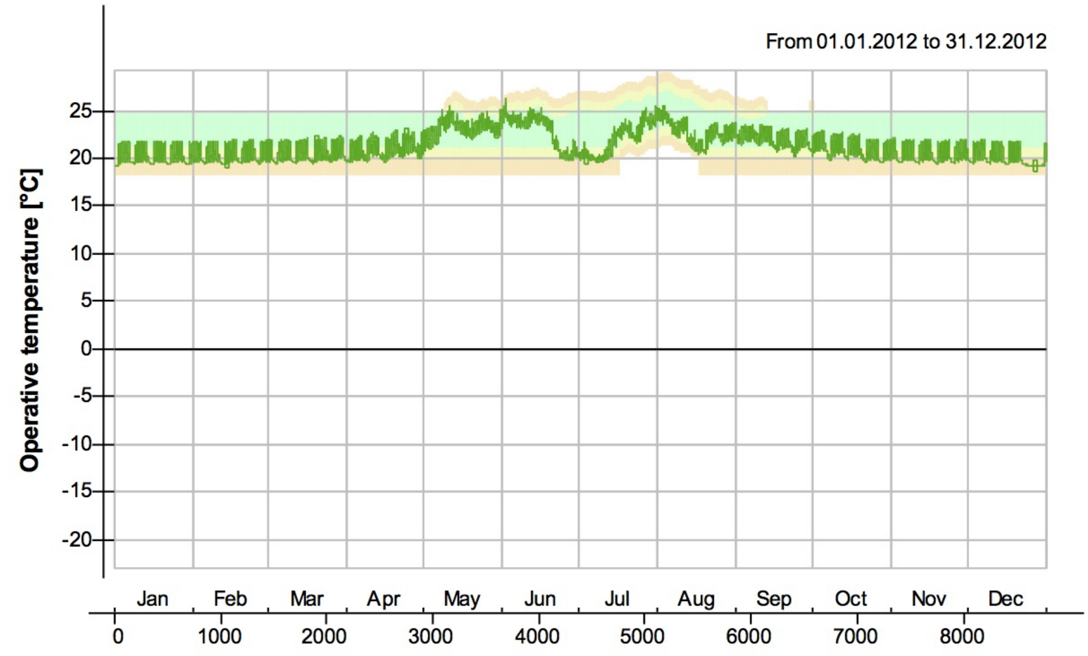
There are some unwanted levels of relative humidity and occasionally daylighting in the zone. However, the air age and CO_2 levels in the zone are low, indicating a decent indoor air quality. Furthermore, the temperature reaches approximately 22°C during the weekdays in the winter, indicating that the indoor temperature is comfortable according to the values defined by Standard Norge (2006), for category A. In May/June the zone satisfies the category B demands for temperature (Standard Norge, 2006). Furthermore, the PPD and PMV levels yield approximately 90% and 95% satisfaction respectively, which satisfies the Standard Norge (2006) category B level, but not category A. The CO_2 level in the zone is quite low throughout the year.

Zone 134 - Classroom, north-east side

This classroom was chosen in order to determine the comfort level in the classrooms on the north-east side of the building. The following describes the comfort in this zone.

The air flow through the internal and external walls varies throughout the year, with the inflow through the internal walls and the outflow through the external walls being the highest. These have occasional peaks throughout the year with a maximum of approximately 15 L/s. The ventilation air flow is the same throughout the year, being at its maximum of approximately 270 L/s during occupancy, and at the minimum level of approximately 22 L/s when the room is unoccupied.

Below, the thermal comfort in the zone is indicated:



Comfort category	No. of occupancy hours
I (best)	2050
II (good)	2206
III (Acceptable)	2208
IV (Unacceptable)	2

Figure 10.9: Zone 134: Thermal comfort

In May/June and in late July/early August the temperature is at 24-25°C. Furthermore, the temperature reaches approximately 22°C during the occupied days of the week in the colder months of the year.

The air age, the CO_2 level and the relative humidity is shown in the graph below:

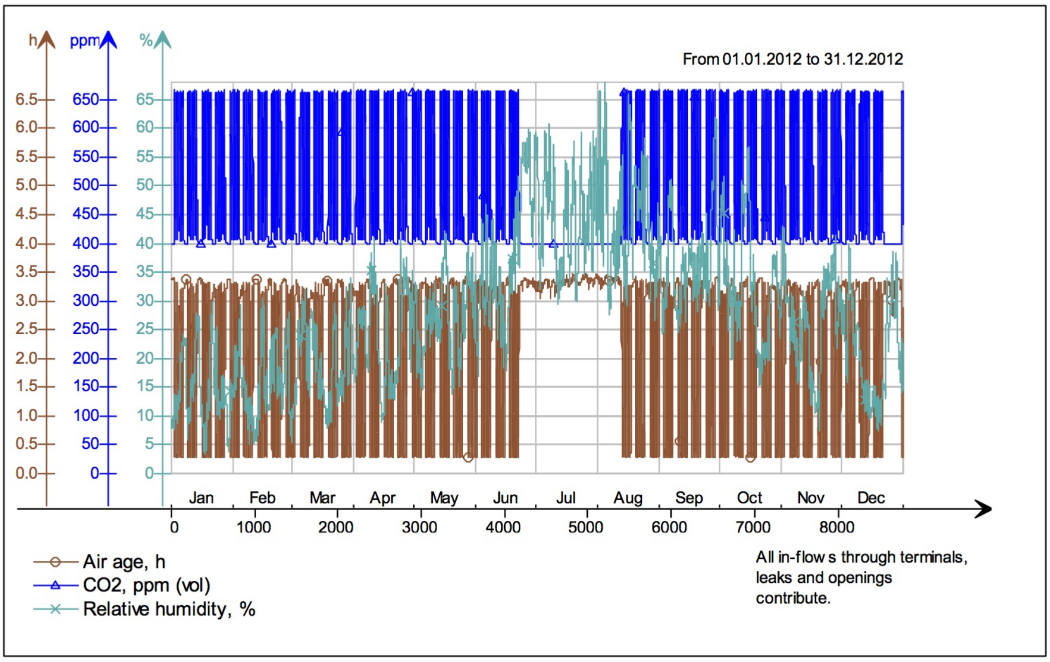


Figure 10.10: Zone 134: Indoor Air Quality

According to the graph above, the CO_2 level is kept below the set point of 750ppm, at only 650ppm, and the air age during occupancy is at approximately 0.3 which is below the passive house requirements (Standard Norge, 2012). Also, the relative humidity does not pass 70% and should not get uncomfortably high (Novakovic, et al., 2007). However, except for mid June to mid October, the RH drops below 20%, which may be uncomfortable and cause irritation to the occupants (Novakovic, et al., 2007).

Fanger's comfort indices are shown over the course of the year in the graph below:

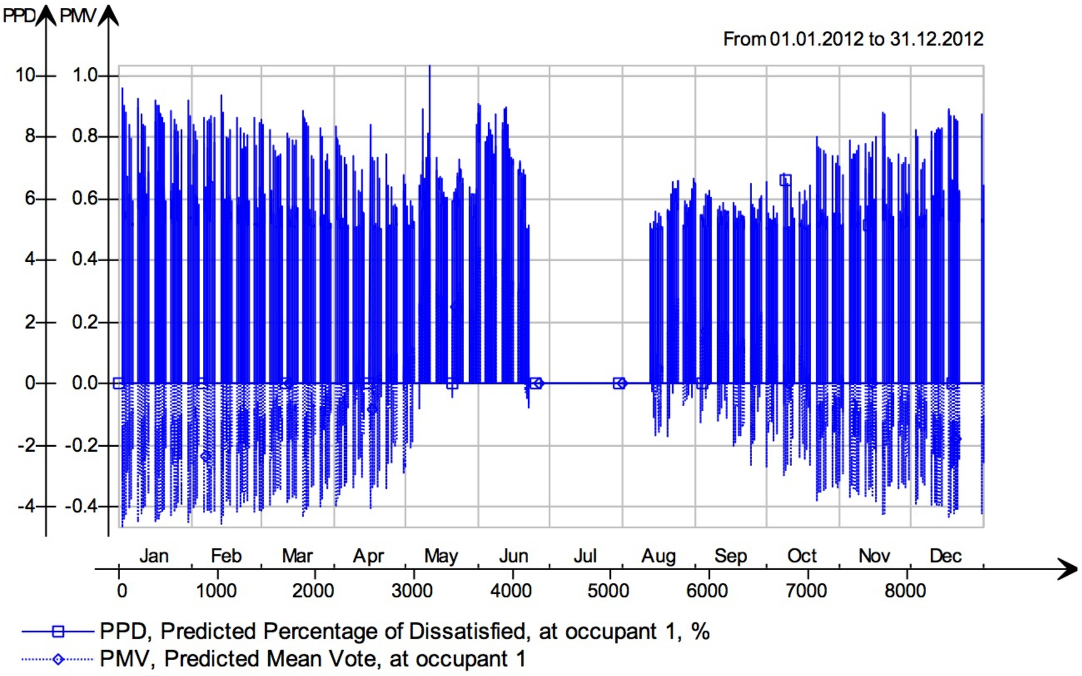


Figure 10.11: Zone 134: Fanger's Comfort Indices

As the PPD level only once passes 10% and the PMV level never passes -0.5, they indicate that more than 90% are satisfied with the indoor environment most of the time, and 95% are satisfied with the indoor environment at all times.

Lastly, the daylight level in the zone is shown in the following graph:

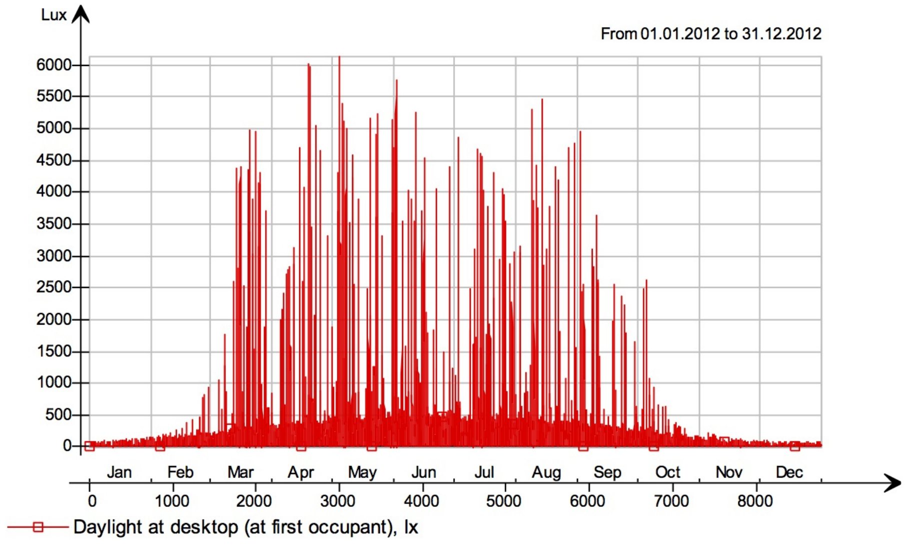


Figure 10.12: Zone 134: Daylighting

The variation through the year is as expected as the zone faces northeast. Considering that the lighting requirement for tasks of high accuracy is 2000 Lux (Novakovic, et al., 2007), the levels in the zone are at times quite high.

Summary

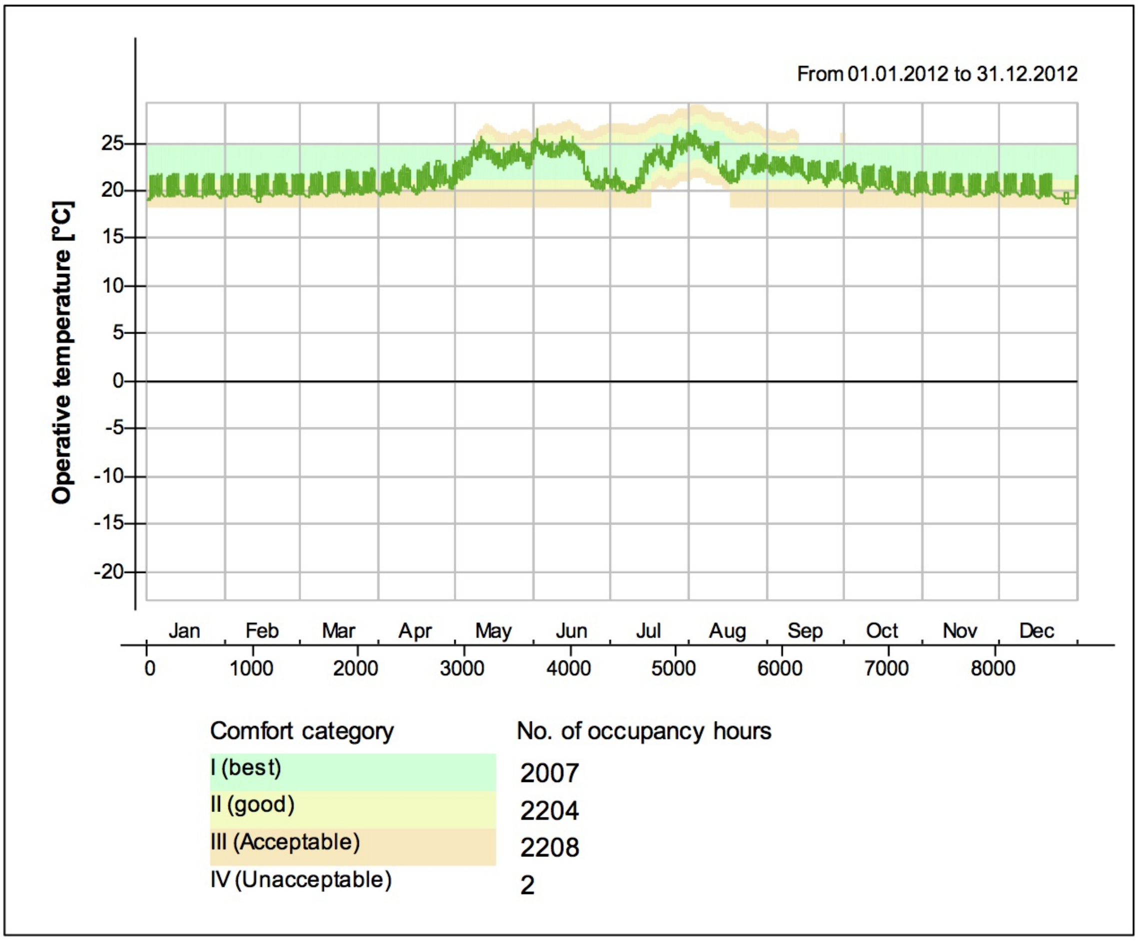
For May/June and July/August the temperature in the zone satisfy the NS-EN ISO 7730:2005 category A summer conditions, in addition to the temperature being at approximately 22°C during the colder months of the year, also complying with category A (Standard Norge, 2006). Although the RH level is a little low from mid October to mid June, the low air age and low CO_2 levels indicate a good indoor air quality. Apart from one peak in PPM, the PPD and PMV indicate an approximate 90% and 95% satisfaction. This satisfies the NS-EN ISO 7730:2005 category B, but not category A (Standard Norge, 2006).

Zone 126 - Computer lab

As the computer lab in room 126 was the room thought to have the worst indoor climate, this zone is studied in detail.

In the zone, the air flow can be roughly separated into air flow through internal and external walls, and air flow supplied and exhausted from the zone through the ventilation system. The inflow and outflow through the internal and external walls varies a little throughout the year, although it stays below 10 L/s. The mechanical inflow and outflow of air is at the given minimum value of approximately 22 L/s when the room is unoccupied, and at its maximum of approximately 264 L/s when the occupants are present.

The thermal comfort in the zone is shown in the graph below:



Comfort category	No. of occupancy hours
I (best)	2007
II (good)	2204
III (Acceptable)	2208
IV (Unacceptable)	2

Figure 10.13: Zone 126: Thermal Comfort

In May/June and in late July/early August the temperature in the zone varies between 23°C to 26°C. During the colder months, the temperature is at approximately 22°C during the occupied days of the week.

Below the graph of the air age, the CO_2 level and the relative humidity is shown:

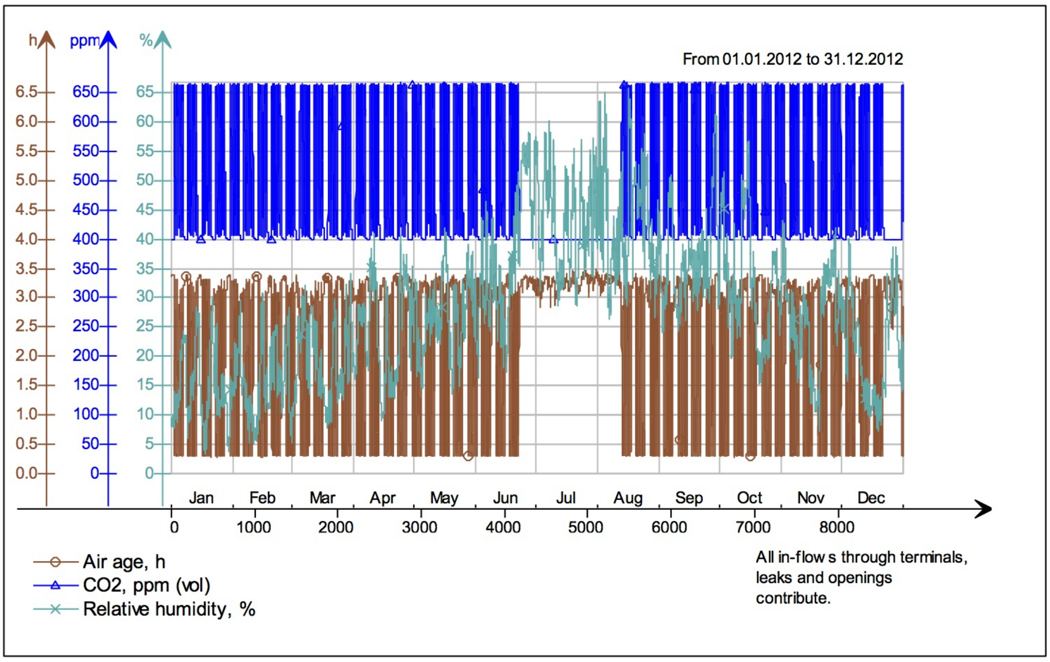


Figure 10.14: Zone 126: Indoor Air Quality

According to the figure above, the CO_2 level is kept below the 750ppm set point, at only 650ppm, and the air age during occupancy is at approximately 0.3 which is below the passive house requirements (Standard Norge, 2012). Also, the relative humidity does not pass 70% and should not get uncomfortably high (Novakovic, et al., 2007). Except for mid June to mid October, the RH drops below 20%, which may be uncomfortable and cause irritation to the occupants (Novakovic, et al., 2007).

To evaluate the comfort in the building, Fanger's comfort indices are shown over the course of the year in the figure below:

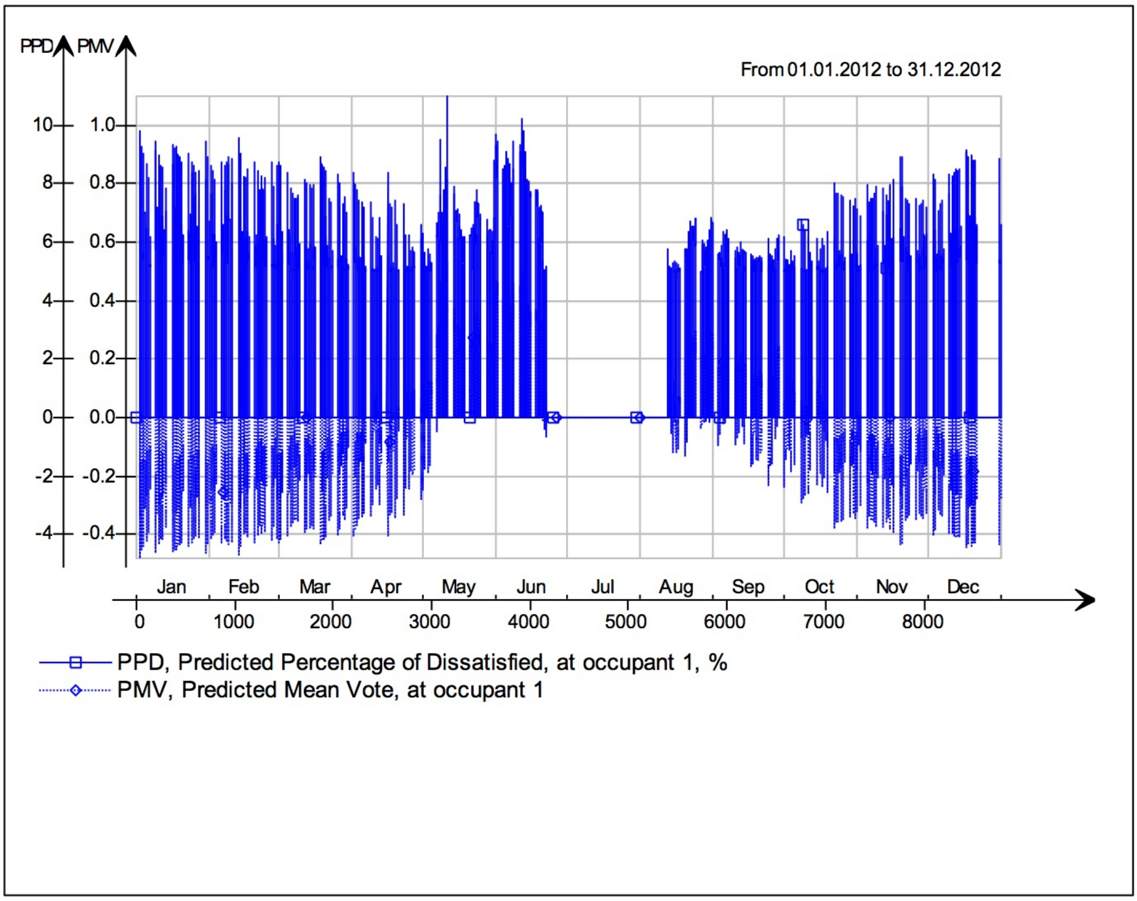


Figure 10.15: Zone 126: Fanger's Comfort Indices

The PPD level only once passes 10% and the PMV level never passes -0.5, indicating that more than 90% are satisfied with the indoor environment most of the time, and 95% are satisfied with the indoor environment all the time.

Lastly, the daylight level in the zone is shown in the following graph:

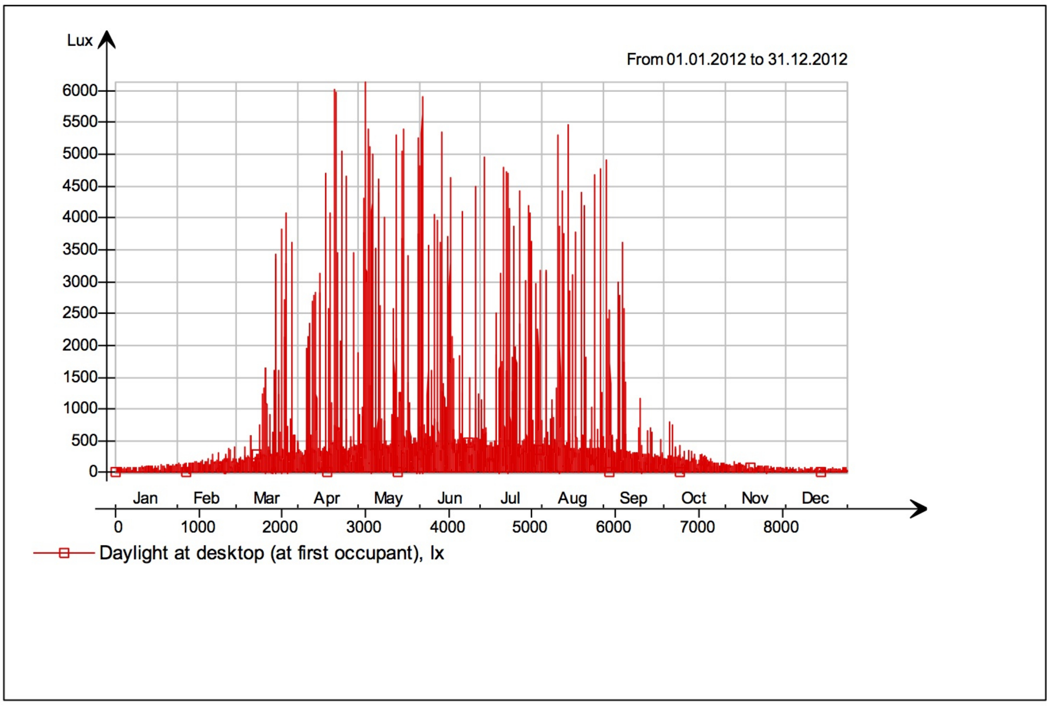


Figure 10.16: Zone 126: Daylighting

As this zone faces northeast, the variation through the year is not surprising. The lighting requirement for tasks of high accuracy is 2000 Lux (Novakovic, et al., 2007), making the levels in the zone at times a little high and some shading may be required by the occupants.

Summary

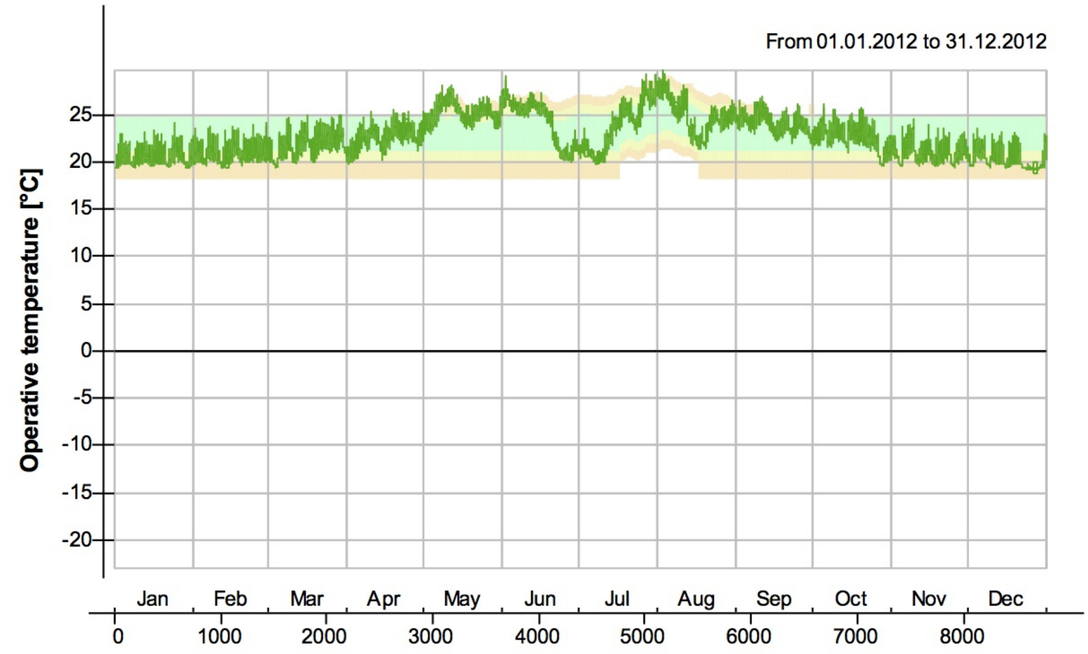
The temperature in the zone is a little high in May/June and July/August, satisfying the category B summer conditions (Standard Norge, 2006). Furthermore, it is kept at approximately 22°C during the occupied days of the week in the colder months, complying with the comfort values in category A set by Standard Norge (2006). Apart from the RH level being a little low from mid October to mid June, the low air age and CO_2 levels indicate that the indoor air quality is quite good in the zone. Lastly, the PPD and PMV, apart from a couple of peaks, comply with the NS-EN ISO 7730:2005 category B values, but not category A (Standard Norge, 2006).

Zone 175 - Work room teachers

As this room is a place where the need for a good indoor environment is of high importance, it is being considered in detail.

The air flow through the internal and external walls of the zone varies throughout the year, between 0 and 10 L/s. The ventilation air flow to and from the zone is at its minimum of approximately 14 L/s when the room is unoccupied, and approximately 125 L/s when the occupants are present.

In the figure below, the thermal comfort in the zone is shown:



Comfort category	No. of occupancy hours
I (best)	1642
II (good)	1925
III (Acceptable)	2054
IV (Unacceptable)	156

Figure 10.17: Zone 175: Thermal Comfort

The graph and comfort category table indicate that the temperature in this zone is quite high most of the year, especially in May/June and mid to late July and August. During the colder months, the temperature reaches 23-24°C during the occupied days of the week.

Below the graph of the air age, the CO_2 level and the relative humidity is shown:

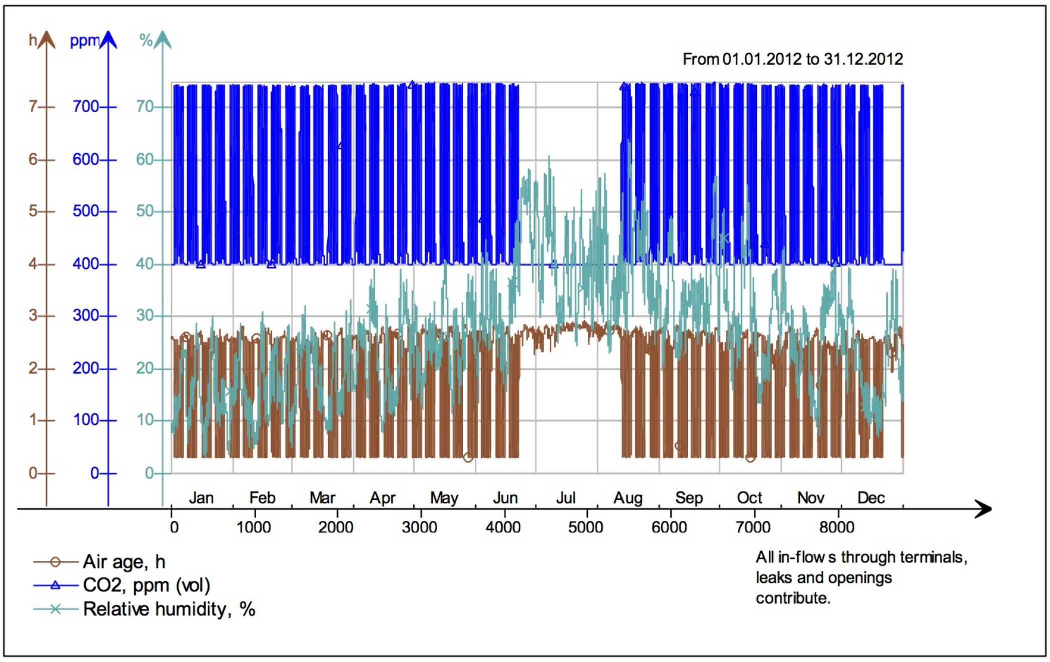


Figure 10.18: Zone 175: Indoor Air Quality

According to the graph above, the CO_2 level is a little higher than the other zones, at approximately 750ppm, which is the set point level, and the air age during occupancy is at approximately 0.3 which is below the passive house requirements (Standard Norge, 2012). Also, the relative humidity does not pass 70% and should not get uncomfortably high (Novakovic, et al., 2007). Except for mid June to mid October, the RH drops below 20%. This may be uncomfortable and cause irritation to the occupants (Novakovic, et al., 2007).

Fanger's comfort indices are shown over the course of the year in the figure below:

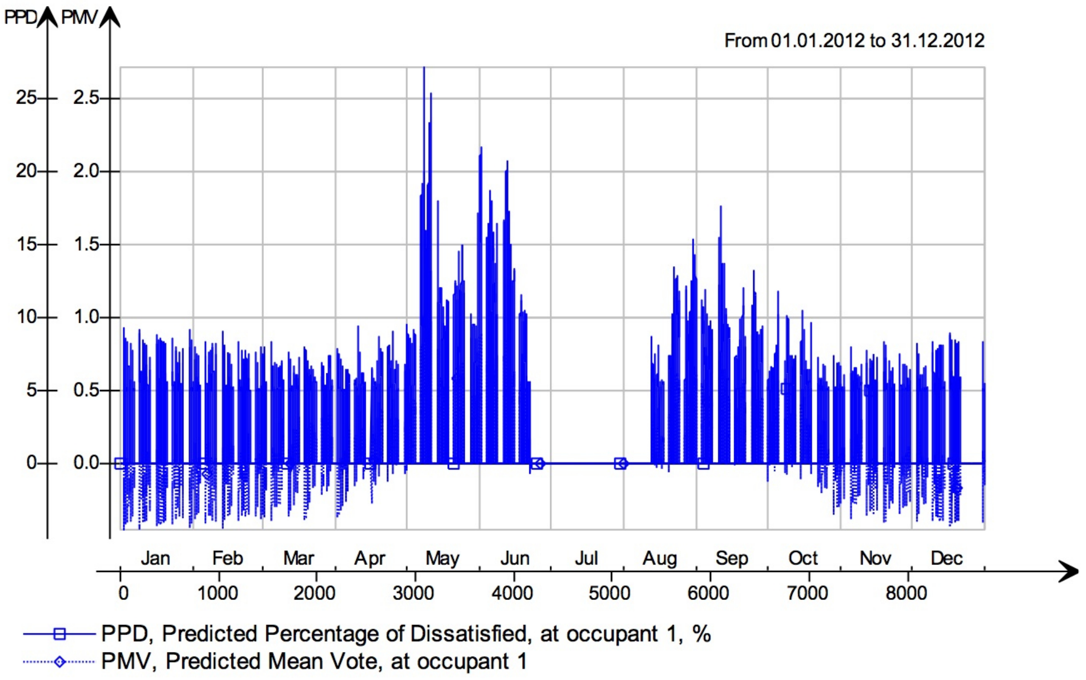


Figure 10.19: Zone 175: Fanger's Comfort Indices

The PPD level passes 10% from May to mid October (except during the holidays), indicating that these months have an increased level of dissatisfied people, exceeding the recommended levels. The PMV level however, does not pass the recommended 5%.

Lastly, the daylight level in the zone is shown in the following graph:

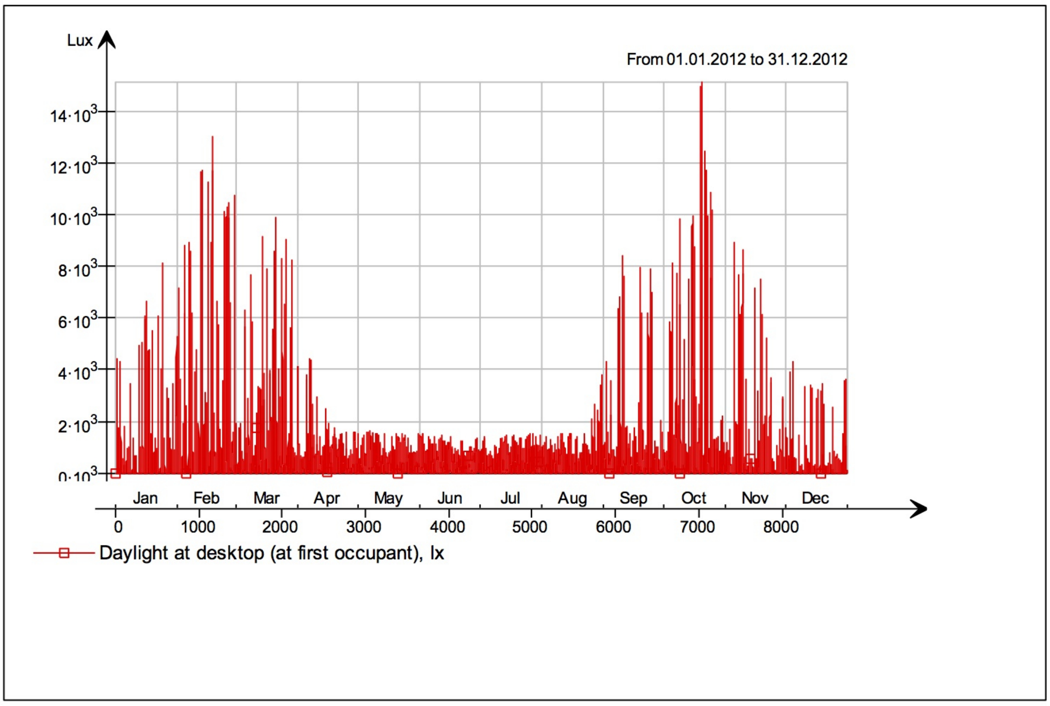


Figure 10.20: Zone 175: Daylighting

As this zone faces south east and is somewhat shaded by the B wing, the variation through the year is as expected. According to Novakovic, et al. (2007), the lighting requirement for tasks of high accuracy is 2000 Lux. This indicates that the levels in the zone are at times quite high and shading may be required by the occupants.

Summary

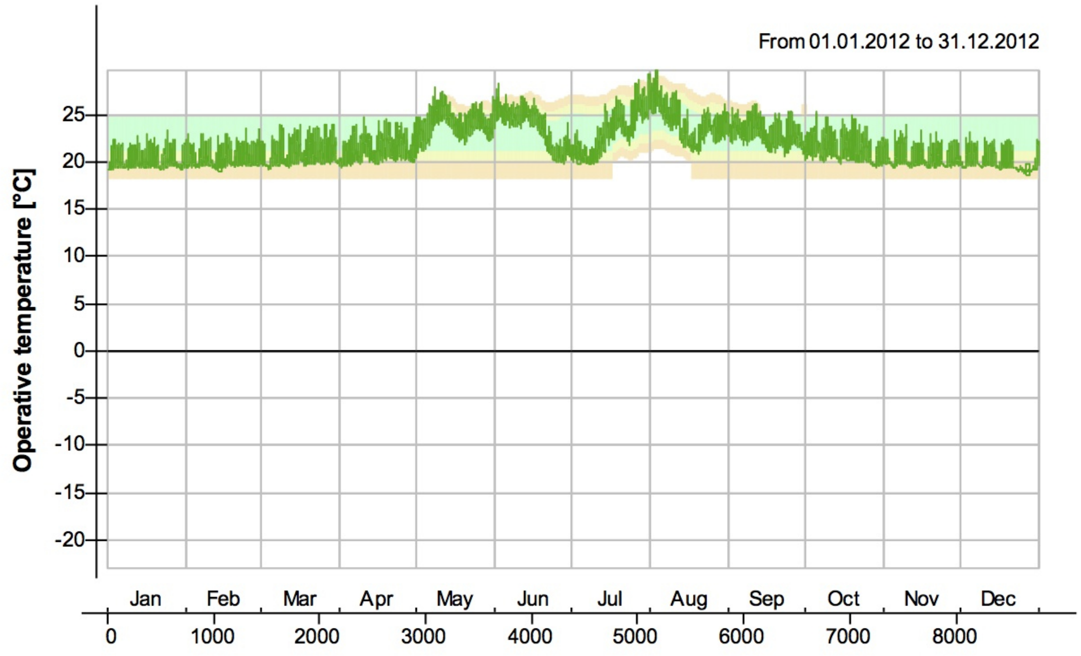
There is a cooling need in this zone in May/June and July/August as the temperature gets up to 30°C, in addition to the temperature during the colder months being a little high, at approximately 23-24°C. The CO_2 level is kept very close to the set point of 750 ppm, but not more, and with the low air age in the zone the indoor air quality should be fairly good in spite of an, at times, low RH level. The PPD level in the zone does not comply with even category C from May to mid October, but the rest of the year it complies with category B (Standard Norge, 2006). The PMV level is kept below the category B limit (Standard Norge, 2006). There is also a significant need for shading in this zone.

Zone 198 - Work room teachers

This is another zone that is both highly exposed to daylight as well as being a zone where the indoor environment is highly important. Therefore, this zone is studied in detail.

The air flow through the internal and external walls of the zone is at its maximum of approximately 270 L/s when the room is occupied, and at its minimum of 25 L/s when there are no people present.

The thermal comfort in the zone is illustrated in the graph below:



Comfort category	No. of occupancy hours
I (best)	1838
II (good)	2108
III (Acceptable)	2169
IV (Unacceptable)	41

Figure 10.21: Zone 198: Thermal Comfort

The graph and comfort category table indicate that the temperature in this zone is quite high most of the year, especially in May/June and mid to late July and August. During the colder months of the year, the temperature in the zone reaches 23-24°C.

The graph of the air age, the CO_2 level and the relative humidity is shown in the figure below:

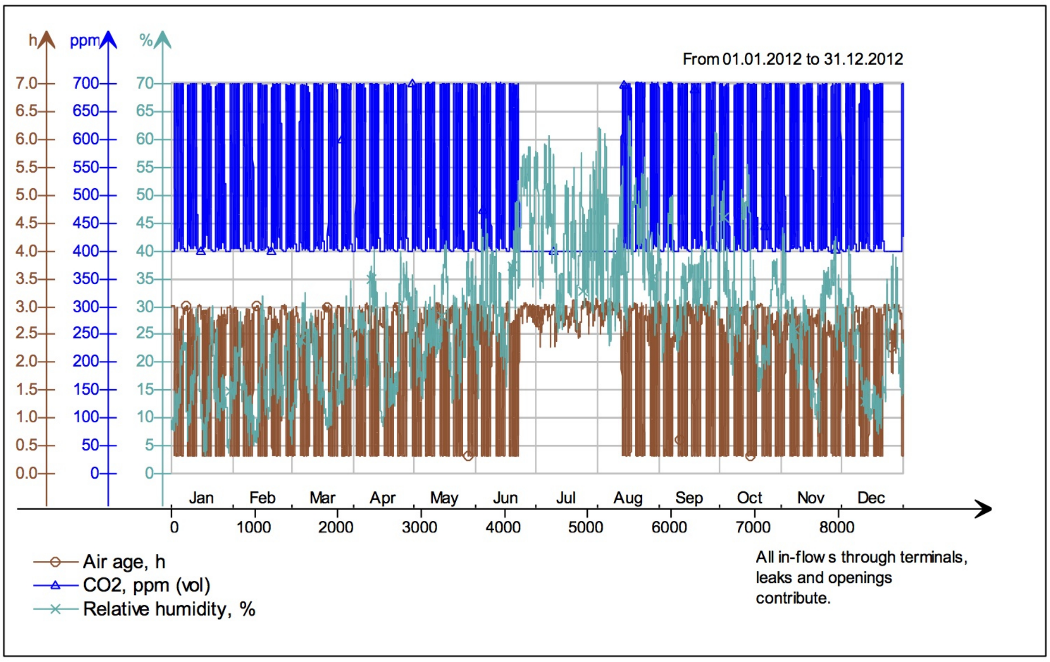


Figure 10.22: Zone 198: Indoor Air Quality

According to the graph above, the CO_2 level is a little higher than the other zones, at approximately 700ppm, but still below the 750 ppm set point level. The air age during occupancy is at approximately 0.3 which is below the passive house requirements (Standard Norge, 2012). Also, the relative humidity should not get uncomfortably high. However, except for mid June to mid October, the RH drops below 20%, which may be uncomfortable and cause irritation to the occupants (Novakovic, et al., 2007).

To evaluate the comfort in the building, Fanger's comfort indices are shown over the course of the year in the graph below:

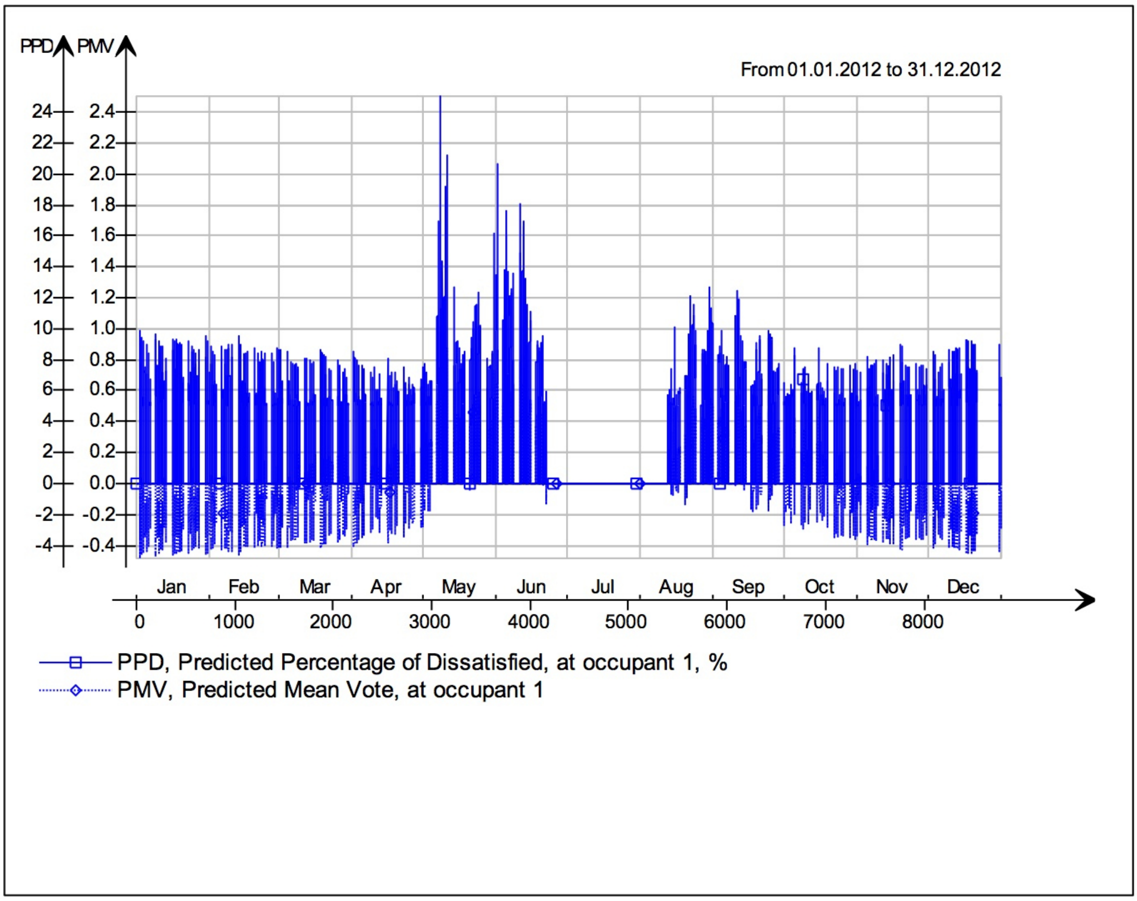


Figure 10.23: Zone 198: Fanger's Comfort Indices

The PPD level passes 10% from May to mid October (except during the holidays), indicating that these months have an increased level of dissatisfied people, exceeding by far recommended levels (Standard Norge, 2006). The PMV level however, does not pass the recommended 5% (Standard Norge, 2006).

The daylight level in the zone is shown below::

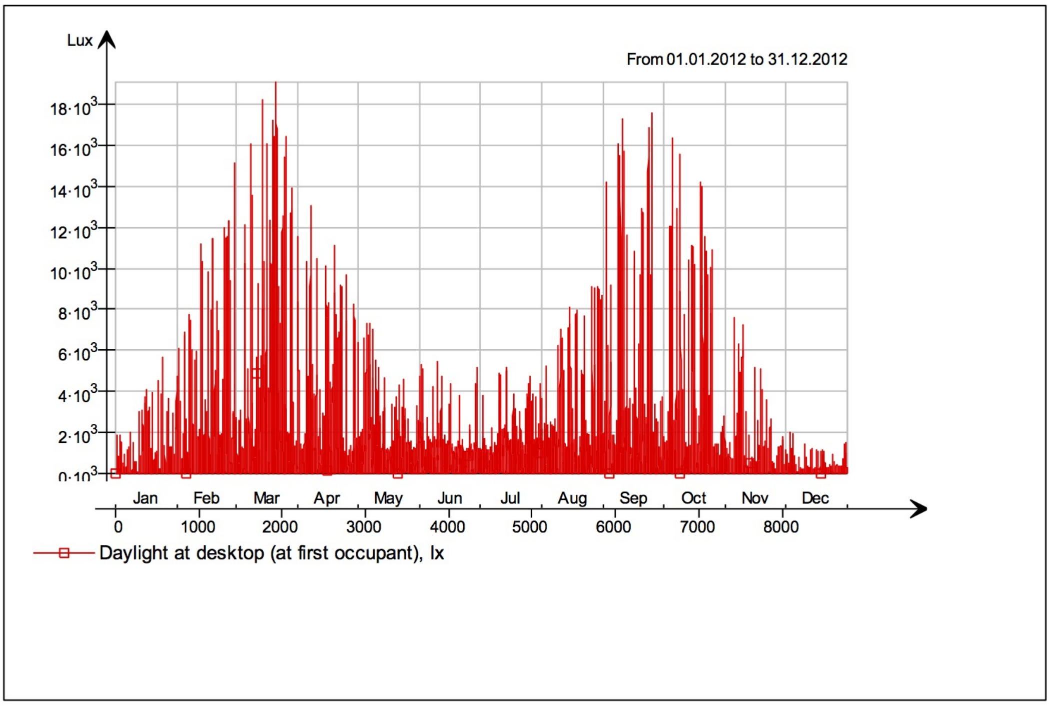


Figure 10.24: Zone 198: Daylighting

As this zone faces south east and is somewhat shaded by the B wing, the variation through the year is not surprising. Considering that the lighting requirement for tasks of high accuracy is 2000 Lux (Novakovic, et al., 2007), the levels in the zone are very high and shading may be required by the occupants.

Summary

The temperature in the zone is quite high in May/June and July/August, indicating a cooling need at these times as the temperature reaches, at times, 30°C. Furthermore, it is at approximately 23-24°C during the colder months of the year, which satisfies category B, but not category A from NS-EN ISO 7730:2005 (Standard Norge, 2006). The CO_2 level and air age are both kept below the comfort limits, indicating a good indoor air quality, in spite of a low RH level from mid October to mid June. From May to mid October the PPD level is far too high, while it satisfies category B the rest of the year (Standard Norge, 2006). The PMV level is kept below the category B limit throughout the year (Standard Norge, 2006). Lastly, there is a significant need for shading in this zone.

Zone 10 - Band room

In order to evaluate the indoor environment in the basement, this zone was chosen as it was mentioned by two women from the user survey as to having a worse indoor climate than other zones.

The air flow through the internal and external walls is very low at approximately zero, but the outflow through the internal walls varies between 0 and approximately 7 L/s. The ventilation air flows through the zone is at its maximum of approximately 220 L/s when the room is occupied, and at its minimum of approximately 18 L/s when no people are present.

Below is a figure describing the thermal comfort in the zone:

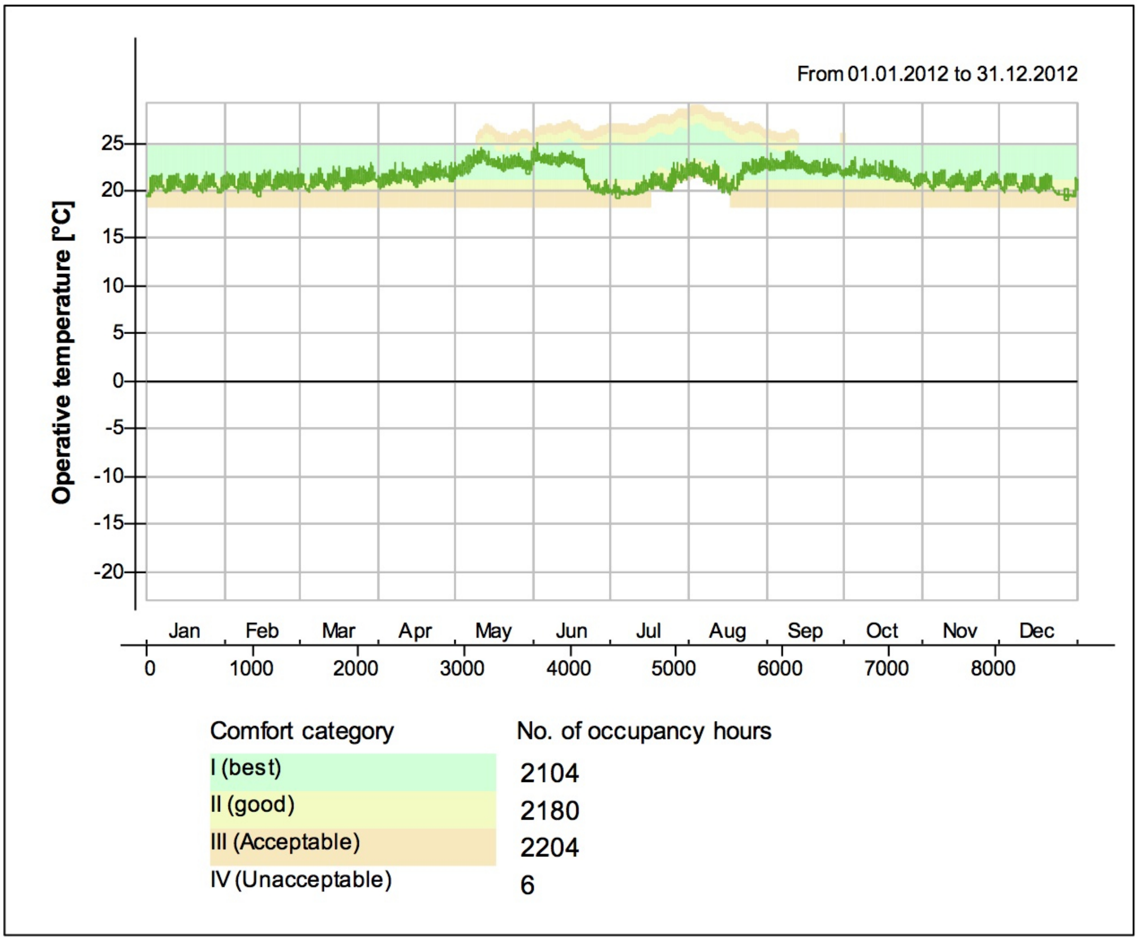


Figure 10.25: Zone 10: Thermal Comfort

In May to September, the temperature in the zone reaches 22-24°C during the occupied weeks. For the occupied days of the week, the operative temperature is at approximately 21-22°C, in the colder months of the year.

The air age, the CO_2 level and the relative humidity are shown below:

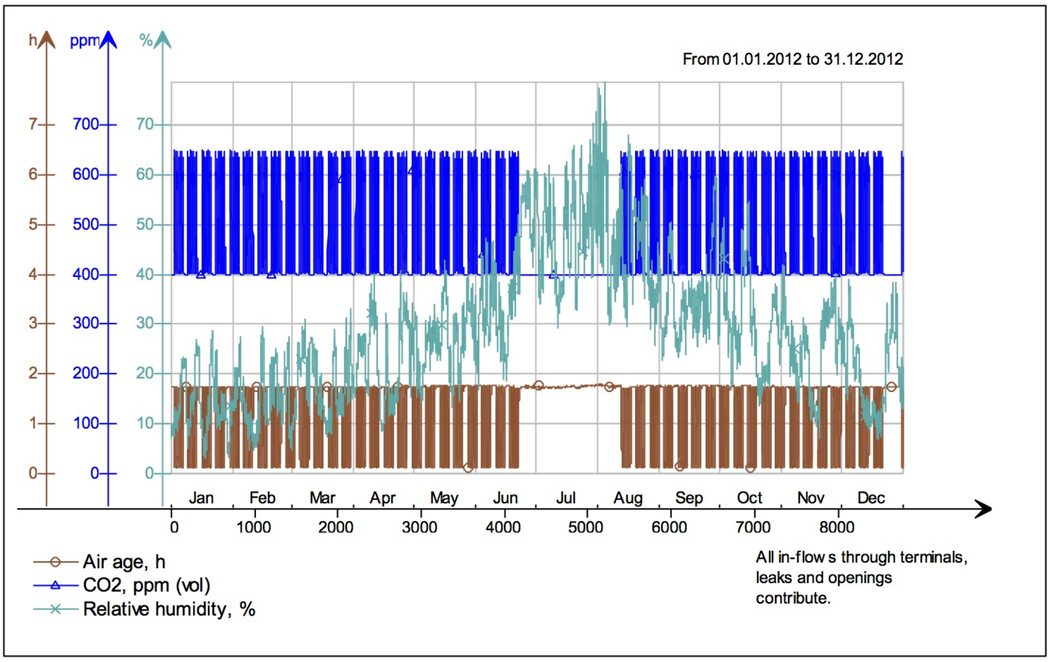


Figure 10.26: Zone 10: Indoor Air Quality

The figure shows that, the CO_2 level is kept below the 750ppm set point, at 650ppm, and the air age during occupancy is at approximately 0.2 which is below the passive house requirements (Standard Norge, 2012). However, the relative humidity is a little high in late July/early August. As it passes 70%, it may be uncomfortably high for the users in this period (Novakovic, et al., 2007). Also, except for mid June to mid October, the RH drops below 20%, which may not be optimal for the occupants (Novakovic, et al., 2007).

Below the Fanger's comfort indices are shown:

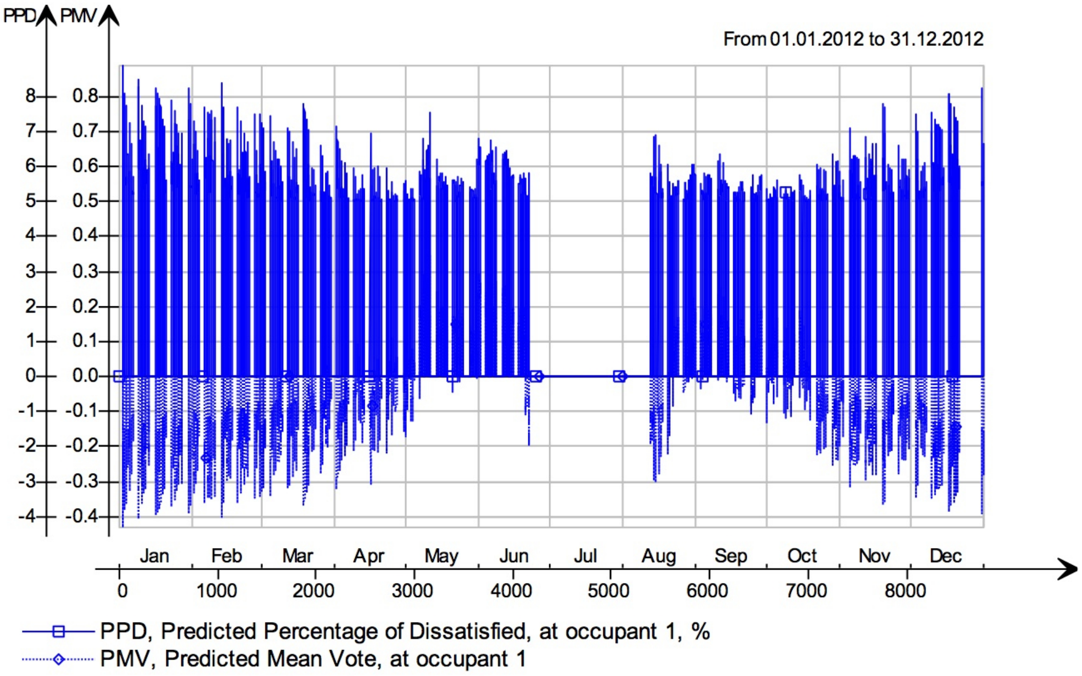


Figure 10.27: Zone 10: Fanger's Comfort Indices

As the PPD and PMV levels never pass 9% and -0.5 respectively, they indicate that more than 90% and 95%, respectively are satisfied with the indoor environment.

The following graph shows the daylighting levels in the zone:

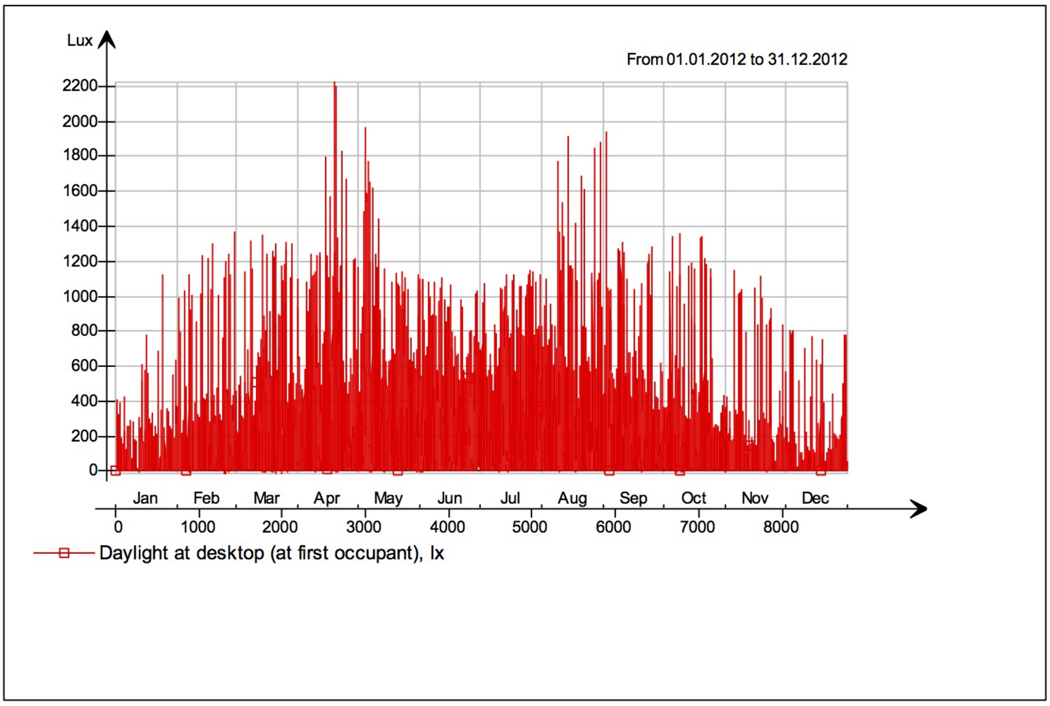


Figure 10.28: Zone 10: Daylighting

The variation through the year is as not surprising as the zone faces northeast. Considering that the lighting requirement for tasks of high accuracy is 2000 Lux (Novakovic, et al., 2007), the levels in the zone are appropriate most of the year, and at times even a little low.

Summary

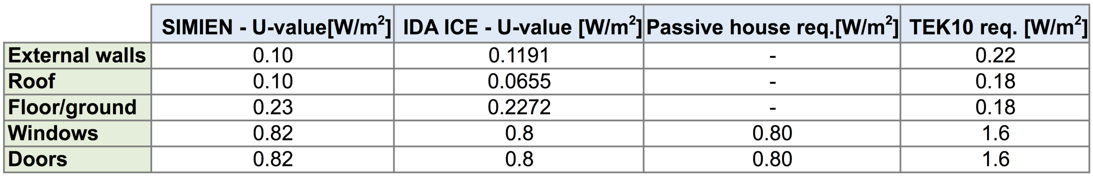
The summer temperatures in the zone satisfy the category B requirements, while the 21-22°C during the colder months of the year satisfy category A (Standard Norge, 2006). This satisfies the category A limits (Standard Norge, 2006). The RH level in the zone is a little high in late July/early August and a little low in mid October to mid June. However, the low CO_2 level and air age in the zone indicate an otherwise good indoor air quality. The PPD and PMV levels satisfy category B limits throughout the year (Standard Norge, 2006).

10.1.2 Comparison of Normative results with SIMIEN and different effects

Normative vs. SIMIEN

After Stasjonsfjellet Skole was finished, the engineers did SIMIEN simulations to evaluate whether the building complies with the passive house standard, NS 3701:2012, and with the technical regulations, TEK10. In order to compare and evaluate the IDA ICE model to the SIMIEN simulation, the Normative scenario was chosen to have as similar conditions as the SIMIEN simulation did when it comes to internal loads and schedule (based on the SIMIEN reports). The building body was designed based on information from the drawings and project documentation. Below is a comparison of the U-values used in the different simulation models, as well as the passive house (Standard Norge, 2012) and TEK10 (Kommunal- og moderniseringsdepartementet, 2010) requirements.

Table 10.4: U-values – Comparison

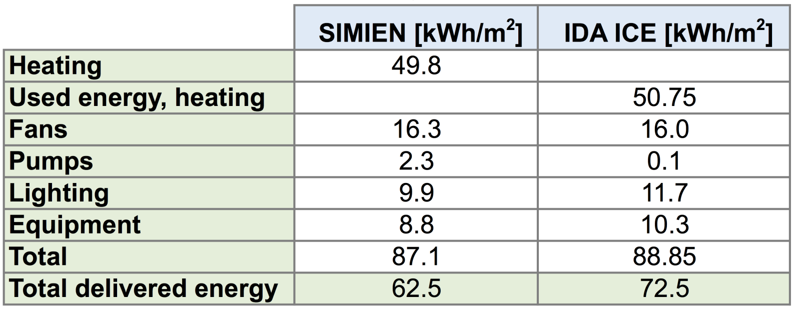


	SIMIEN - U-value[W/m^2]	IDA ICE - U-value [W/m^2]	Passive house req.[W/m^2]	TEK10 req. [W/m^2]
External walls	0.10	0.1191	-	0.22
Roof	0.10	0.0655	-	0.18
Floor/ground	0.23	0.2272	-	0.18
Windows	0.82	0.8	0.80	1.6
Doors	0.82	0.8	0.80	1.6

The table shows that according to the values used in IDA ICE, the only U-value that does not comply with the passive house standard and TEK10 is the U-value of the external floor. For the SIMIEN values, the windows and doors have a slightly too high U-value compared to the passive house requirement (Standard Norge, 2012).

In both the SIMIEN simulation for the passive house evaluation and the IDA ICE Normative simulation, some key energy calculations were done. As the delivered energy was not calculated in the TEK10 simulation in SIMIEN, only the results from the passive house evaluation are studied here. The results are listed in table 10.5 below:

Table 10.5: Energy Calculations



	SIMIEN [kWh/m^2]	IDA ICE [kWh/m^2]
Heating	49.8	
Used energy, heating		50.75
Fans	16.3	16.0
Pumps	2.3	0.1
Lighting	9.9	11.7
Equipment	8.8	10.3
Total	87.1	88.85
Total delivered energy	62.5	72.5

The energy demand for fans, pumps, lighting and equipment for the IDA ICE simulation are assumed to be the same as the delivered energy for the same posts.

The table shows that the energy demand and heating demand is nearly the same for the two cases, but that the delivered energy to the SIMIEN building is much lower than the delivered energy to the IDA ICE building. The delivered energy is expected to be lower than the energy demand as there is a ground source heat pump installed in the building. However, the heat pump appears to save a significantly higher amount of energy for the SIMIEN building compared to the IDA ICE model. As the settings for the SIMIEN heat pump are only assumed to be the same as for the IDA ICE model, which is based on the functional description of the actual heat pump installed, it is likely that they do not comply.

Although no cooling was installed in the building, the passive house evaluation in SIMIEN yielded a net cooling demand of 4.3 kWh/m^2, with the required max demand being 5.0 kWh/m^2 (also from the SIMIEN report). This was to be covered by a cooling battery in the air handling unit that was not installed.

Due to time and software limitations, the zone simulations in SIMIEN done by the engineers was not studied in detail in this report.

Normative - External shading

One of the effects that was studied was the installation of external shading outside the windows. The shading that was used was external overhangs over the windows.

Energy

The energy delivered to the building when shading was installed was 0.4 kWh/m^2 less than the original simulation. The reduced delivered energy came from the energy for heating.

The shading simulation resulted in a percentage of hours when the operative temperature is above 27°C in the worst zone of 14%, which is 1% higher than that of the original simulation. It also resulted in the number of hours of lost work due to under- or overheating being 1494.9h, while without shading, the number was 2135.1h.

Zones

The indoor air quality and the air flow in each of the zones were approximately the same as the original simulation for each of the zones, except zone 10. The Fanger's comfort indices are also approximately the same for the original simulation and zones 111, 134 and 126. The PPD level in zones 10, 175 and 198 is a little lower and the relative humidity is higher. Although, Fanger's comfort indices are lower.

Although there were some improvements in some of the zones for some of the comfort measures, the most significant improvement in all zones was the reduction in daylighting. The daylight level was drastically reduced, making it darker inside. This is to be expected when you introduce shading into the building. As too high daylight levels can cause uncomfortable glare, this is a welcome improvement, especially in the zones facing the south and southwest. The delivered energy to the building was the same in both scenarios, indicating that the reduced daylight did not make it necessary for further lighting.

Normative - Internal shading - Curtains

Although it was not originally ascertained whether there were curtains installed in the building, a simulation was run to evaluate the effects of having curtains in the room.

The heating demand was, as could be expected, mildly reduced, by 1.8 kWh/m^2, when curtains were introduced to the building. Since the curtains would have a slight insulating effect, this result was not very surprising. As the bulk of the heating demand is covered by the ventilation heating coil, most of the reduction in energy used for heating came from the ventilation heating. There was also a smaller reduction in zone heating.

Regarding the building comfort references, the only difference between the original and the curtain simulation was that the percentage of hours when operative temperature is above 27°C in the worst zone increased by 2%. As the average and the total percentage was not changed, this indicates that the increase was local and not a problem for the whole building. The lost work due to under or over heating also increased, by as little as 39 hours. These increases indicate that the temperature in the building was not significantly altered as curtains were installed.

The temperatures, air flows and heating in the air handling units did not change significantly, but there were some changes in the zones studied.

Zones

For all the zones, the indoor air quality and the air flows in the zones were the same as for the original scenario. Apart form a significant peak in PPD in mid-August, the Fanger's comfort indices were the same or a little improved compared to the original scenario. This was the same for all zones except zone 10 which had no peak in mid-August. All zones had a slight, but not significant, reduction in daylighting.

Normative - Internal gains

In order to evaluate the effects of the internal gains in the building, a simulation was done without any occupants, lighting or equipment gains in the building. The following describes the results compared to the Normative simulation.

As could be expected, the delivered energy to the building was significantly reduced when the internal loads were removed. There were no delivered energy for lighting or equipment, and the energy demand for fans was reduced, as there would be no people present in the VAV zones. However, without the heat gain from the equipment, lighting and people, the delivered energy for heating increased drastically, from 34.4 kWh/m^2 to 48.9 kWh/m^2, making the total delivered energy as high as 60.6 kWh/m^2.

Although the heating need in the building was increased, the percentage of hours when the operative temperature was above 27°C in the worst zone was reduced. This indicates and confirms that the internal gains cause a big portion of the hours where the operative temperature exceeds 27°C.

Zones

With internal loads reduced to zero, the indoor air quality parameters changed predictably. The CO_2 levels in all the zones were reduced to 400 ppm, which is the default outdoor air level. Furthermore, the air age and the relative humidity had a slight increase in all the zones.

A slight increase in the air age and RH could be expected as the ventilation air flow in the zones was a little reduced. This may also be the cause of the PPD levels being a little higher throughout the year, being higher in the winter months than in the summer. In the zones where there initially were high peaks in the warmer months, the peaks have been reduced except for one appearing in august. The daylighting levels in the zones are the same as before, which is not surprising considering that nothing was physically changed on the facade.

Normative - Reduced occupancy

In order to evaluate the effects of reducing the occupancy in the building, a simulation was run with only 60% occupancy in the building. As could be expected, the total energy delivered to the building was reduced by 3.1 kWh/m^2. Of these, so much as 2.1 kWh/m^2 were due to reduced energy for fans. As most of the occupied zones in the building have VAV control, the reduced occupancy is expected to reduce the need for supply air, reducing the need for fan power. Although the heat gain from the occupants is reduced, the need for heating the ventilation air is reduced when the air flow is reduced. This, in turn, led to an increased heating demand locally in the zones, although the total was still less than the original heating demand.

Although there were changes in the energy use, the percentage of occupancy hours where the operative temperature exceeded 27°C did not change for either of the three measures. This may indicate that the hours when the operative temperature in the building is too high are not caused by the number of occupants and their heat gain. When it comes to hours of lost work due to over or under temperature, the percentage of total hours was increased, but not significantly.

Zones

For the indoor air quality, there were a few changes. In all zones, the CO_2 levels decreased a little. The CO_2 level in each zone was reduced by approximately 50-60 ppm. The last indoor air quality parameter, the relative humidity, was the same as before for all zones. Also affecting the indoor air quality, the ventilation supply air was a little reduced in all zones. As the ventilation is demand controlled, a reduced occupancy is expected to result in reduced supply air.

The Fanger's comfort indices also changed for this case. The PPD levels were all a little reduced, with the peaks in the spring being reduced, but with a "new" peak in august. The same applied for all zones. The PMV levels were approximately the same as before, although it was slightly reduced or slightly increased in a few zones. Lastly, the daylighting levels were the same as before for all zones. This was to be expected, as nothing affecting the building body was changed.

Normative - Position of occupants

In the original simulation, the occupants in the rooms were placed in the middle of the room. To evaluate the effects of the positioning in the room, a simulation was done with the occupants positioned closer to the windows/facade.

As could be expected, the percentage of hours when the operative temperature is above

27°C in the worst zone increased when the occupant was placed closer to the window. The new percentage was 15%, with a 2% increase. The percentage of total occupant hours with thermal dissatisfaction increased by 1%, yielding a total of 7%. For the hours of work lost due to under or over heating, the number of hours increased a little too.

Zones

For all the zones, the indoor air quality and the air flows are the same as the original simulation. Except for zone 10, the Fanger's comfort indices are mostly unchanged except for one or two peaks in mid-July/mid-August. In zone 10, however, they were approximately the same as for the original simulation. As could be expected, the daylighting in the zones was much higher, indicating a significantly higher level of glare and discomfort for a person sitting close to the window. This was the same for all zones except zone 111, which could be expected as the roof provides some shading on this side of the A wing. For zones 175 and 198, the peaks and pattern of the daylight levels over the course of the year were different. In the original simulation, the daylight levels peaked in the spring and in the autumn, while in this simulation, the levels gradually increased, peaking in the summer, and then gradually decreasing again. This is likely due to the position of the sun in the sky, making the highest daylight level for a person sitting in the middle of the room occur in the autumn and the spring when the sun is lower in the sky. For a person sitting closer to the window, the highest daylight level occurs in the warmer season when the sun is higher in the sky and more intense.

For the other two zones, 134 and 10, the daylighting levels were higher throughout the year, with a similar pattern to the original simulation. Zone 111 was the only zone which had a lower daylight level, with a more even pattern than the original simulation. In zone 126, the daylight levels were much higher, and had a similar distribution through the year, except a higher peak in the middle of summer.

Normative - Cooling need

In order to establish the effect of installing cooling in the air handling units, a simulation was performed with cooling coils in the air handling units being in operation. The following describes the findings.

Firstly, the effects of allowing for cooling in the air handling units resulted in the percentage of hours when the operative temperature in the worst zone being above 27°C to be reduced by 3%. The percentage for the average zone and of total occupant hours of thermal dissatisfaction were not changed. In addition to the temperature in the worst zone decreasing, the work lost due to under or overheating was reduced by approximately 272 hours. This indicates that the ventilation cooling has some effect, but is not sufficient to obtain an optimal indoor climate.

As could be expected, the energy delivered to the building was slightly increased when cooling was introduced to the air handling units. As the electric cooling was increased from 0 to 2.6 kWh/m^2 and the heating decreased from 34.4 kWh/m^2 to 33.9 kWh/m^2, the total delivered energy increased from 72.3 kWh/m^2 to 74.5 kWh/m^2. This is not a high increase, indicating that this would not be a costly improvement in operation.

When it comes to used energy there were some changes to both the heating and cooling energy. Naturally, as no energy was used for cooling in the original simulation, this was increased quite significantly by 46 832.3 kWh. The zone heating and the AHU heating were changed, with the zone heating increasing, and the AHU heating reducing. The most significant changes in heating occurred in the warmer months, when the cooling need was highest, resulting in a higher heating demand. As the temperature set point was quite high throughout the year, with 19°C during unoccupied hours, the need for heating for these times was not so unnatural.

Another effect of allowing for AHU cooling was that the total ground source heat was reduced and the ground source cold increased. However, the ground source heat increased during the colder months, while it decreased in the months requiring cooling. As the use of the bore holes was different in this scenario, it is expected to use the bore holes and ground as thermal storage, increasing the available heat in the colder months.

Zones

For all zones, the CO_2 level and the air age was the same as before. The relative humidity was the same most of the year, except during the summer where the peaks were reduced except for one in August. The air flows in the zones were unchanged, while the Fanger's comfort indices were changed for all zones. The PPD levels were a little lower, except a new peak in August, for zones 134, 126, 111 and 10. For zone 198 the PPD level was much better from May to September, and a little better the rest of the year. The PPD level in zone 175 was better throughout the year. For all zones the PMV level was a little worse during the summer, with a peak in August (and for some a small one in May), and a little better during the winter. Lastly, the daylight levels were the same, which could be expected considering that the building body was unchanged.

Conclusions

Several conclusions can be made concerning the effects studied here.

When introducing external shading, the operative temperature increased and the amount of "unacceptable" hours decreased. Naturally, the daylighting levels were also significantly reduced. In order to increase the actinic comfort in the building and provide better conditions for learning, shading should be considered. Here, fixed external overhangs over the windows were used, but to prevent any additional heating need in the darker months and optimize the use of solar heat gain in the building, external blinds or screens are recommended. These will have an increased effect on the building, as well as provide local control.

Internal curtains proved to have a very little effect on the building and zones, although the heating demand and the daylighting levels were predictably reduced. Although they are a cheap and easy solution, the external shading proved much more efficient and would be recommended.

When removing the internal gains form the building, including the occupants, the delivered energy to the building was noticeably reduced. However, without the heat gain from the occupants, lighting and equipment, the heating demand was predictably increased. It is therefore shown that the effects of the internal gains are significant and not to be taken for granted.

Reducing the occupancy in the building resulted in a reduced energy demand. However, although the local heating demand increased, the ventilation heating demand was decreased so much that in total the necessary heating was reduced. Interestingly, the PPD showed that the reduced occupancy increased the percentage of people satisfied, indicating that the building and building services may be dimensioned for too few people. If the systems had been upgraded to supply 40% more people, the occupant satisfaction would likely increase.

In the original simulation, the occupants were positioned in the middle of the room. When they were moved closer to the windows and the facade, the daylighting levels increased significantly. Therefore, the need for shading will be much higher for the occupants located closer to the windows.

Lastly, the normative scenario was simulated with working cooling coils in the air handling units. Although they reduced the PPD, they were not sufficient to provide all the necessary cooling in the building. The energy demand in the building may have gone up, but as the occupants are more comfortable, this may be worth it. The increased delivered energy was less than that calculated in SIMIEN.

10.2 Simulation Results and Analysis of Scenario Two - Actual

In the following, the results from the Actual simulation and the simulations of different effects are presented and analyzed. The simulations were initially done in IDA ICE version 4.6.1, but it was later discovered that a bug in the program version had interfered with the results for the hours of occupancy in the different comfort categories. The graphs presented here for thermal comfort are therefore from a simulation in IDA ICE version 4.6.2. The other results were not affected by this bug and are therefor from the version 4.6.1 simulation (as the simulations above also are done in version 4.6.1).

10.2.1 Actual Analysis

The results considered most important and relevant from the Actual scenario are presented and analyzed here.

Energy

In this simulation, it was found that the energy use of the building added up to a total of 65.2 kWh/m^2. A delivered energy overview is shown below:

Table 10.6: Delivered energy overview

		Delivered energy		**Demand**	**Cost**	
		kWh	**kWh/m^2**	**kW**	**Kr**	**Kr/m^2**
🟨	Lighting, facility	29237	7.5	15.37	24879	6.4
🟩	Equipment, facility	30442	7.8	23.83	25906	6.7
🟦	Electric cooling	0	0.0	0.0		
	Energy pumps	263	0.1	0.33	224	0.1
	Energy fans	46535	12.0	27.75	39600	10.2
	Total, Facility electric	106477	27.4		90609	23.3
	Total	106477	27.4		90609	23.3
□	Equipment, tenant	1848	0.5	1.37		
□	Heating, tenant	144924	37.3	361.4		
	Total, Tenant electric	146772	37.8		0	0.0
🟩	CHP electricity	0	0.0	0.0		
	Total, Produced electric	0	0.0		0	0.0
	Grand total	253249	65.2		90609	23.3

The delivered energy overview shows that over half the total energy delivered to the building is associated with heating. The energy need for fans is the second highest demand, and the lighting and equipment are almost equal. As previously mentioned, it is to be expected that the energy demand for heating is the highest.

The monthly delivered energy for the actual use of the building is shown in the graph below:

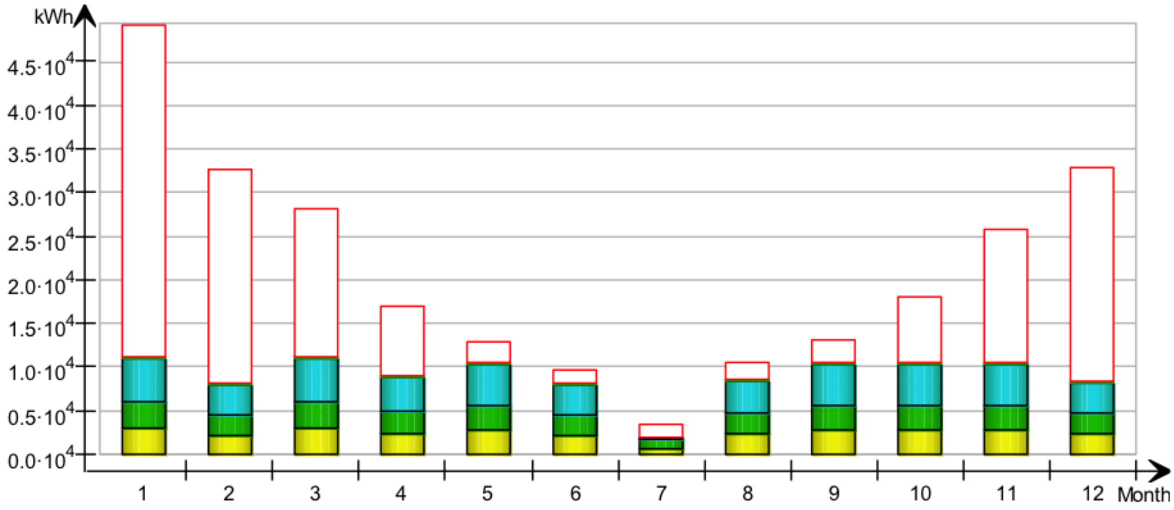
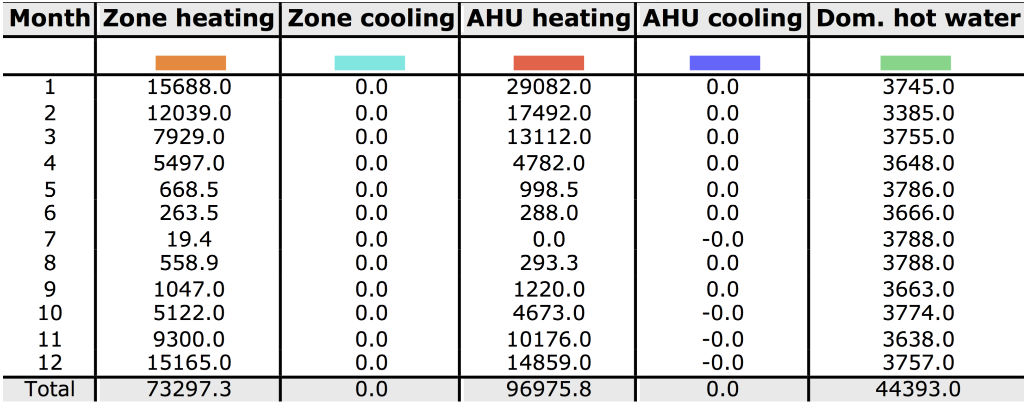


Figure 10.29: Monthly delivered energy

As the graph shows, the monthly delivered energy is highest in the winter months, with lower energy demands the closer to July you get, with July being the month with by far the least energy demand. As the whole of July is a holiday, with no people present and with lower ventilation and temperature demands, this is to be expected. The used energy in the building is illustrated in the table below:

Table 10.7: Used Energy



Month	Zone heating	Zone cooling	AHU heating	AHU cooling	Dom. hot water
	🟧	🟦	🟥	🟦	🟩
1	15688.0	0.0	29082.0	0.0	3745.0
2	12039.0	0.0	17492.0	0.0	3385.0
3	7929.0	0.0	13112.0	0.0	3755.0
4	5497.0	0.0	4782.0	0.0	3648.0
5	668.5	0.0	998.5	0.0	3786.0
6	263.5	0.0	288.0	0.0	3666.0
7	19.4	0.0	0.0	-0.0	3788.0
8	558.9	0.0	293.3	0.0	3788.0
9	1047.0	0.0	1220.0	0.0	3663.0
10	5122.0	0.0	4673.0	-0.0	3774.0
11	9300.0	0.0	10176.0	-0.0	3638.0
12	15165.0	0.0	14859.0	-0.0	3757.0
Total	73297.3	0.0	96975.8	0.0	44393.0

The air handling units are, as previously explained, meant to ensure a temperature rise to a constant 19°C. Therefore, it is natural that the AHU heating is higher than the zone heating. The table shows that except for in July and August, the AHU heating is higher than the zone heating. In July and August, the heating demand is very low, and the outdoor air temperature is quite high, making the little temperature rise necessary up to the radiators.

Ground heat

The Actual use simulation results yielded a ground source energy use of 64 737.0 kWh, which is so little as 44.7% of the total heating demand of the building. Considering that the heat pump is meant to supply 90% of the building heating demand, in addition to a smaller new building which is not considered here, this is quite little.

Building comfort and work loss results

As previously mentioned, the three building comfort reference measures are:

- Percentage of hours when operative temperature is above 27°C in worst zone
- Percentage of hours when operative temperature is above 27°C in average zone
- Percentage of total occupant hours with thermal dissatisfaction

Firstly, the worst zone had a percentage of 61%, while the average zone was only 3%. The percentage of total occupant hours with thermal dissatisfaction was as high as 11%. This percentage is quite high, indicating that there might be a significant cooling demand in the building.

Even though the percentage of occupant hours with thermal dissatisfaction was so high for this case, the amount of lost working hours was quite low. The lost work due to under or overheating is listed below:

Table 10.8: Working hours lost

Month	**Total Working Hours**	**Lost Working Hours**
1	43004.0	101.1
2	29432.0	69.2
3	41105.0	85.0
4	31744.0	68.8
5	39464.0	250.8
6	27565.0	276.6
7	0.0	0.0
8	29432.0	139.4
9	39243.0	94.3
10	39240.0	54.6
11	39240.0	64.6
12	29429.0	52.9
Total	388898.0	1257.2

The table indicates a higher number of lost working hours in the warmer months (except, of course, July where there are no people in the building). In January, the number of lost working hours is also quite high, but as this is the month with the highest total number of working hours, this is not surprising. Nevertheless, as the total number of lost working hours only equates to 0.323% of the total amount of working hours, over- or under heating may not be a problem.

AHU - temperature

The temperatures in the air handling units are approximately the same for all six of them. Below is a graph which illustrates the dry-bulb temperature of the outdoor air, the supply air and the return air for AHU1:

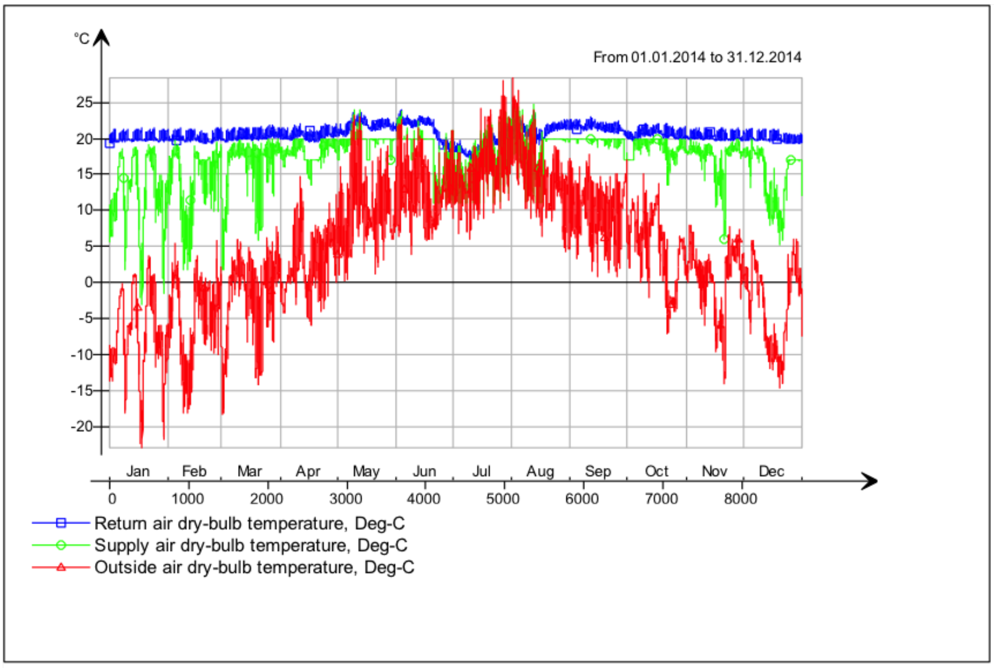


Figure 10.30: Air flow temperature in AHU1

The outdoor temperature varies through the year as expected, with lower temperatures in the winter, which increases until late July/early August, where it peaks and then gradually decreases back to low temperatures in December. The supply air temperature is somewhat more constant, with a few significant temperature drops through the winter months. In the summer, the supply air temperature increases due to the lack of cooling in the air handling unit. The temperature drops in the supply air can be caused by distribution losses in the system. The return air temperature is very close to constant throughout the winter, spring and autumn, but decreases in early July, before it increases around July/August.

AHU - air flows

For all six air handling units in the building, the supply and return air flows were approximately the same for each week. In all AHUs except for AHU4, the supply air was overall a little higher than the return air. In figure 10.31 below, the air flow trend in all AHUs except AHU4 is illustrated by the air flow in AHU3. Figure 10.32 shows the trend in AHU4.

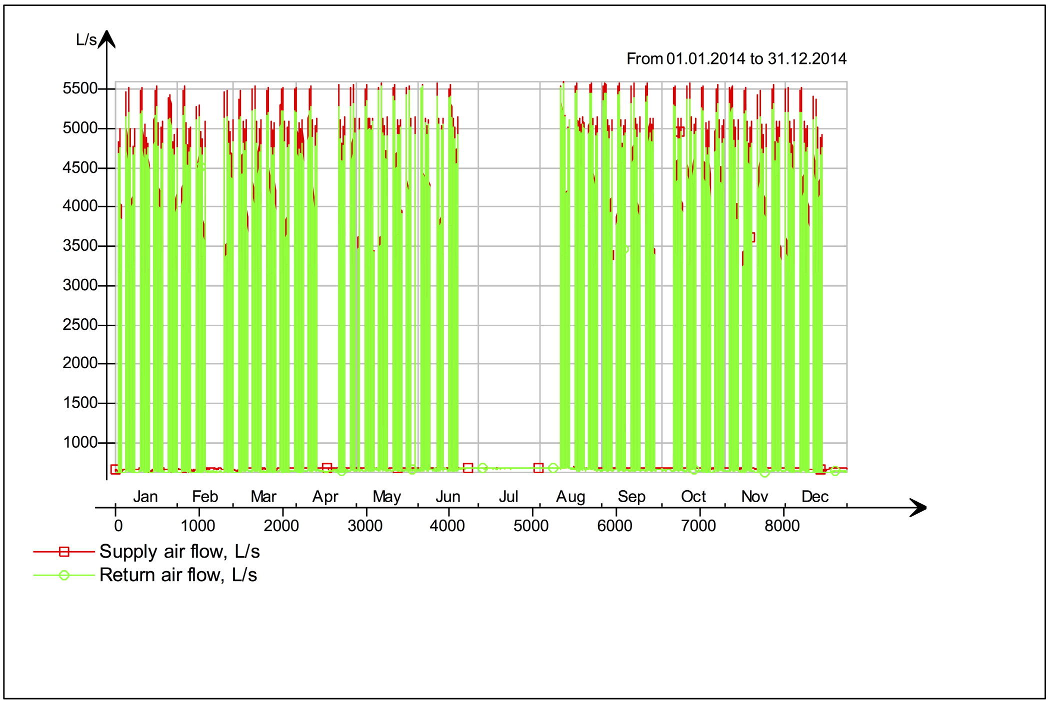


Figure 10.31: Air flow in air handling unit three

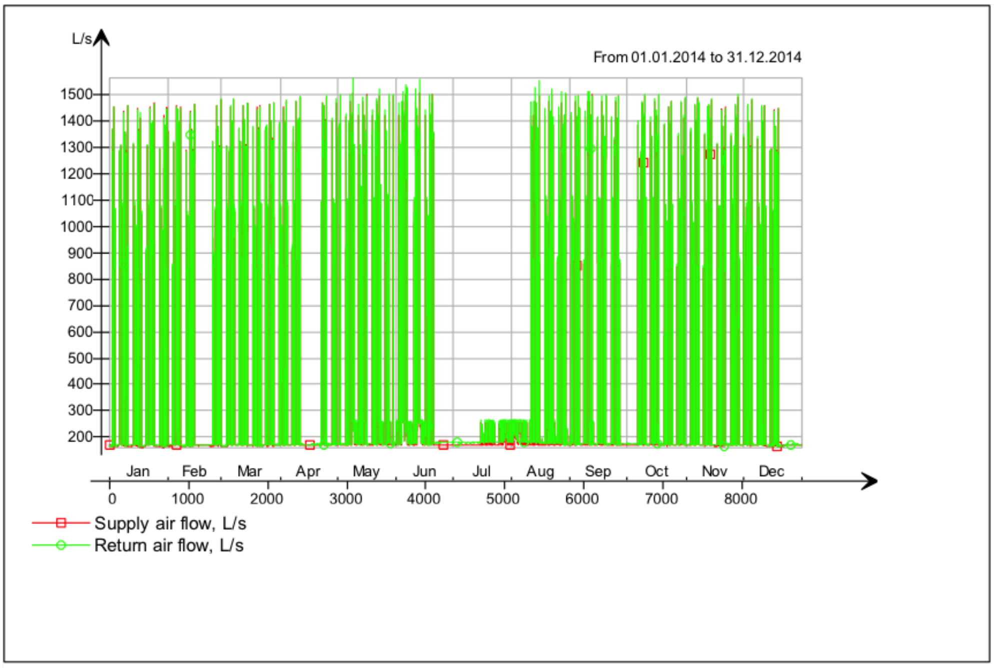


Figure 10.32: Air flow in air handling unit four

During the holidays and weekends, the air flows are reduced to a minimum, as there are no occupants in the building at this time. In the warmer months the air flow rates increase a little as the under tempered air has a cooling effect. For the rest of the year, the air flows are approximately the same. Compared to the Normative scenario, there are higher differences between the different days of the week, which is to be expected as this scenario takes the different schedules for each day of the week into account.

AHU - heating, heat recovery, cool recovery

In order to ensure the temperature of the supply air, the air handling units all have heating coils and heat recovery units installed. Two AHUs have a cross flow heat exchanger, while the rest have rotating heat exchangers. In order to reduce the energy demand, the heat exchangers preheat the air before it enters the heating coils. For this simulation, the actual heat exchanger efficiencies are used, resulting in the following percentage of the total heating:

- AHU1: 88.7%
- AHU2: 63.2%
- AHU3: 86.4%

- AHU4: 75.4%
- AHU5: 87.5%
- AHU6: 83.7%

The heat exchangers in AHU2 and AHU4 are both the cross flow heat exchangers. The cross flow heat exchangers have a lower efficiency than rotating heat exchangers, making it expected that the recovered heat from these heat exchangers is lower than for the others.

The heat exchangers in AHU1, AHU2 and AHU6 have a cooling effect in May, June and July, those in AHU3 and AHU4 have a cooling effect in July and August, while the heat exchanger in AHU5 has a cooling effect only in July. For all six AHUs, the cooling effect is highest in July, even though the air flow in the building is at its lowest at this time.

Indoor climate in selected zones

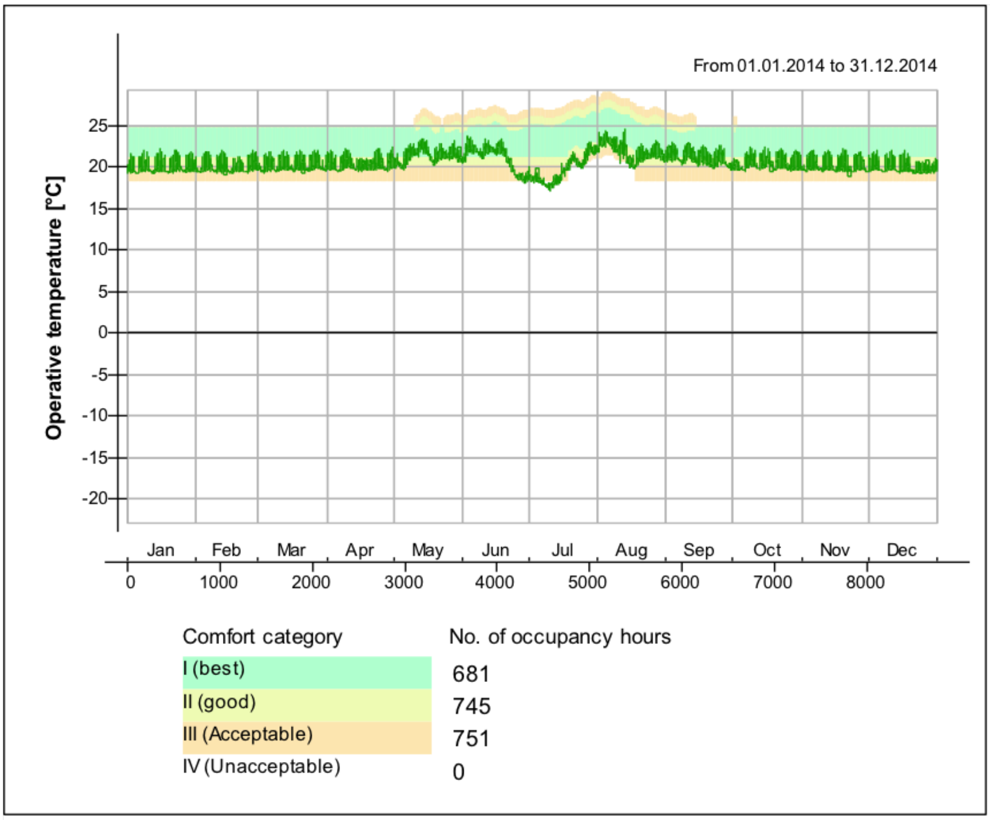
As for the Normative simulation, selected zones are chosen to study the indoor climate in the building. The zones chosen are the same as for the Normative simulation, chosen based on location and characteristics. For each zone, the following is considered:

- Air flow in zone
- Thermal comfort
- Indoor air quality
- Fanger's comfort indices
- Daylighting

Zone 111 - Classroom, south-west side

The air flow through the zone walls, both internal and external, is quite low apart from a few peaks here and there, never exceeding 15 L/s. The mechanical supply and return air is at its minimum of approximately 22 L/s whenever the building is not in use. When the building is in use, but the room is unoccupied, the ventilation air flow is at the set point minimum of 118.3 L/s. During occupied hours, the ventilation air flow is initially increased to the maximum flow rate of 333 L/s, before it is reduced to approximately 268 L/s.

The thermal comfort in the zone is shown in the graph below:



Comfort category	No. of occupancy hours
I (best)	681
II (good)	745
III (Acceptable)	751
IV (Unacceptable)	0

Figure 10.33: Zone 111: Thermal Comfort

In the colder months of the year, the temperature is at approximately 21-22°C. In May/June and in July/August, the temperature rises a couple of degrees, and then drops below 20°C during the summer when the building is unoccupied.

The graph of the air age, the CO_2 level and the relative humidity is shown below:

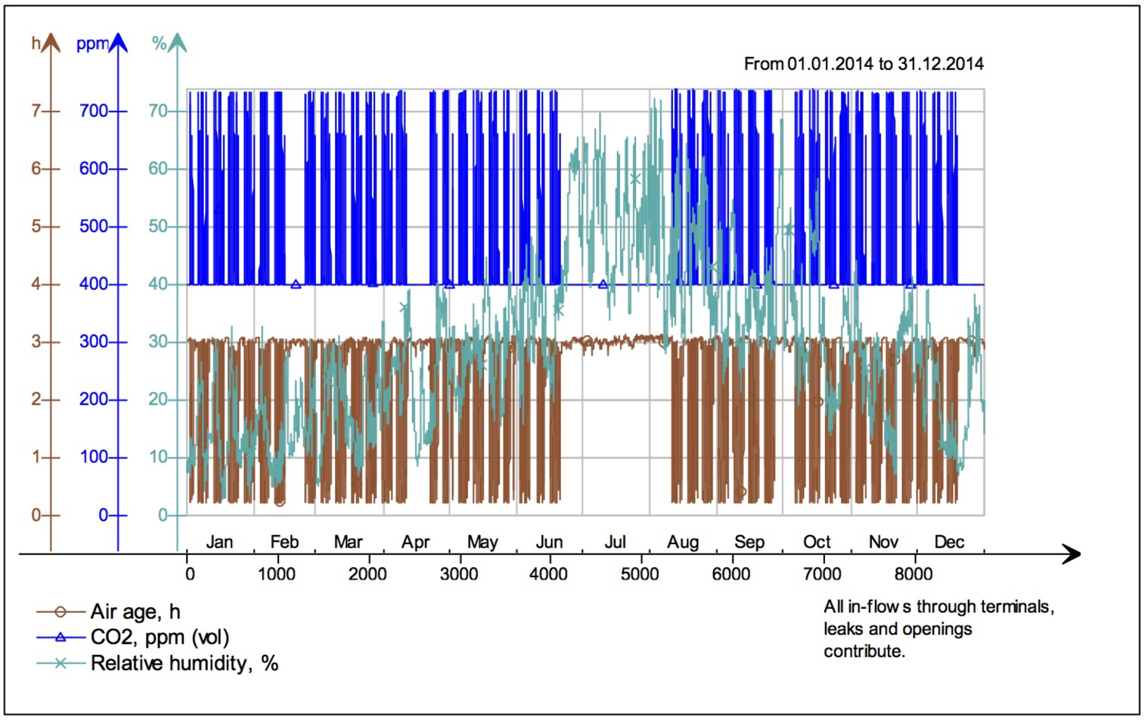


Figure 10.34: Zone 111: Indoor Air Quality

The graph above shows that the CO_2 level is approximately at 730ppm and the air age is approximately 0.3 during, which is below the passive house requirements (Standard Norge, 2012). However, the relative humidity is a little high in late July/early August. As it passes 70%, it may be uncomfortably high for the users in this period (Novakovic, et al., 2007). Also, except for June to mid October, the RH drops below 20%, which can be uncomfortable and cause irritation to the occupants (Novakovic, et al., 2007).

To evaluate the comfort in the building, Fanger's comfort indices are shown over the course of the year in the graph below:

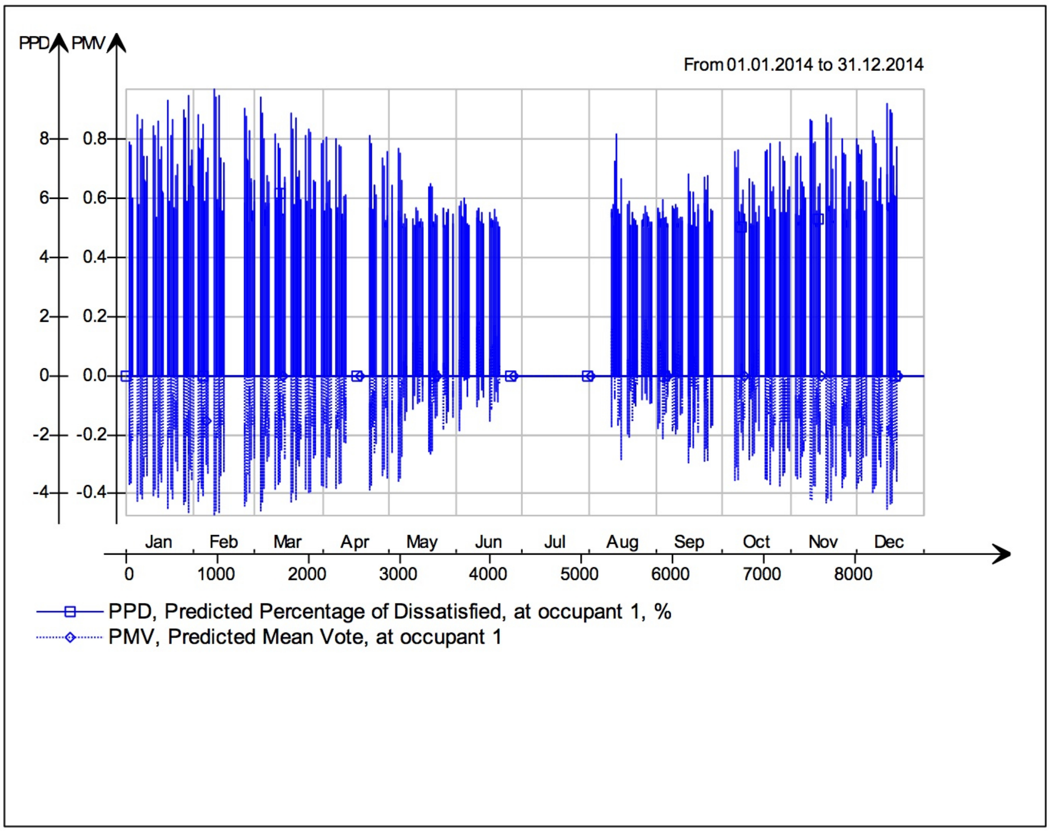


Figure 10.35: Zone 111: Fanger's Comfort Indices

As the PPD and PMV levels never pass 9% and -0.5 respectively, they indicate that more than 90% and 95%, respectively are satisfied with the indoor environment.

Lastly, the daylight level in the zone is shown in the following graph:

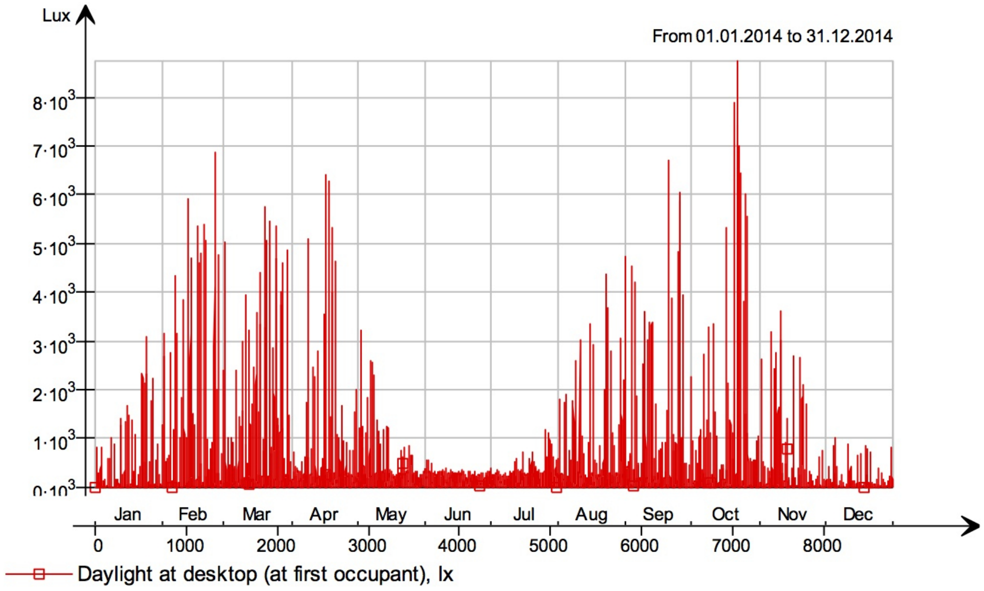


Figure 10.36: Zone 111: Daylighting

As this zone faces southwest, the variation through the year is as expected. Considering that the lighting requirement for tasks of high accuracy is 2000 Lux (Novakovic, et al., 2007), the levels in the zone are at times quite high and additional shading may be required by the occupants.

Summary

During the colder months of the year, the temperature in the zone is kept at approximately 21-22°C. From May to August, however, it varies a bit and increases a couple of degrees during the occupied weeks. The air age and the CO_2 levels in the zone are below the set points, which indicates a high indoor air quality, in spite of an at times too high or too low RH. The PPD and PMV levels in the zone satisfy the comfort category B (Standard Norge, 2006). The daylighting in the zone is at times quite high, and may indicate an additional need for shading.

Zone 134 - Classroom, north-east side

Through the internal and external walls in this zone, the air flow is quite low, with a few occasional peaks, but never exceeding approximately 15 L/s. The ventilation air supplied to the room is at its maximum of 333 L/s when the room is occupied. When the building is in use, but the room is unoccupied, the ventilation air flow is at the set point minimum of 115.2 L/s. Whenever the room is unoccupied, the ventilation air flows are reduced to the minimum of approximately 22 L/s.

Below, the thermal comfort in the zone is shown:

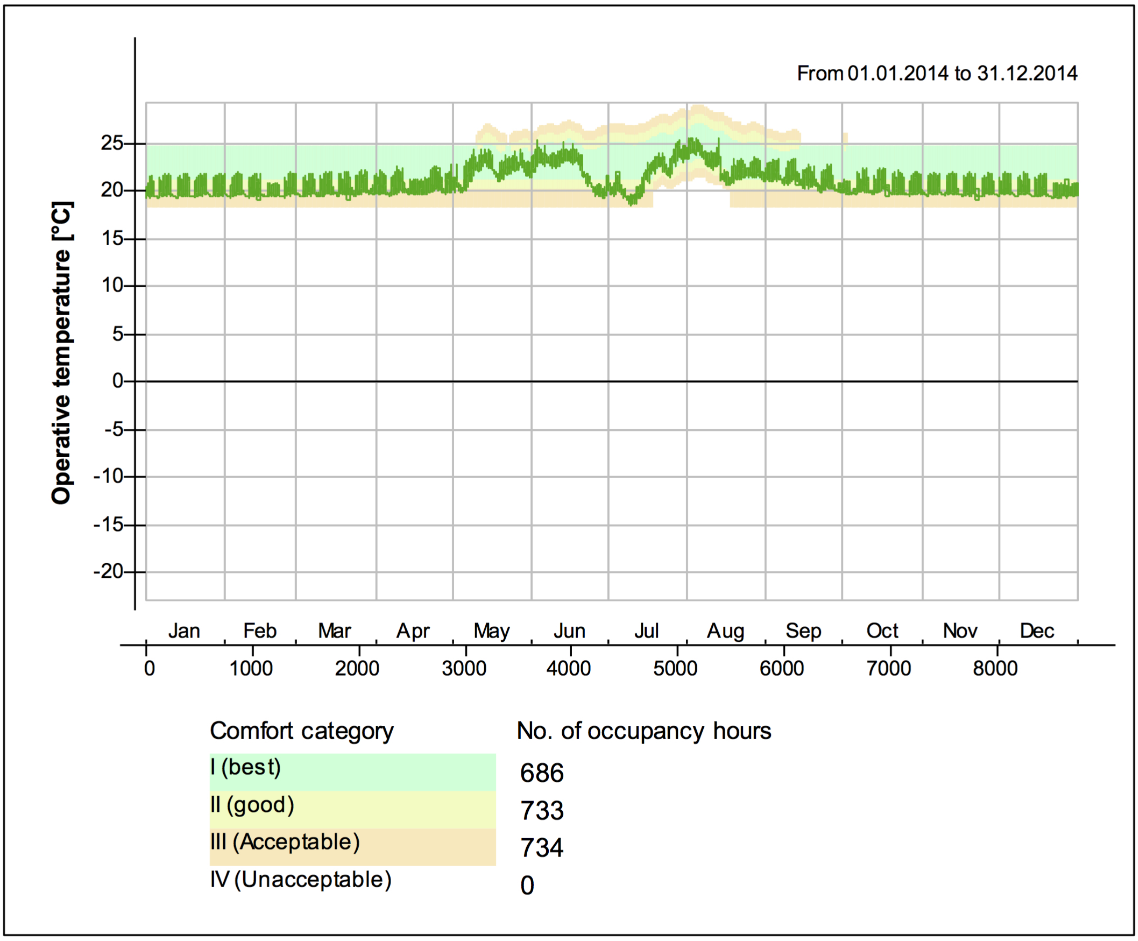


Figure 10.37: Zone 134: Thermal Comfort

In May/June and July/August the graph shows that the temperature increases to 24-25°C, while in the colder months of the year it is at 21-22°C. Furthermore, during the unoccupied months of the summer, the temperature drops to around 19-20°C.

The graph of the air age, the CO_2 level and the relative humidity is shown below:

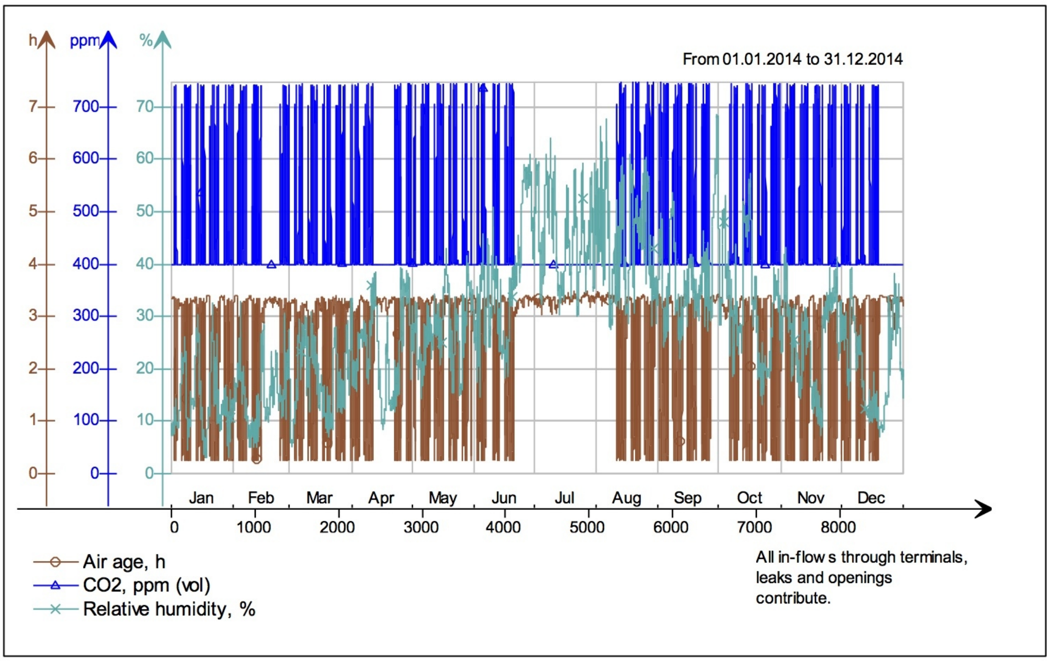


Figure 10.38: Zone 134: Indoor Air Quality

The CO_2 level is kept approximately at 740ppm during occupancy and the air age is at approximately 0.3, which is below the passive house requirements (Standard Norge, 2012). Also, the relative humidity does not pass 70% and should not get uncomfortably high (Novakovic, et al., 2007). However, except for mid June to mid October, the RH drops below 20%, which may be uncomfortable and cause irritation to the occupants (Novakovic, et al., 2007).

In the figure below, Fanger's comfort indices are shown:

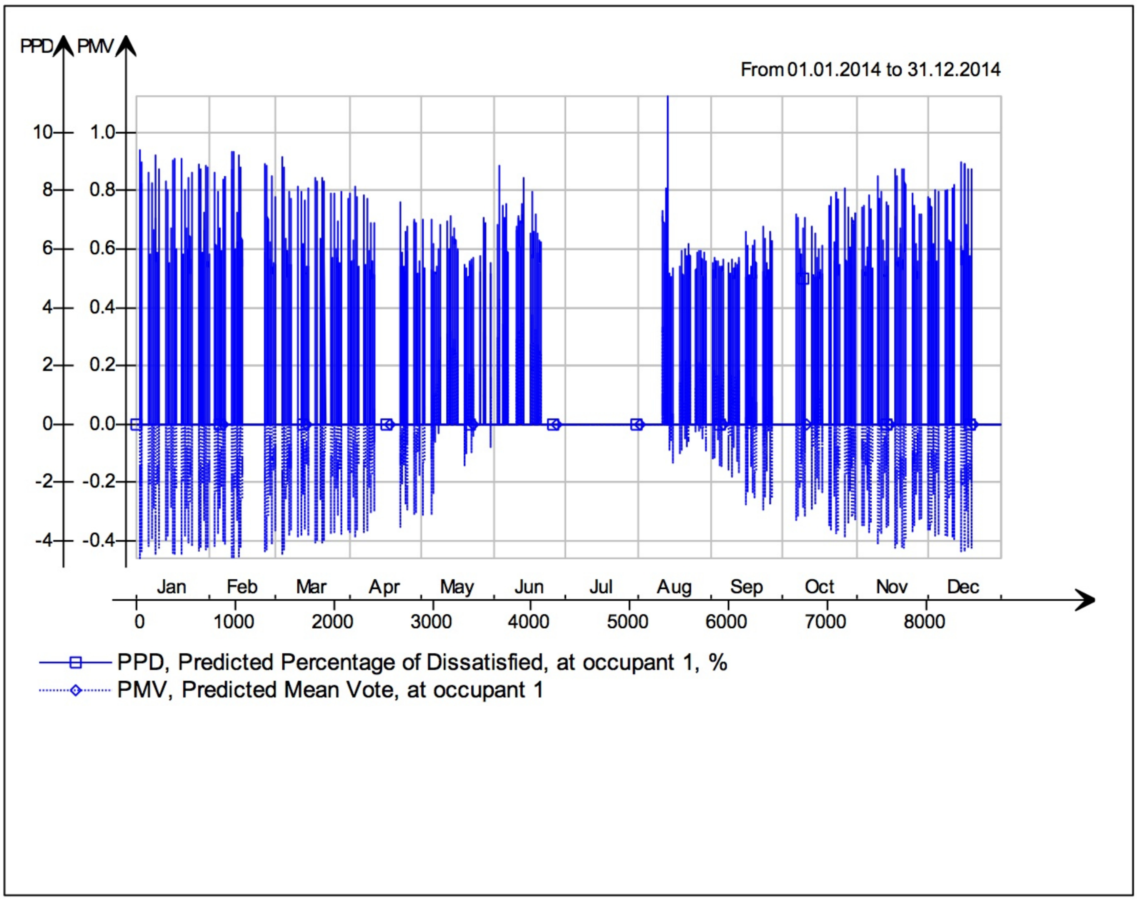


Figure 10.39: Zone 134: Fanger's Comfort Indices

As the PPD level only once passes 10% and the PMV level never passes -0.5, they indicate that more than 90% are satisfied with the indoor environment most of the time, and 95% are satisfied with the indoor environment all the time.

Here, daylight level in the zone is shown in the following figure:

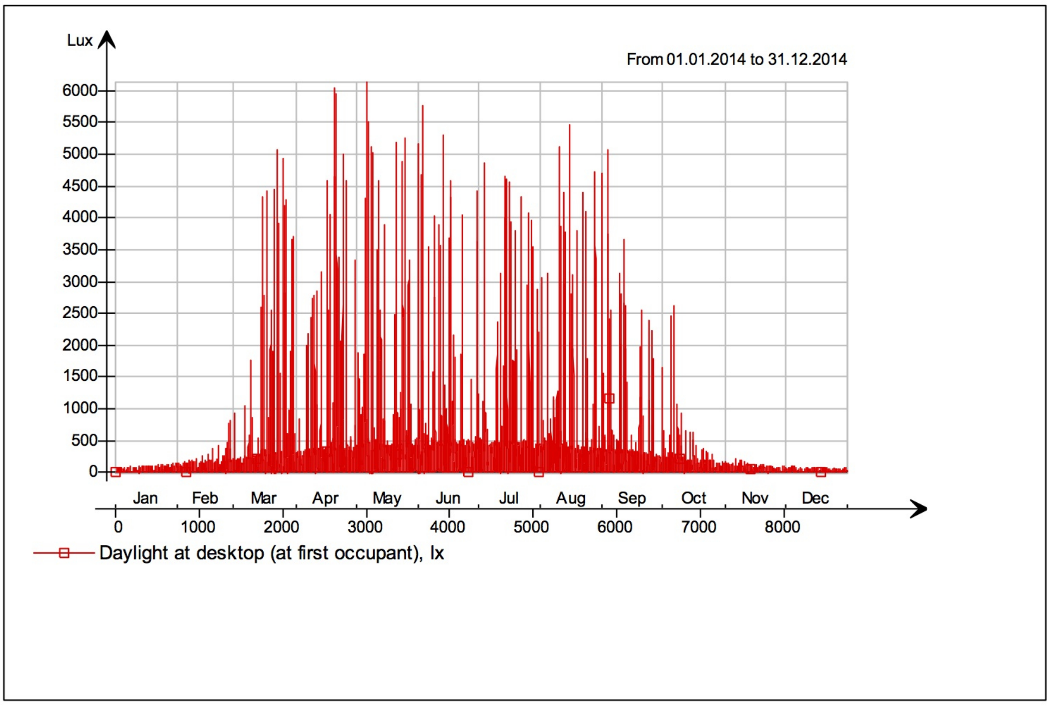


Figure 10.40: Zone 134: Daylighting

The variation through the year is not unexpected as the zone faces northeast. According to Novakovic, et al. (2007), the lighting requirement for tasks of high accuracy 2000 Lux. The levels in the zone can therefore, at times, be quite high and shading may be necessary.

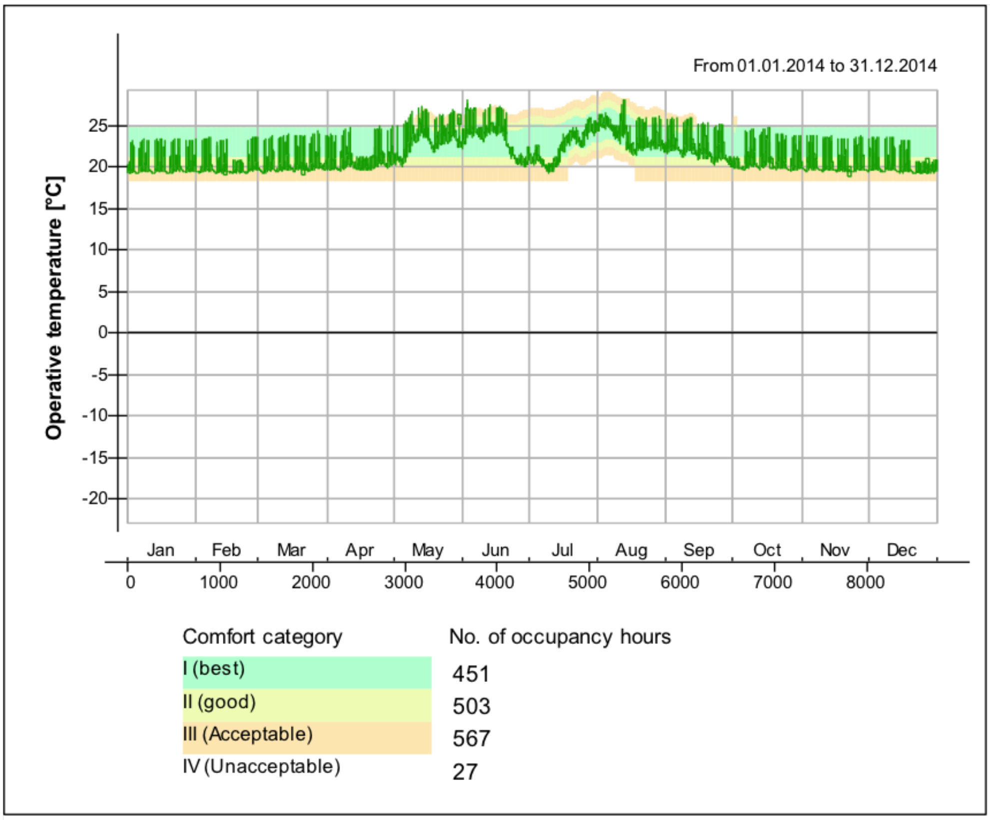
Summary

The temperature in the zone is at approximately 21-22°C during the colder months of the year, while in May/June and July/August the temperature increases to 24-25°C. During the summer holidays, the temperature drops to 19-20°C. In spite of a low RH level from mid October to mid June, the air age and CO_2 levels indicate a good indoor air quality. The PPD and PMV level satisfy the category B levels throughout the occupied times of the year, except for a once occurring peak (Standard Norge, 2006).

Zone 126 - Computer lab

As for the zones mentioned, the air flow through the internal and external walls of the building is very low, with occasional peaks never exceeding 15 L/s. The ventilation air flow is at its highest, approximately 305 L/s, when the zone is occupied, but it does not reach the set point maximum of 320.1 L/s. When the building is in use, but the room is unoccupied, the ventilation air flow is at the set point minimum of approximately 113.4 L/s.

The thermal comfort in the zone is shown in the graph below:



Comfort category	No. of occupancy hours
I (best)	451
II (good)	503
III (Acceptable)	567
IV (Unacceptable)	27

Figure 10.41: Zone 126: Thermal Comfort

In the colder months of the year the temperature is quite high, at 23-24°C. From May to August the temperature is at 24-25°C during the occupied weeks, and drops to approximately 20°C when the room is unoccupied.

In the figure below, the air age, the CO_2 level and the relative humidity is shown:

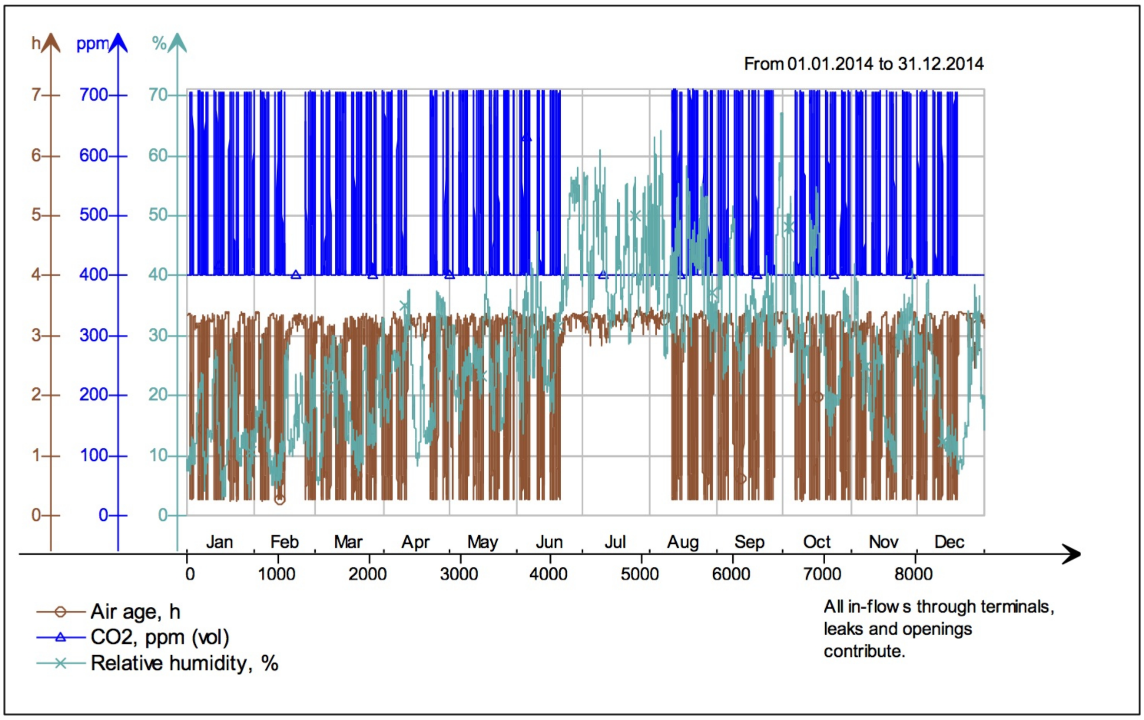


Figure 10.42: Zone 126: Indoor Air Quality

According to the graph above, the CO_2 level is at approximately 710ppm, and the air age during occupancy is at approximately 0.3. This is below the passive house requirements of maximum 1000 ppm and an air age of 0.6 (Standard Norge, 2012). Also, the relative humidity should not get uncomfortably high. However, except for mid June to mid October, the RH drops below 20%, which may be uncomfortable and cause irritation to the occupants (Novakovic, et al., 2007).

Fanger’s comfort indices are shown over the course of the year in the graph below:

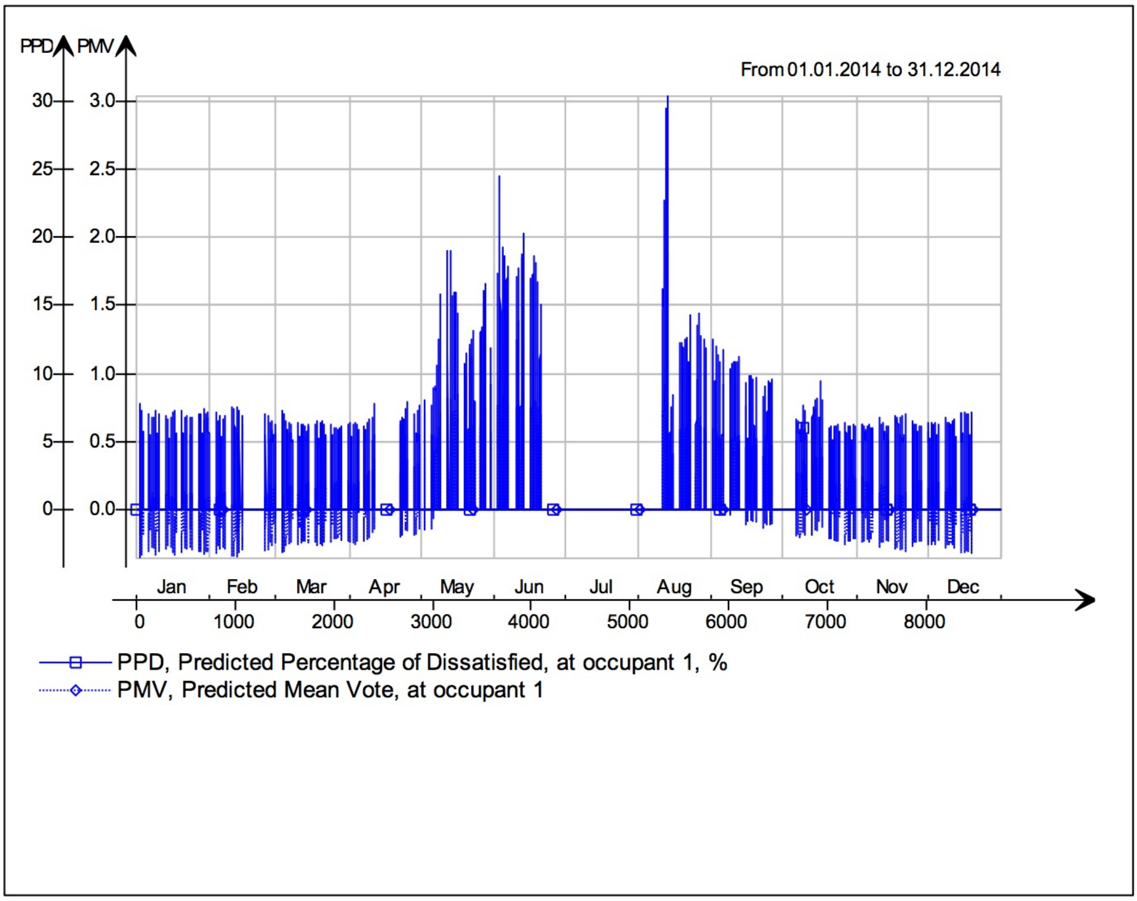


Figure 10.43: Zone 126: Fanger’s Comfort Indices

The PPD level passes 10% from May to mid September (except during the holidays), indicating that these months have an increased level of dissatisfied people. The PMV level however, does not pass 5%

In the figure below, the daylighting level is shown:

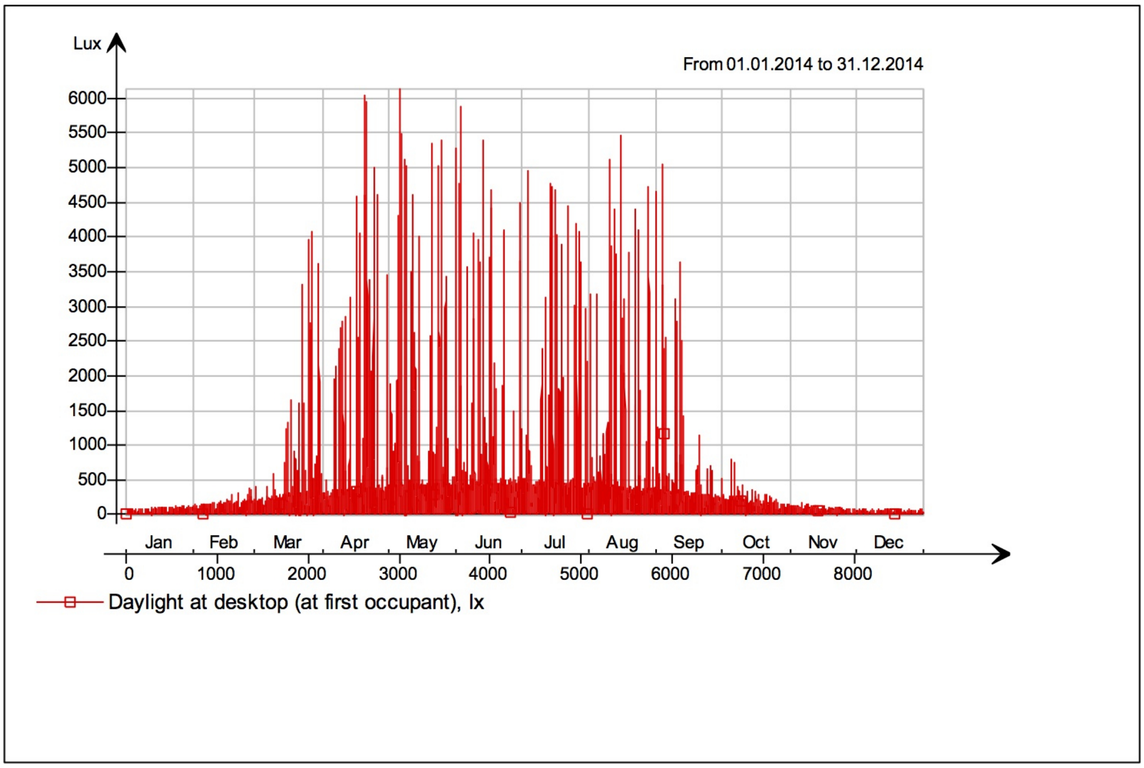


Figure 10.44: Zone 126: Daylighting

As this zone faces northeast, it is expected to have a daylighting level varying as in the figure above. The lighting requirement for tasks of high accuracy is 2000 Lux (Novakovic, et al., 2007). Therefore, the levels in the zone are at times a little high and some shading may be required by the occupants.

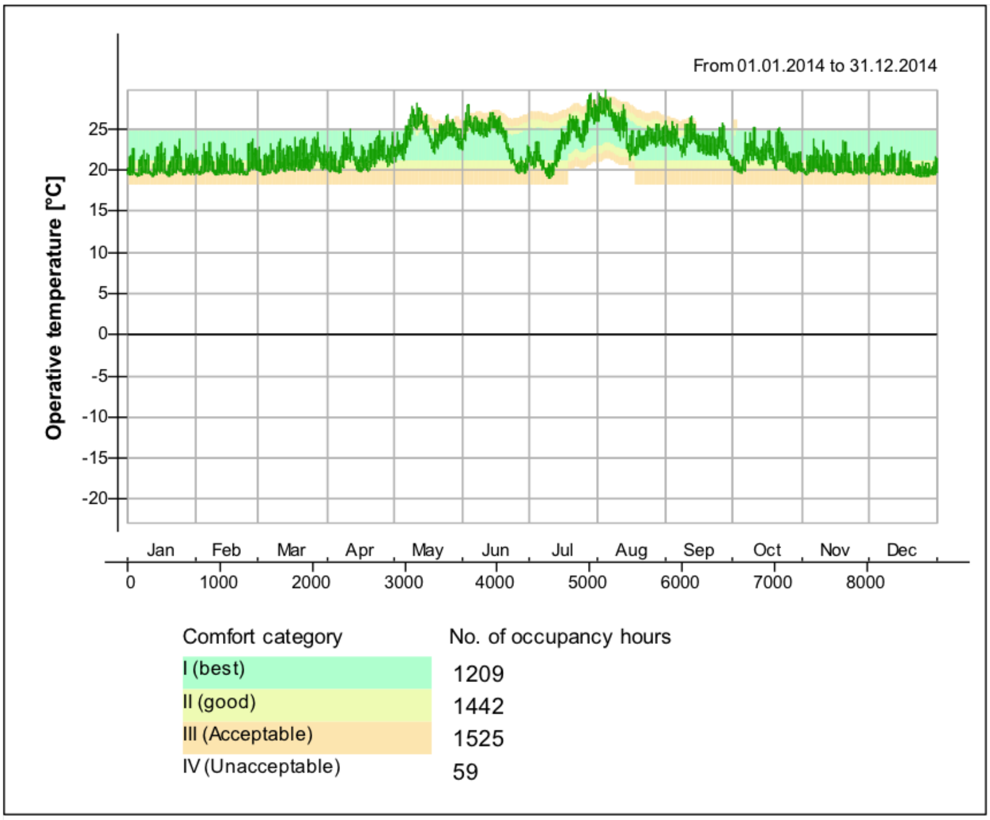
Summary

In the colder months of the year, the temperature is quite high, at 23-24°C. From May to August, the temperature reaches 26-27°C during occupancy, and is reduced to approximately 20°C during the summer holidays. Although the RH gets quite low from mid October to mid June, the CO_2 level and air age in the room indicate a good indoor air quality. The PPD level in the zone is alarmingly high from May to mid September, but the rest of the year it satisfies the category B requirement (Standard Norge, 2006). The PMV level, however, satisfies the category B level throughout the year (Standard Norge, 2006).

Zone 175 - Work room teachers

In this zone, the air flow rates through the internal and external walls all vary a little throughout the year, with occasional peaks never exceeding approximately 10 L/s. During occupancy the ventilation air flow through the zone is at its maximum of approximately 112 L/s, even though the set point maximum is 126.4 L/s. When the room is unoccupied, the ventilation air flow is at the minimum level of 14 L/s.

The figure below shows the thermal comfort in the zone:



Comfort category	No. of occupancy hours
I (best)	1209
II (good)	1442
III (Acceptable)	1525
IV (Unacceptable)	59

Figure 10.45: Zone 175: Thermal Comfort

Throughout the year the temperature is quite high in this zone. From May through September the temperature is very high at 25-30°C, except for a drop to 20-23°C during the summer holidays. Furthermore, during the colder months, the temperature varies from 21°C to 25°C.

The air age, the CO_2 level and the relative humidity is shown in the figure below:

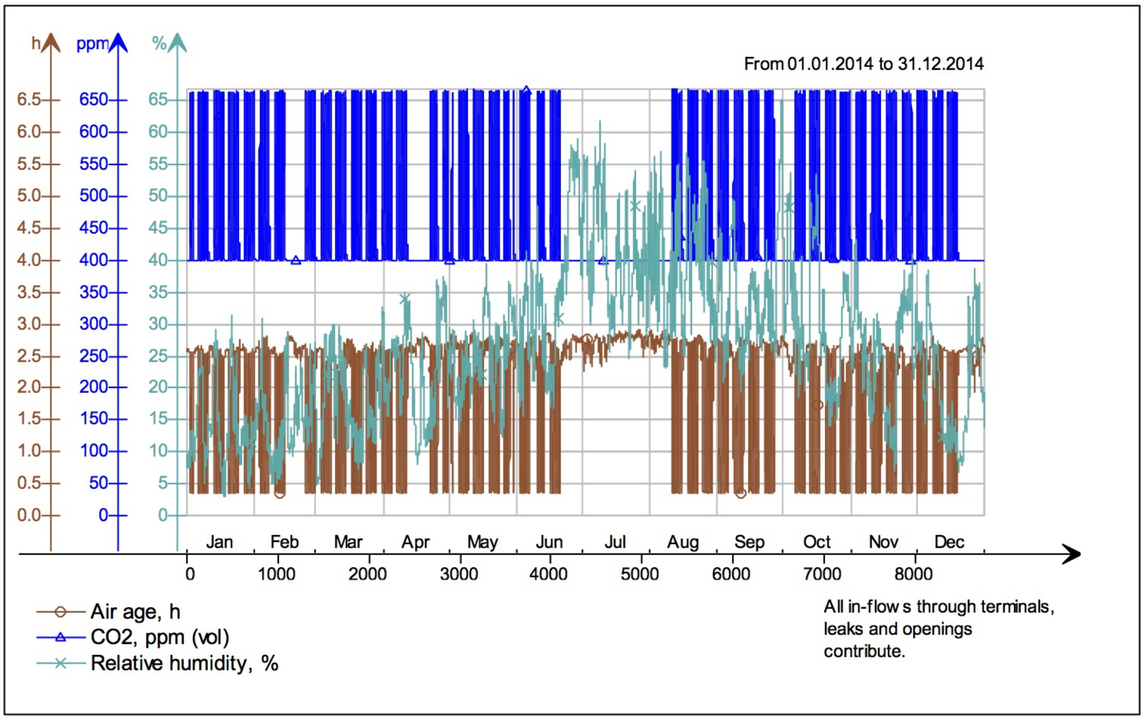


Figure 10.46: Zone 175: Indoor Air Quality

According to the figure above, the CO_2 level is at approximately 660ppm, and the air age during occupancy is at approximately 0.4. This is below the passive house requirements (Standard Norge, 2012). Also, the relative humidity does not get uncomfortably high. Furthermore, except for mid June to mid October, the RH drops below 20%, which may be uncomfortable and cause irritation to the occupants (Novakovic, et al., 2007).

In order to evaluate the comfort in the building, Fanger's comfort indices are shown in the graph below:

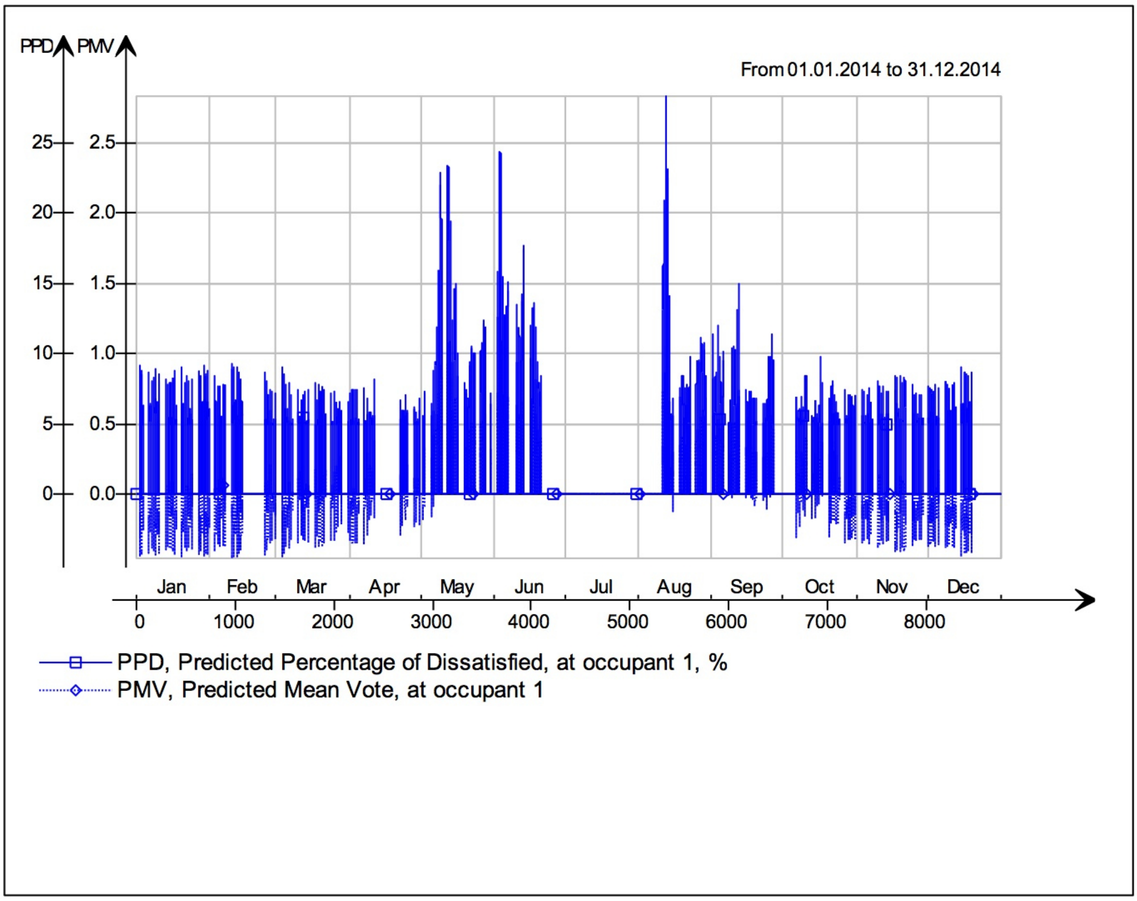


Figure 10.47: Zone 175: Fanger's Comfort Indices

The PPD level passes 10% from May through September (except during the holidays), indicating that these months have an increased level of dissatisfied people. The PMV level however, does not pass 5%.

The daylight level in the zone is shown in the following graph:

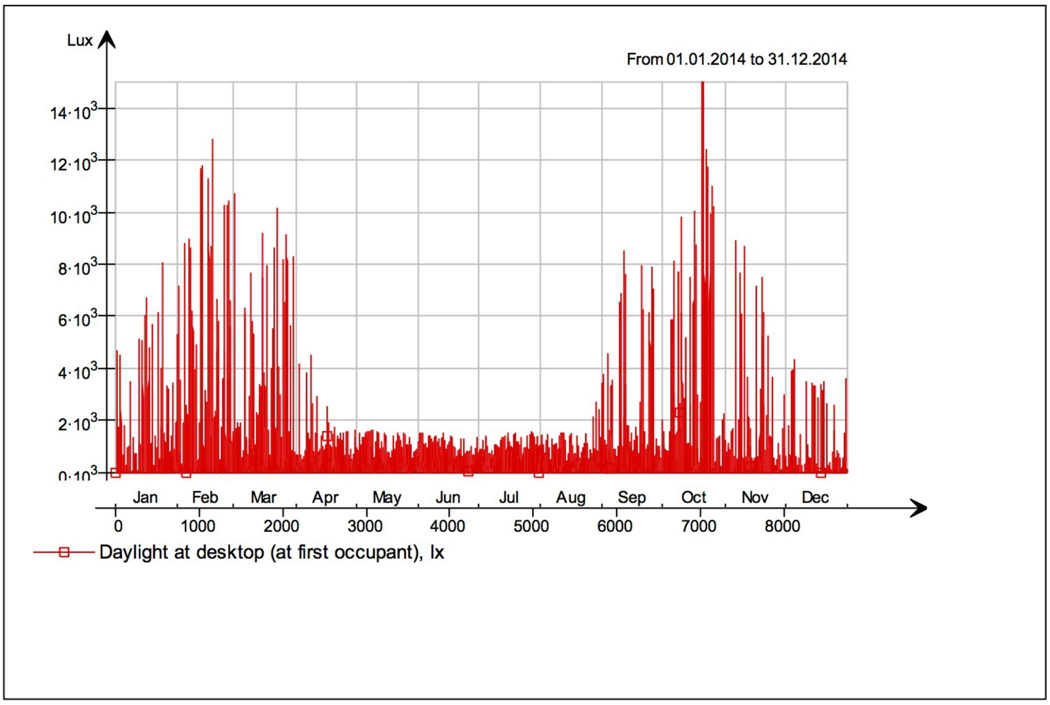


Figure 10.48: Zone 175: Daylighting

As this zone faces south east and is somewhat shaded by the B wing, the variation through the year is as expected. Novakovic, et al. (2007) define the lighting requirement for tasks of high accuracy to be 2000 Lux. This indicates that the levels in the zone are at times very high and shading may be required.

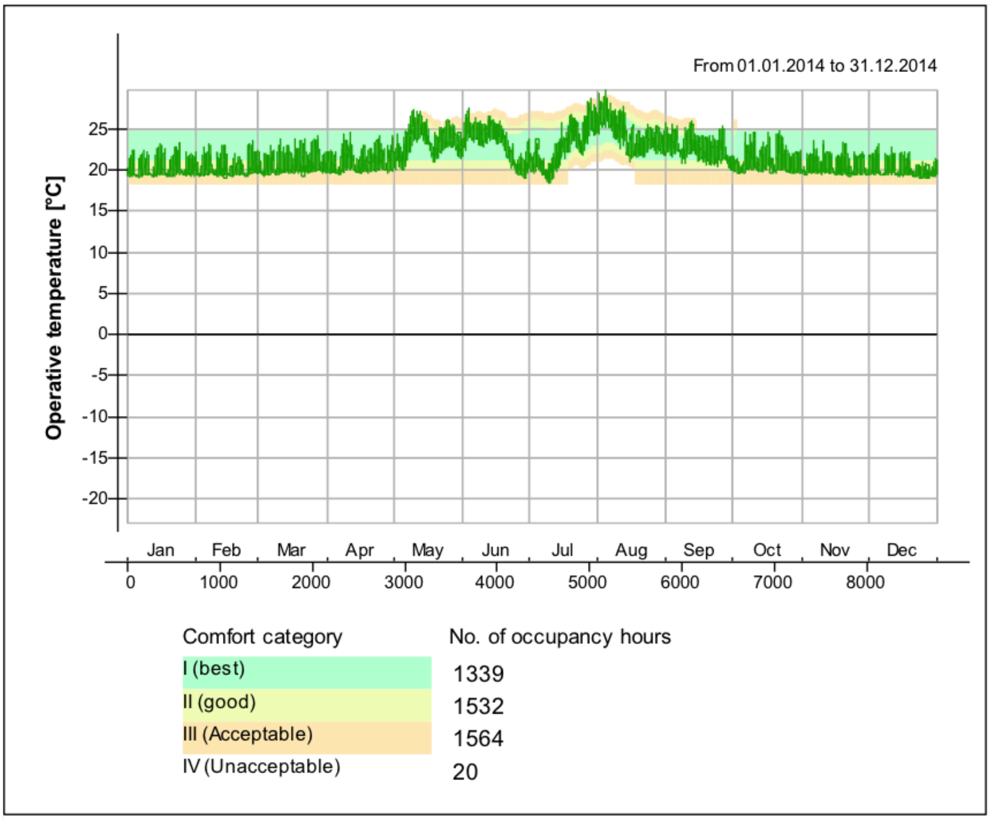
Summary

The temperature in this zone is quite high throughout the year. In the colder months it varies between 21°C and 25°C, being in the higher end of the scale most of the time. From May to mid August, the temperature increases to 25-30°C, except for when the room is unoccupied when it drops to 20-23°C. The relative humidity is quite low from mid October to mid June, but the CO_2 level and the air age in the room indicate that the indoor air quality is still quite good. From May through September the PPD level is alarmingly high, but satisfies the category B requirements the other months of the year (Standard Norge, 2006). The PMV is at approximately 0 when the PPD level is too high, but satisfies the category B requirements for the colder months of the year (Standard Norge, 2006). The daylighting level in the room is also quite high, indicating a strong need for shading in the zone.

Zone 198 - Work room teachers

The inflow and outflow through the internal and external walls in this zone is a little higher than in other zones and varies quite a bit throughout the year. However, the peaks never exceed approximately 22 L/s. When the zone is occupied the ventilation supply air is at a maximum, of approximately 275 L/s, even though this is not the maximum set point air flow, which is 287.5 L/s. Whenever the room is unoccupied, the air flow rate is reduced to a minimum of only approximately 28 L/s, even though the minimum set point ventilation air flow is 141 L/s.

The thermal comfort in the zone is shown in the graph below:



Comfort category	No. of occupancy hours
I (best)	1339
II (good)	1532
III (Acceptable)	1564
IV (Unacceptable)	20

Figure 10.49: Zone 198: Thermal Comfort

According to the graph, the temperature is quite high throughout the year. During the colder months of the year, the temperature varies from 21°C to 25°C, and increases further from May through August, to 25-30°C. During the summer holidays, the temperature drops to 19-24°C.

Below the graph of the air age, the CO_2 level and the relative humidity is shown:

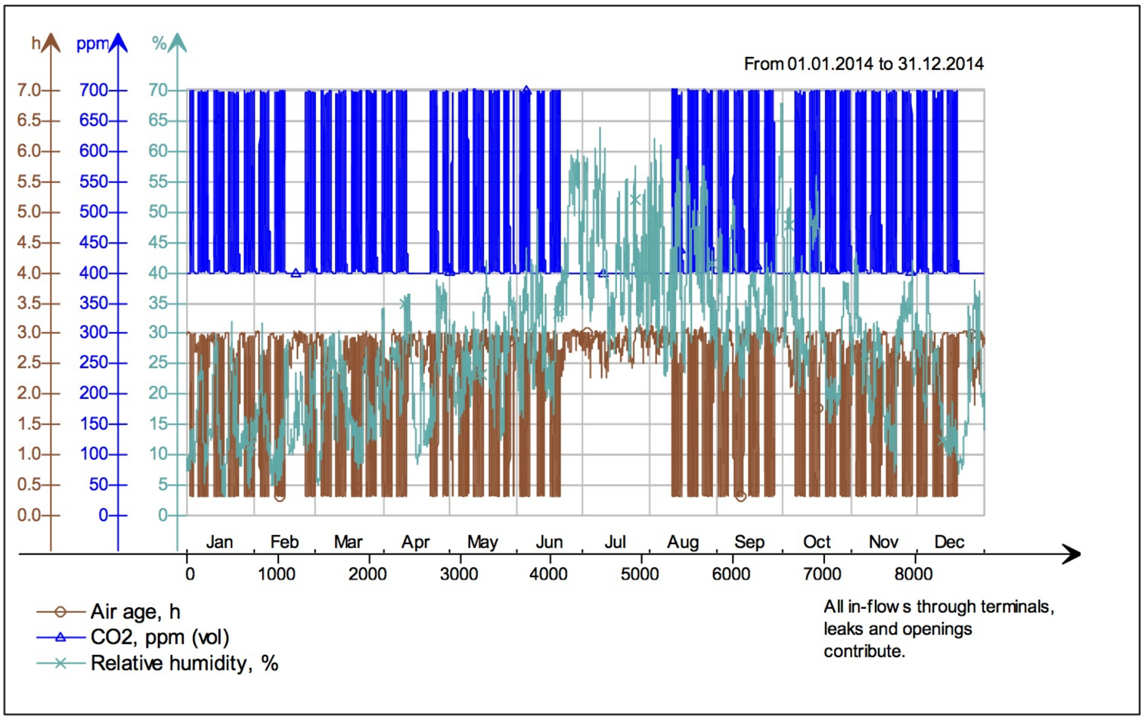


Figure 10.50: Zone 198: Indoor Air Quality

According to the graph above, the CO_2 level is a little higher than the other zones, at approximately 700ppm, and the air age during occupancy is at approximately 0.3 which is below the passive house requirements (Standard Norge, 2012). Also, the relative humidity does not pass 70% and should not get uncomfortably high (Novakovic, et al., 2007). However, except for mid June to mid October, the RH drops below 20%, which may be uncomfortable and cause irritation to the occupants (Novakovic, et al., 2007).

To evaluate the comfort in the building, Fanger's comrfort indices are shown over the course of the year in the graph below:

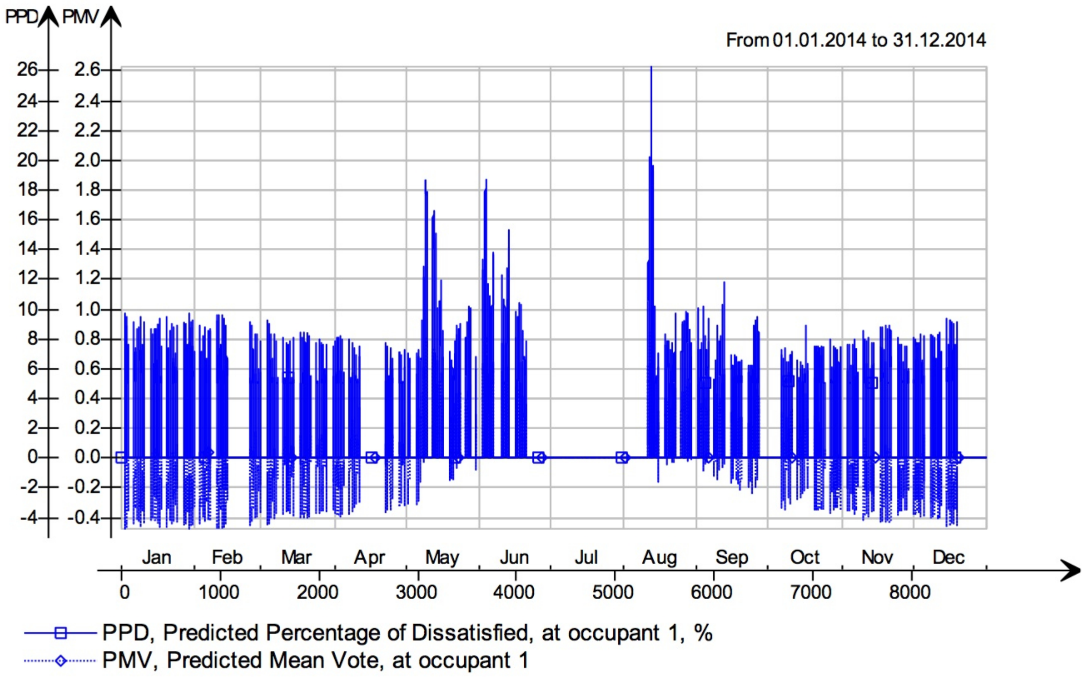


Figure 10.51: Zone 198: Fanger'S Comfort Indices

The PPD level passes 10% from May to mid September (except during the holidays), indicating that these months have an alarmingly high level of dissatisfied people. The PMV level however, does not pass the 5% demand of category B (Standard Norge, 2006).

The daylight level in the zone is shown below:

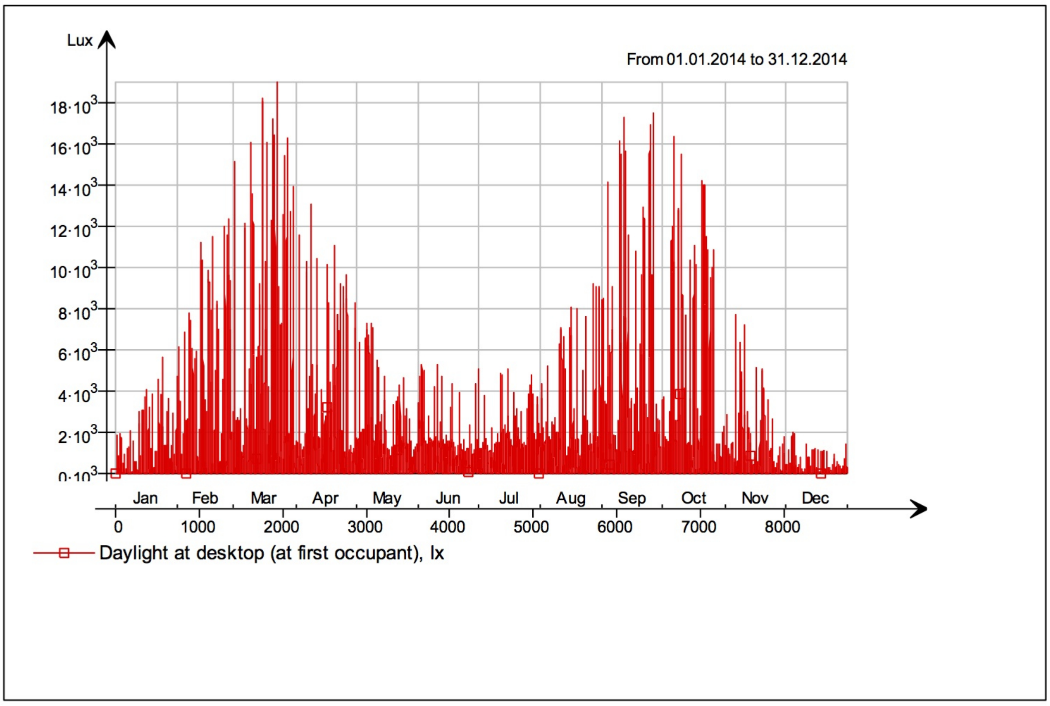


Figure 10.52: Zone 198: Daylighting

As this zone faces south east and is somewhat shaded by the B wing, the variation through the year is as expected. Considering that the lighting requirement for tasks of high accuracy is 2000 Lux (Novakovic, et al., 2007), the levels in the zone are at times quite high and shading may be required by the occupants.

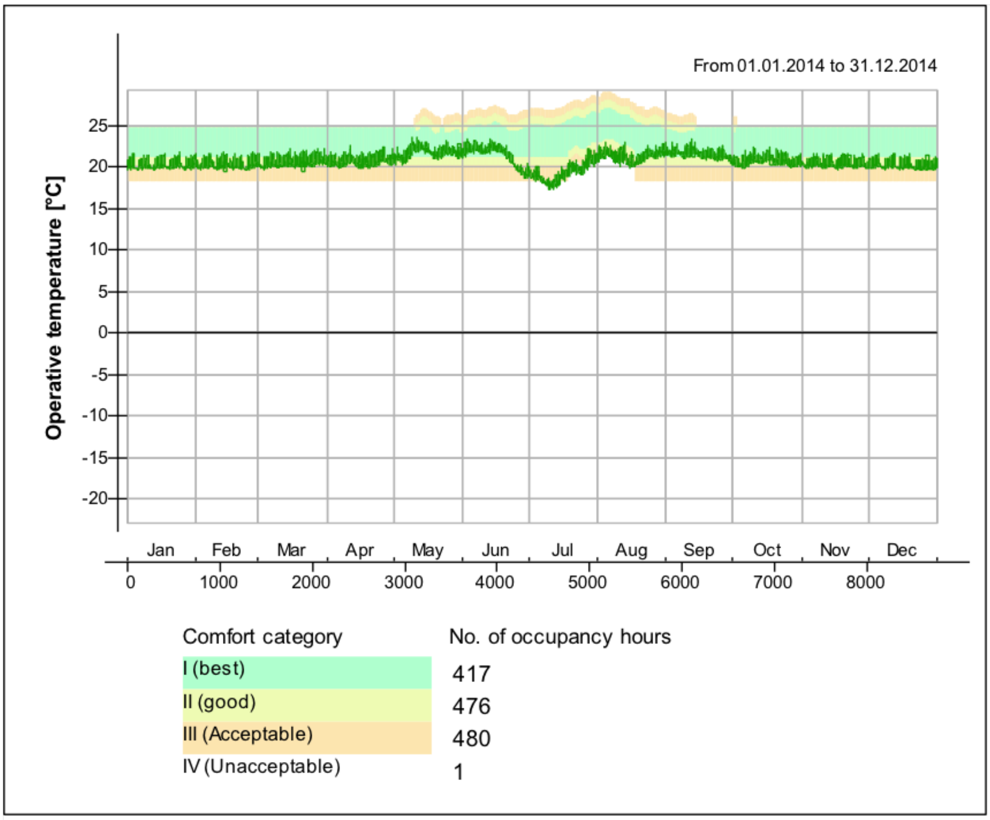
Summary

The temperature in the zone is high throughout the year. From May through August the temperature reaches 25-30°C, except for a drop to 19-24°C when the building is unoccupied. In the winter months, the temperature is still quite high, at 21-25°C, being mostly in the higher end of the interval. Apart form a low RH level from mid October to mid June, the CO_2 level and air age in the zone indicate a good indoor air quality. From May to mid September the PPD level is very high, while the PMV level is approximately 0. The rest of the year, both indices satisfy the category B criteria (Standard Norge, 2006). The daylighting level in the zone is quite high, indicating a strong need for shading in the zone.

Zone 10 - Band room

During the occupancy hours, the ventilation air flow is at its maximum of almost 260 L/s, which is much lower than the set point maximum of 417 L/s. When the room is unoccupied, but the building is in use, the ventilation air flow is reduced to either the set point minimum of approximately 72 L/s or to approximately 193 L/s. When the air flow rate is closer to maximum it is at the 193 L/s level, and then it is further reduced to the set point minimum. The inflow and outflow through the internal and external walls is very low in this zone, at less than 5 L/s.

In the graph below, thermal comfort in the zone is shown:



Comfort category	No. of occupancy hours
I (best)	417
II (good)	476
III (Acceptable)	480
IV (Unacceptable)	1

Figure 10.53: Zone 10: Thermal Comfort

The graph shows that the temperature in the zone is at approximately 22°C during the colder months of the year, and increases to 23-24°C in May-June. While the zone is unoccupied in the summer, the temperature drops to 17-19°C.

The air age, the CO_2 level and the relative humidity is shown in the graph below:

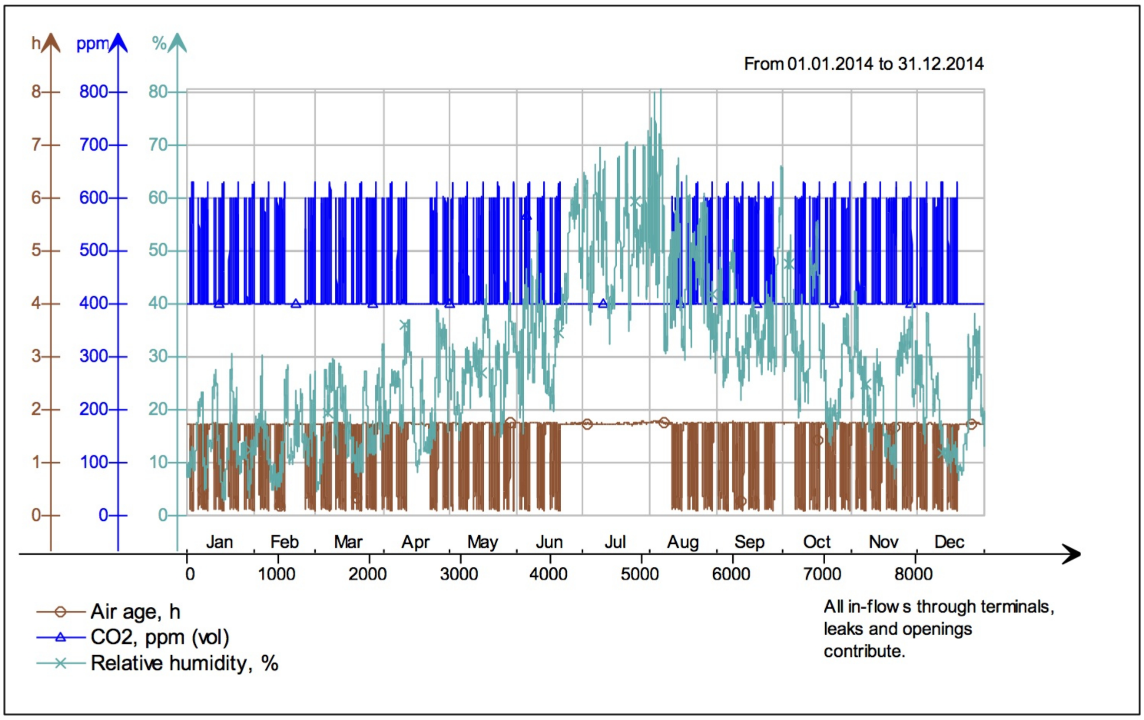


Figure 10.54: Zone 10: Indoor Air Quality

Although the CO_2 level in the zone is kept at 600/630 ppm, the relative humidity passes 80% in July/August, but at this time the building is not occupied. From mid October to June it drops below 20%, which may be uncomfortable for the occupants (Novakovic, et al., 2007). The air age is at an acceptable 0.2.

To evaluate the comfort in the building, Fanger's comfort indices are shown over the course of the year in the graph below:

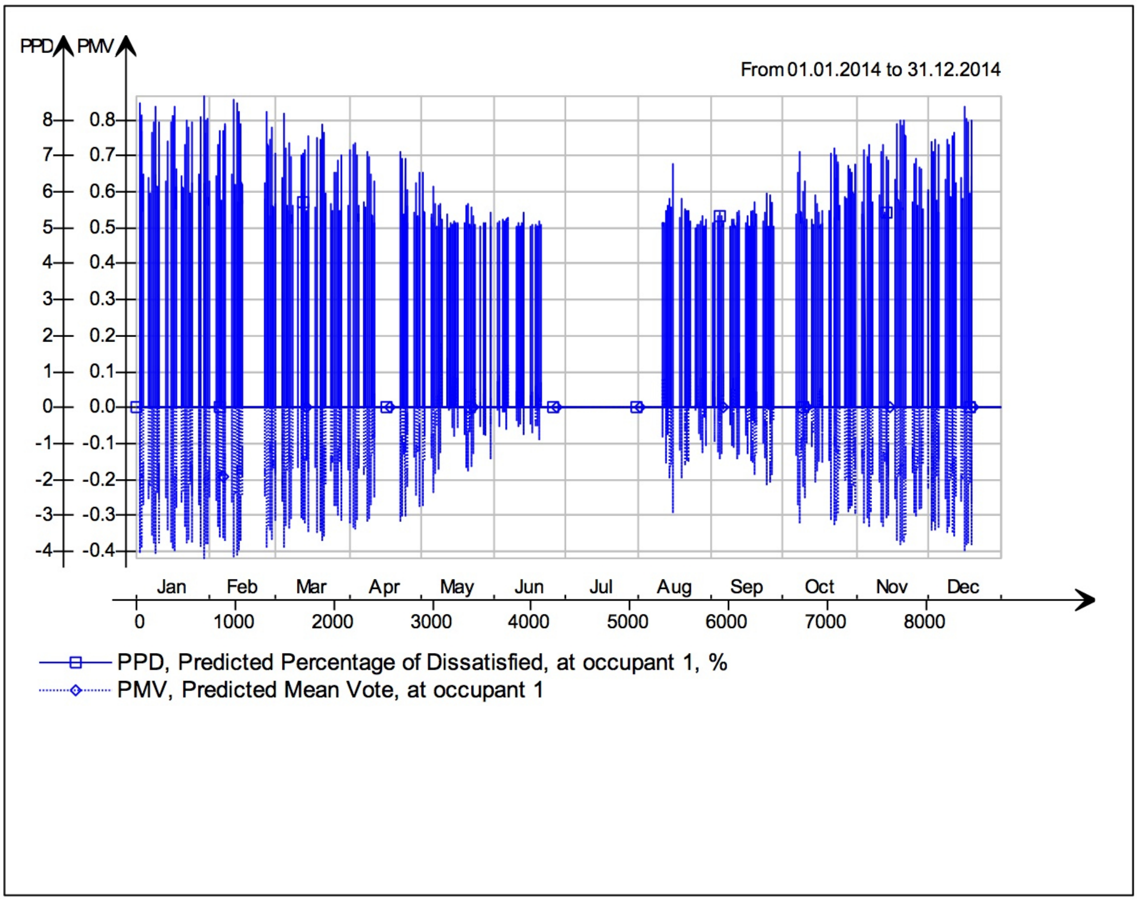


Figure 10.55: Zone 10: Fanger's Comfort Indices

As the PPD and PMV levels never pass 9% and -0.5 respectively, they indicate that more than 90% and 95%, respectively are satisfied with the indoor environment.

The daylight level in the zone is shown in the following graph:

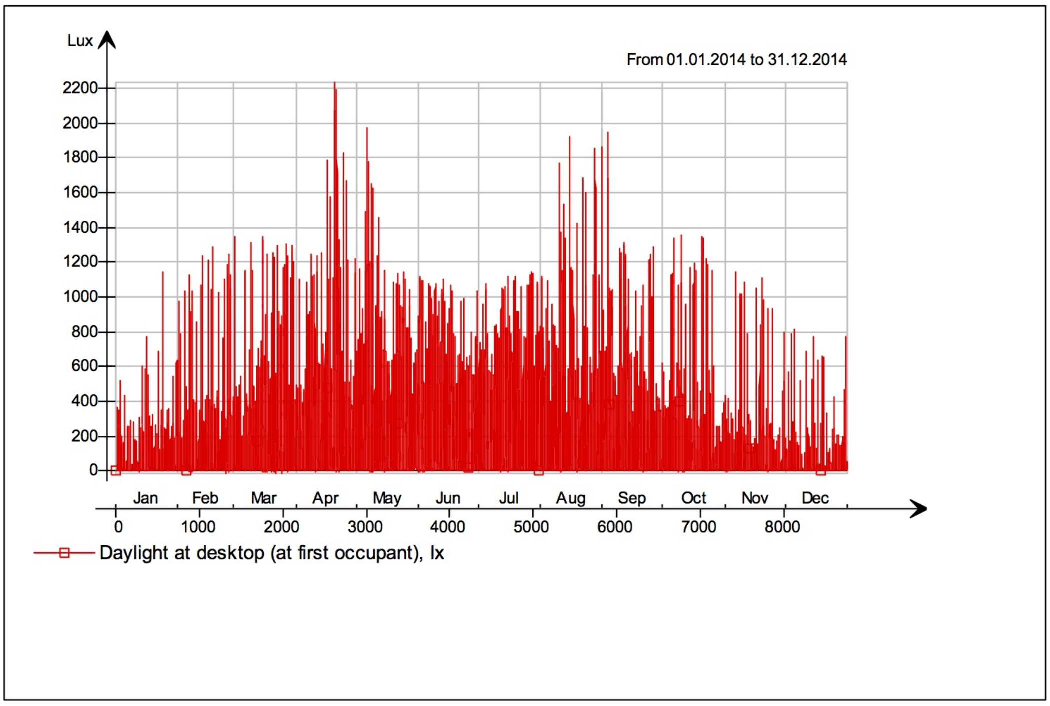


Figure 10.56: Zone 10: Daylighting

As this zone faces northeast, the variation through the year is as expected. Considering that the lighting requirement for tasks of high accuracy is 2000 Lux (Novakovic, et al., 2007), the levels in the zone are appropriate most of the year, and at times even a little low.

Summary

The temperature is at approximately 22°C during the colder months of the year and increases to 23-24°C in May-June. During the summer holidays the temperature drops to 17-19°C. The indoor air quality in the zone appears to be good according to the CO_2 level and air age, although the RH does get a little low from mid October through June. During the occupied months of the year the PPD and PMV levels satisfy the category B requirements (Standard Norge, 2006). The daylighting levels in this zone may at times be a little low, indicating that the need for electric lighting might be higher than in the other parts of the building.

10.2.2 Comparison of Actual results with the user survey and different effects

In the following the effects of different installations and settings will be analyzed.

Actual vs. User survey

In the user survey showed that may still found the temperature in the building overall to be a little too low. The results from the zone analysis here indicate that the temperature is, apart from some extreme cases (zone 126, 175 and 198), quite normal and complying with the NS-EN ISO 7730:2005 category A level (Standard Norge, 2006). This indicates that the temperature in the building is at a level considered to be quite comfortable, in spite of the comments from the users. However, as some of the users claimed that the temperature varies significantly from room to room, the effects of controlling the temperature in the zones according to occupancy may be the cause for the temperature problems. When there are no people present, there will be highly reduced internal gains from the occupants, reducing the temperature to 19°C. When the occupants then come from a warmer room, the temperature may feel quite low and it may take time for it to increase and reach a similar level as in the room they just left. Furthermore, as pointed out by one of the survey participants, the temperature feels fine in the classrooms during the classes when the teacher is moving around, while when the teacher sits down and is still, the temperature in the common room feels quite cold, indicating that the 21-22°C is appropriate for a person standing and lightly moving around, but it may be a little too low for a person sitting still. Due to time restrictions, the temperature variations in each zone throughout the day was not studied in this thesis, but could be of interest for later study.

In zone 126 the temperature proved to be quite high due to the added load from the computers. Although the indoor air quality appeared to be sufficiently good, the PPD levels in the warmer months of the year indicated that the indoor climate is not satisfactory in this zone. This complies with the results from the user survey, with complaints concerning the computer room in zone 126.

Zones 175 and 198 are both teacher work rooms, which were pointed out by three of the women to have a poorer indoor climate than the rest of the building. They were also commented on as being very hot when the sun was shining directly into the rooms, as they are angled towards the south and southwest, respectively. This claim is supported by the findings in the IDA ICE simulation, with both the temperature, PPD and PMV levels, as well as the daylighting levels having undesirable values. With the shading demand also shown from the simulation results, the high temperatures in the zones appear to be caused by the high amount of solar gains into the room. The indoor climate here may therefore be very much improved by introducing shading on the south and southwest facing facades.

For all the zones introduced to this building, the RH level in the building is quite low from mid October to June/mid June. According to Novakovic, et al. (2007) this is very common for buildings in the Norwegian climate without humidification installed. Furthermore, low RH levels increase the rate of evaporation of sweat from the skin, which can make people feel cold even at moderate temperatures (Novakovic, et al., 2007). The low RH in the building may therefore be the reason for the occupants to complain about the temperature, even though it is at a reasonable level.

Actual - External Shading

As for the Normative scenario, the effect of installing external shading in the building was studied. Due to time limitations, only external overhangs over the windows were used. With the roof continuing past the external facade on the west facing wall of the north wing, the use of external shading of this kind was considered redundant.

The percentage of hours when the operative temperature was above 27°C in the worst zone was reduced from 61% to 57%, but the percentage of hours in the average zone and the percentage of total occupant hours with thermal dissatisfaction were only reduced by 1%. The number of hours of lost work due to under or over heating was reduced by 314 hours.

With external shading introduced to the building, the total energy delivered to the building increased by 2 kWh/m^2 due to heating. As the shading will reduce the solar gains in the building, this is to be expected.

Zones

For indoor air quality, there were only a change in the relative humidity, with both the air age and CO_2 level being the same as for the original simulation. The RH was a little higher for zones 134, 126, 10 and 175. For zone 111 there was no change in RH, while zone 198 had a higher RH. For all zones, the air flow rate was the same as for the original simulation, but the changes in Fanger's comfort indices were not the same for all zones. For zone 111 they were the same as before, but for zones 134 and 175 the PPD was lower in the summer months, with peaks highly reduced. Zones 126 and 198 had a significant reduction in their PPD levels, although in zone 198 the level was still quite high. Zone 10 was the only one of the seven that had an increased PPD level. Regarding the PMV levels, almost all zones had worse levels than before, although none as low as -5. Only zone 111 had no change in PMV levels. As can be expected when introducing shading in a building, the daylight levels were decreased in almost every zone.

Actual - No internal gains

In order to establish the effects of not having any internal gains in the building, a simulation was done to compare to the original scenario.

The percentage of hours when the operative temperature is above 27°C in the worst zone was reduced by so much as 51%. The percentage for the average zone was reduced from 3% to 1%, while as there were no occupants present, the percentage of total occupant hours with thermal dissatisfaction was reduced to 0. With no occupants there were no working hours and hence no working hours lost due to under or over heating.

Another effect of having no internal gains is that the energy demand for the building was reduced by 8.2 kWh/m^2. As the need for lighting and equipment will become 0 when there are no occupants present, this is not unexpected. The energy for fans was also reduced a little, but with the high amount of CAV in the building, the reduction was not expected to be too big. The total energy reduction from these factors was 17.5 kWh/m^2. However, with no internal heat gains the heating demand in the building increased by 9.4 kWh/m^2, yielding the 8.2 kWh/m^2 total energy demand reduction.

Zones

For all zones, the following changes applied:

- The CO_2 level was constant at 400 ppm as there were no people present (this is the same as the natural level)
- The air age was a little higher throughout the year
- The relative humidity was a little higher
- The ventilation air flow was lower, while the air flow through walls were the same
- The daylighting levels were the same

This only leaves the changes in Fanger's comfort indices. For zones 134, 111 and 10 the PPD levels were a little worse, while for zones 126, 198 and 175 the peaks in the summer months were much lower and the rest of the year the levels were approximately the same. The PMV levels were a little worse in the summer in all zones.

Actual - 100% Occupants

For the building comfort references, there was only an increase in the percentage of hours when the operative temperature was above 27°C in the worst zone from 61% to 67%. The percentage for the average zone and for total occupant hours with thermal dissatisfaction were both the same as before. The number of working hours lost due to over or under heating was only slightly increased.

As increasing the occupancy will increase the need for ventilation air flow, the energy use for fans was expectedly increased by 0.9 kWh/m^2. However, as the heating delivered to the building was reduced by 1.4 kWh/m^2, the total energy delivered was reduced by 0.5 kWh/m^2.

Zones

For most of the zones, the effects of having an occupancy level of 100%. The following changes were the same for all zones:

- The CO_2 level increased, with 40 to 150 ppm
- The air age and relative humidity was the same as before
- The PPD level increased from May to September/October
- The PMV level was the same as before
- The daylighting level was the same as before

The only change that varied between the zones was the change in ventilation air flow. For some of the zones, zones 134 and 111, the air flow was the same as before, at its maximum level. For the other zones however, the ventilation air flow rates increased to the set point maximum level.

Conclusions of effects

When introducing external shading into the building, the simulation results showed that the percentage of hours when the operative temperature was above 27°C was reduced, in addition to a slight reduction in work lost. The most important effect, however, was that the critical zones 126, 175 and 198 all had reduced PPD levels and lower daylighting levels. The comfort in the exposed parts of the building can therefore be said to increase when shading is introduced.

When there were no internal gains in the building, the air age naturally increased as the VAV would be at its minimum levels at all times. Furthermore, the total energy demand for the building decreased, although the heating demand significantly increased. This indicates that the internal gains are important for the heating demand to be kept low when there are people present.

Lastly, the effect of having 100% occupancy in the building resulted in the percentage of hours when the operative temperature was above 27°C to increase. The PPD level increased and the air quality was worsened, indicating that the increased occupancy has an adverse effect on the indoor environment of the building. The only positive effect of having 100% occupancy was that the energy demand for heating, was reduced. As the VAV would, at 100%, require more energy, this energy post was reduced, although in total there was an energy reduction.

Chapter 11

Discussion of Simulation Results

In this chapter the results from the different simulations and scenarios are discussed and used to explain the second and third task of the objectives.

11.1 Is the HVAC strategy in Stasjonsfjellet Skole able to obtain a satisfactory indoor climate?

In order to answer this task, the results from the normative and from the actual simulations, are discussed.

11.1.1 Normative scenario

The following will present and discuss the results from the normative simulation scenario.

Normative results

The normative scenario was meant to be compatible with what was intended for the building from the engineers' perspective and calculations. Therefore it was to be comparable to the SIMIEN model and results that were made by the engineers. Apart from the efficiency of the heat pump, most of the energy results from the Normative scenario were approximately the same as for the SIMIEN simulation. The energy yield from the heat pump appeared to have been estimated to be much higher in the SIMIEN calculations compared to the results from the IDA ICE model. Nevertheless, the two models were similar, and the results from the normative scenario can therefore be assumed to be relatively comparable to what was intended from a standards and regulations point of view. The cooling demand that was found in the normative simulations with cooling resulted in a mere 2.6 kWh/m^2 energy demand for cooling, while the SIMIEN result was 4.3 kWh/m^2.

The results from the normative simulation showed that the average zone only had 1% of hours when the operative temperature was above 27°C. However, as many as 6% of the occupancy hours were of thermal discomfort, indicating that the comfort in the building is not ideal. The number of working hours lost due to over or under heating was also quite high, although the percentage was quite low. In May and June the number of working hours lost was highest at over 800 hrs. As these, in addition to August, are the warmest months of occupancy, it can be assumed that the working hours lost are due to the temperature in the building being quite high.

In addition to general results on the comfort in the building, the simulation results presented show the comfort in some selected zones. To represent the zones on the southwest side of the A wing, classroom number 111 was presented. For the north side of the A wing, classroom 134 was chosen. As the teachers had pointed room 126 out as a particularly uncomfortable room, this was also taken into account. The same thing was the reason behind choosing zone 175 and 198, as they were both south (and south west for zone 198) facing rooms. Lastly, zone 10 was evaluated to study the indoor environment in the basement. Although many of the values from the zones vary amongst them, the indoor air quality appears to be sufficient in all zones. The RH level is low in all zones during the colder months of the year, but with the Norwegian climate this is to be expected (Novakovic, et al., 2007). The PPD and PMV levels are mostly compliant with the category B values (Standard Norge, 2006), although from May to mid October the PPD level in zones 175 and 198 are very high and not within any comfort category (Standard Norge, 2006). In total the indoor climate seems to be somewhat satisfying in most of the zones for most of the year, except for zones 175 and 198 where the PPD levels indicate that the indoor climate is not by far good enough. The daylighting level is a little high except in zone 10 where it is at times a little too low. In zones 175 and 198 in particular, the daylighting is so high shading would be highly recommended.

The ventilation in the zones appears to work as it should, but the thermal comfort indicates that not installing cooling in the air handling units may have been a mistake, especially since the increased energy demand was so low.

These results show that although the requirements are, at least mostly, met for the building as a whole, the comfort level locally in some of the zones is not ideal. Although some zones are not too bad, others are quite uncomfortable, indicating that the generalization of the building has resulted in variable comfort levels throughout the building.

Effects of installations

For the normative scenario, six different effects were studied. They all had different impacts on the building's performance and indoor environment.

Firstly, both internal and external shading was considered. The external shading results showed that the daylighting was reduced and particularly in zones 175 and 198 (the teacher work rooms) the PPD levels were lower. For these rooms in particular, and it can be assumed for the other zones along the south facade, the installation of shading would be highly beneficial. The internal shading, involving curtains, did not provide any significant improvements to the building, although the heating demand was somewhat reduced. Although the effects of external shading here did have a positive effect, the effects could have been even higher if the shading type introduced had been external screens or similar solutions. The screens would be easier to control and could have a higher effect as they can be drawn down to cover more of the window, depending on the position of the sun in the sky. They could also have an increased effect on zones where windows are not directly facing the sun.

In addition to studying shading, the effects of the internal gains in the building were looked into. Firstly, all internal gains were removed, predictably resulting in a significantly higher heating demand. Then a reduced occupancy of only 60% was studied, and found to have several effects on the indoor environment of the building. With less people in the building, the required ventilation air flow would be reduced, resulting in less ventilation heating. However, as less air was provided to heat the building, the need for local heating from the radiators increased. Another effect of reduced occupancy was that the PPD was lowered. This may indicate that the systems in the building may be under-dimensioned and better suited for less occupants than are present.

With the internal gains and the occupancy having effects on the heating demand, the position of the occupant in the room was also significant. When the occupants were moved from the center of the zones to a position much closer to the facade, there was a 2% increase in the percentage of hours when the operative temperature was above 27°C in the worst zone. The thermal dissatisfaction was up 1% and the daylighting was significantly worse. These results indicate that the position of the occupant is highly important. As the differences in the comfort conditions will vary through the room, it would be recommended to use measures such as external shading to even out the conditions through the room.

Lastly, the effects of installing cooling coils in the air handling units were studied. In contrast to the 2% increase when moving the occupants to the facade, the cooling in the air handling units reduced the percentage of hours when the temperature was above 27°C in the worst zone by 3%. The amount of work lost was reduced by 272 hrs and especially zones 198 and 175 had a lower PPD. The results showed that although not sufficient, the small measure of introducing a cooling coil to the air handling unit had a highly positive effect on the indoor environment.

From these results it can be concluded that introducing external shading and cooling to the building would be highly beneficial for the indoor environment. Also, the internal gains and portion of occupants present in the building would affect the energy use and the comfort in the building. The position of the occupants in the rooms along the facade also affect how the indoor environment is perceived, being worse closer to the windows and exposure to sunlight.

11.1.2 Actual scenario

This simulation was done in order to evaluate the indoor environment in the building as realistically as possible.

Actual results

For this scenario, the percentage of hours when the operative temperature was above 27°C was as high as 63% in the worst zone and 3% in the average zone. Furthermore, the percentage of total occupant hours of thermal discomfort was as high as 11%. These results indicate a significant difference between the normative scenario and the realistic actual scenario.

From the zone analysis, several conclusions can be drawn. Firstly, all zones have a decent indoor air quality, in spite of a slightly low relative humidity in the colder months of the year. In zones 126, 175 and 198 the temperature gets quite high throughout the year, with only zone 126 satisfying the category B requirements, and the other two satisfying category C (Standard Norge, 2006). The other zones have a temperature of 21-22°C in these months, which complies with category A (Standard Norge, 2006). In the occupied parts of the summer, the temperature in zones 126 complies with category C and zones 175 and 198 have even higher temperatures (Standard Norge, 2006). The other zones satisfy category B in the summer (Standard Norge, 2006). These zones also satisfy category B for Fanger's comfort indices throughout the year, while zones 126, 175 and 198 have very high PPD levels in the same months as their temperature is too high, but satisfy category B the rest of the year (Standard Norge, 2006). Except for in zone 10 in the basement, all zones show a varying need for shading. For zones 175 and 198 this need is very high, and is probably also the cause for the high temperatures here.

In this scenario, the effects of not having installed external shading or cooling in the building become even more prominent. It is clear that the thermal comfort in the building is not ideal in all zones. Especially along the south facing facades, the daylighting and solar heat gain becomes a problem for the comfort in the building, a problem the ventilation system does not take care of.

Effects of installations

Also here the effects of external shading, no internal gains and changed occupancy were studied.

The effects of external shading were the most prominent. The percentage of hours when the temperature was above 27°C was reduced to 57% in the worst zone, and 2% in the average zone. The percentage of occupancy hours of thermal discomfort was reduced to 10%. The working hours lost due to under or over heating were reduced by 314 hrs, and all zones had a reduced PPD level. The highest reduction in PPD was seen in zones 126 and 198, which incidentally were two of the worst zones in the initial simulations. The daylighting level was also overall reduced, which would be expected when shading a building.

In addition to studying the effects of external shading, the internal gains in the building were removed. With no occupants, the percentage of hours when the temperature was above 27°C was reduced for both the worst case and for the average zone, and there was no occupancy hours of thermal discomfort. Furthermore, the energy delivered to the building was reduced by 8.2 kWh/m^2.

Lastly, increasing the load of occupants to 100% was studied. This resulted in an increase of the percentage of hours when the worst zone had a temperature above 27°C to 67%. The ventilation air flow increased, but the energy delivered to the building was reduced as the heating demand was reduced. Furthermore, the PPD levels increased from May to September/October.

The effects of external shading shown in the normative scenario were even more prominent in the actual scenario, making it clear that installing external shading in the building could be very beneficial for the indoor environment. Furthermore, the internal gains and level of occupants also support the conclusions from the normative scenario.

Does the focus on reduced energy have an adverse effect on the indoor environment?

In order to evaluate this question, the user survey and the conclusions and results from the actual scenario are discussed.

The retrofitting of the building clearly had a highly positive effect on the indoor climate according to the user survey. Although there are many different opinions regarding the indoor environment in the building, it is clear that many find the temperature to be a little too low. The reasons for this may be that the set point is set too low or that the systems react too slowly and that the response time in, for example, the morning is not ideal. As the rooms are not in use at all times, the temperatures will naturally vary when one room has a high amount of internal gains and one has little. Additionally, the low RH levels in the building may cause the occupants to, from mid October to June, feel cold even though the temperature in the building is moderate and at its design level (Novakovic, et al., 2007). The temperature should therefore be set higher.

Even though the temperature in the building overall is considered as being too low, the temperature in the work room for teachers proved to be quite high, especially in the warmer months, indicating a cooling need in the building. As the building has only been in use since August, it is likely that this was not pointed out by the occupants due to their lack of experience with the warmer times of the year.

As the building does comply with the standards and regulations it is required to, the results from the simulations indicate that these demands are generalized to a point where the resulting building has high differences in comfort levels from room to room. Although some differences are to be expected, the comfort of the occupants will be reduced by it, which was also pointed out by one of the participants of the survey.

Chapter 12

Conclusions and suggestions for future work

In order to review the challenges for HVAC systems in buildings renovated to low-energy standards, as well as the development trend in the market, some literature was studied and a case study of three office buildings was performed. To answer the second and third task of analyzing and determining whether the HVAC solutions in the case building, Stasjonsfjellet Skole, were capable of providing a satisfactory indoor climate, and whether the focus on reducing the energy demand in the building had an adverse effect on the indoor environment, a user survey and several IDA ICE simulations were performed. Lastly, the question of whether the conclusions from these case studies can be extended to other buildings is here answered based on the results and conclusions from all four case studies.

In the following, the conclusions that are drawn from the study are presented and summarized, before suggestions for future work are presented.

12.1 Conclusions

As there were four tasks to be studied and answered, their respective conclusions are summarized here.

12.1.1 Review of the challenges for HVAC systems in buildings renovated to low-energy standards as well as of the HVAC development tend in the market

From the case studies, the trend in solutions chosen were seen as they all had heat pumps, heat exchangers in the AHUs, occupancy control, BMS and energy follow up system installed. Essentially, the solutions were tailored to the buildings and their characteristics, which was also highlighted as important in the literature.

As there was a high level of owner involvement in all three case studies, it is likely that the buildings would not have achieved everything they had without the owners setting high demands for the solutions that were chosen. This may not be a given for all construction projects, and may cause difficulties in implementing optimal, but costly, solutions, as the willingness of the client may not be there.

As was pointed out by Ma, et al. (2012) regulations and policies may provide subsidies, but they also set minimum demands for energy efficiency. Although, for the facades in both Grensesvingen 7 and for Fredrik Selmers vei 4, the standards and regulations had adverse effects and may have worked against their intention. These cases show that it can be challenging to choose and to implement optimal solutions when the standards and regulations do not allow it.

Both the meeting with Oslo Areal and the literature and emphasized that in order for the systems in these types of buildings to work optimally, everything needs to be designed and constructed perfectly, as well as the systems have to work together as a whole.

In the literature and the case studies it was emphasized that a focus and importance of high levels of occupant control was important for comfort (Barlow and Fiala, 2007). However, this may be challenging to implement.

12.1.2 Based on a case study, the HVAC strategy implemented in the renovation will be analyzed and its ability to obtain a satisfactory indoor climate (especially as regards ventilation)

Firstly, the literature showed that the effects and abilities of ventilation strategies depend on their purpose (Cao, et al., 2014). For Stasjonsfjellet Skole, the HVAC system in the building did appear to, in some places, be able to provide a sufficiently comfortable indoor environment in the building. However, for a lot of the users the temperatures was not always satisfactory. The need for cooling, and external shading, was prominent especially in particularly exposed zones where the solar gains are high. This need may not be as high as the results in this study indicates due to trees that may provide some shading, but it can be assumed that without considerable vegetation or other shading objects close to the building, the need for shading and cooling will be prominent. In addition to a cooling need, the user survey indicated that the temperature in many parts of the building is too low, meaning that either the set point temperature is not optimal, or the variable heat gain from the occupants may make the temperature too low when they are entering a colder room. This is concluded further for the next question. Although the building complies with the standards it is supposed to, the standards' demands appear to be too general, making the comfort levels of the users vary significantly from room to room. In some of the rooms in the building, the comfort levels are acceptable, even though they are not perfect. This is, however, not the case everywhere, which may cause disturbances for the users. Furthermore, with average values for a building as a whole, the generalized values can result in a low or non existing cooling demand due to unrealistic values.

12.1.3 Based on the case study, evaluate whether the focus on reducing the energy use in a building could potentially have an adverse effect on the indoor climate, with a focus on the psychological aspect through a survey (how the occupants experience the building/comfort).

As the laws and regulations are followed for the building, it was found that these generalize demands of a building, making the indoor environment and comfort level in the different rooms vary significantly. As there is concluded to be a cooling need in, at least parts of the building, the focus on saving energy on this clearly has an adverse effect on the occupants even though the energy demand of the cooling batteries is low. Also, the temperature in parts of the building appears to be too low for the occupants. As most rooms have occupancy control which lowers the temperature when there are no people present, latency in the system may cause the temperature to be too low for most of the short while the occupants are present. The relative humidity was also quite low from mid October to June, which may cause the occupants to feel cold even at moderate temperatures (Novakovic, et al., 2007). Therefore, for these months, the thermal comfort of the occupants may require even higher temperatures than those that are normally sufficient. This focus on reducing energy use by demand controlling the HVAC systems and keeping the temperature at 21°C may therefore also have an adverse effect on the occupants.

12.1.4 Can the conclusions and results from these case studies be extended to other buildings?

From the office building case studies, the importance of owner involvement, willingness and demands will be important and challenging for all buildings. Furthermore, retrofitting standards and regulations will also set limits and may make it challenging for any retrofitting project to reach its goals. The conclusion concerning the importance and difficulty of every aspect of the building working together will also be applicable to other buildings and not only retrofitted building projects. The same goes for the importance of high occupancy control

Regardless of the building type, climate or orientation, there will be differences in the requirements for the different rooms in a building, making the conclusion that only using standard values for a whole building will result in variable indoor environments from room to room, a valid conclusion for any building, retrofitted or new.

Every building is different, and so the results presented from all four case studies will be somewhat restricted in their application to other buildings. However, for similar school buildings where there is no cooling installed and little or no external shading, the conclusions will most likely be the same. Generally, both retrofitted and new buildings can be expected to have a cooling demand and shading demand in zones facing the sun. Although the local climate and orientation etc. will have high effects on the building's indoor environment, it is natural to assume that buildings in similar climates will experience differences in the comfort levels in the different rooms.

12.2 Future Work

Although several conclusions have been made in this report, there are still questions left to be answered. As all buildings studied in this report had only been in use for a number of months, investigations should be done into whether the conclusions made here can be applied when the occupants have more experience with the buildings. Also, as several approximations were made to the IDA ICE model, actual measurements in the school building could reveal different results than those obtained here. Thirdly, the temperature variations through the day and week were not studied here due to time restrictions. This will therefore be highly recommended for future work. Lastly, the cooling demand for the actual scenario would also be of interest for future study to compare to the normative cooling demand and to see the effects of cooling in the south facing zones.

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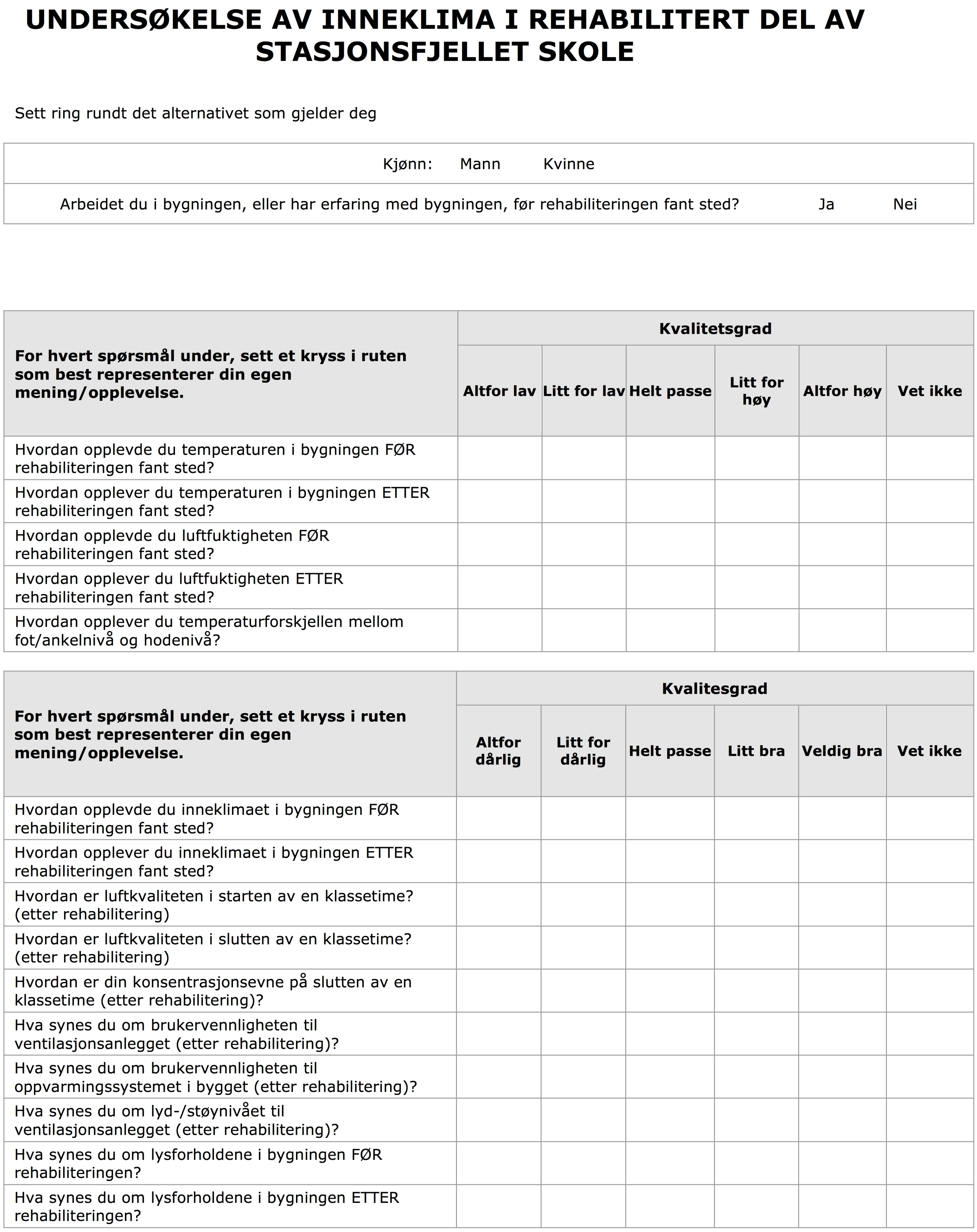
Appendix A - User Survey



UNDERSØKELSE AV INNEKLIMA I REHABILITERT DEL AV STASJONSFJELLET SKOLE

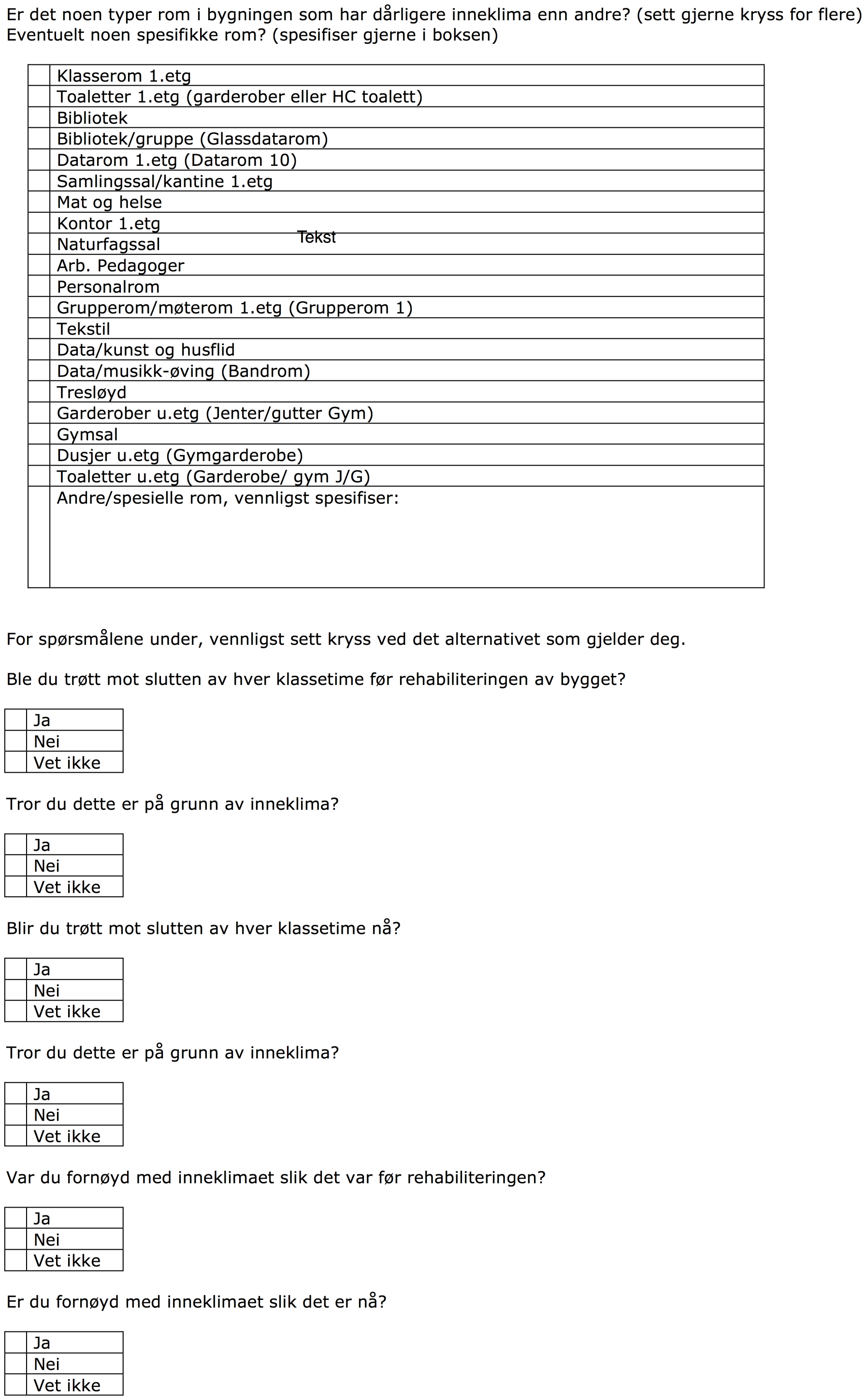
Sett ring rundt det alternativet som gjelder deg

Kjønn: Mann Kvinne		
Arbeidet du i bygningen, eller har erfaring med bygningen, før rehabiliteringen fant sted?	Ja	Nei

For hvert spørsmål under, sett et kryss i ruten som best representerer din egen mening/opplevelse.	**Kvalitetsgrad**					
	Altfor lav	**Litt for lav**	**Helt passe**	**Litt for høy**	**Altfor høy**	**Vet ikke**
Hvordan opplevde du temperaturen i bygningen FØR rehabiliteringen fant sted?						
Hvordan opplever du temperaturen i bygningen ETTER rehabiliteringen fant sted?						
Hvordan opplevde du luftfuktigheten FØR rehabiliteringen fant sted?						
Hvordan opplever du luftfuktigheten ETTER rehabiliteringen fant sted?						
Hvordan opplever du temperaturforskjellen mellom fot/ankelnivå og hodenivå?						

For hvert spørsmål under, sett et kryss i ruten som best representerer din egen mening/opplevelse.	**Kvalitesgrad**					
	Altfor dårlig	**Litt for dårlig**	**Helt passe**	**Litt bra**	**Veldig bra**	**Vet ikke**
Hvordan opplevde du inneklimaet i bygningen FØR rehabiliteringen fant sted?						
Hvordan opplever du inneklimaet i bygningen ETTER rehabiliteringen fant sted?						
Hvordan er luftkvaliteten i starten av en klassetime? (etter rehabilitering)						
Hvordan er luftkvaliteten i slutten av en klassetime? (etter rehabilitering)						
Hvordan er din konsentrasjonsevne på slutten av en klassetime (etter rehabilitering)?						
Hva synes du om brukervennligheten til ventilasjonsanlegget (etter rehabilitering)?						
Hva synes du om brukervennligheten til oppvarmingssystemet i bygget (etter rehabilitering)?						
Hva synes du om lyd-/støynivået til ventilasjonsanlegget (etter rehabilitering)?						
Hva synes du om lysforholdene i bygningen FØR rehabiliteringen?						
Hva synes du om lysforholdene i bygningen ETTER rehabiliteringen?						

Figure A1: Survey, page one



Er det noen typer rom i bygningen som har dårligere inneklima enn andre? (sett gjerne kryss for flere)
Eventuelt noen spesifikke rom? (spesifiser gjerne i boksen)

☐	Klasserom 1.etg
☐	Toaletter 1.etg (garderober eller HC toalett)
☐	Bibliotek
☐	Bibliotek/gruppe (Glassdatarom)
☐	Datarom 1.etg (Datarom 10)
☐	Samlingssal/kantine 1.etg
☐	Mat og helse
☐	Kontor 1.etg
☐	Naturfagssal Tekst
☐	Arb. Pedagoger
☐	Personalrom
☐	Grupperom/møterom 1.etg (Grupperom 1)
☐	Tekstil
☐	Data/kunst og husflid
☐	Data/musikk-øving (Bandrom)
☐	Tresløyd
☐	Garderober u.etg (Jenter/gutter Gym)
☐	Gymsal
☐	Dusjer u.etg (Gymgarderobe)
☐	Toaletter u.etg (Garderobe/ gym J/G)
☐	Andre/spesielle rom, vennligst spesifiser:

For spørsmålene under, vennligst sett kryss ved det alternativet som gjelder deg.

Ble du trøtt mot slutten av hver klassetime før rehabiliteringen av bygget?

☐	Ja
☐	Nei
☐	Vet ikke

Tror du dette er på grunn av inneklima?

☐	Ja
☐	Nei
☐	Vet ikke

Blir du trøtt mot slutten av hver klassetime nå?

☐	Ja
☐	Nei
☐	Vet ikke

Tror du dette er på grunn av inneklima?

☐	Ja
☐	Nei
☐	Vet ikke

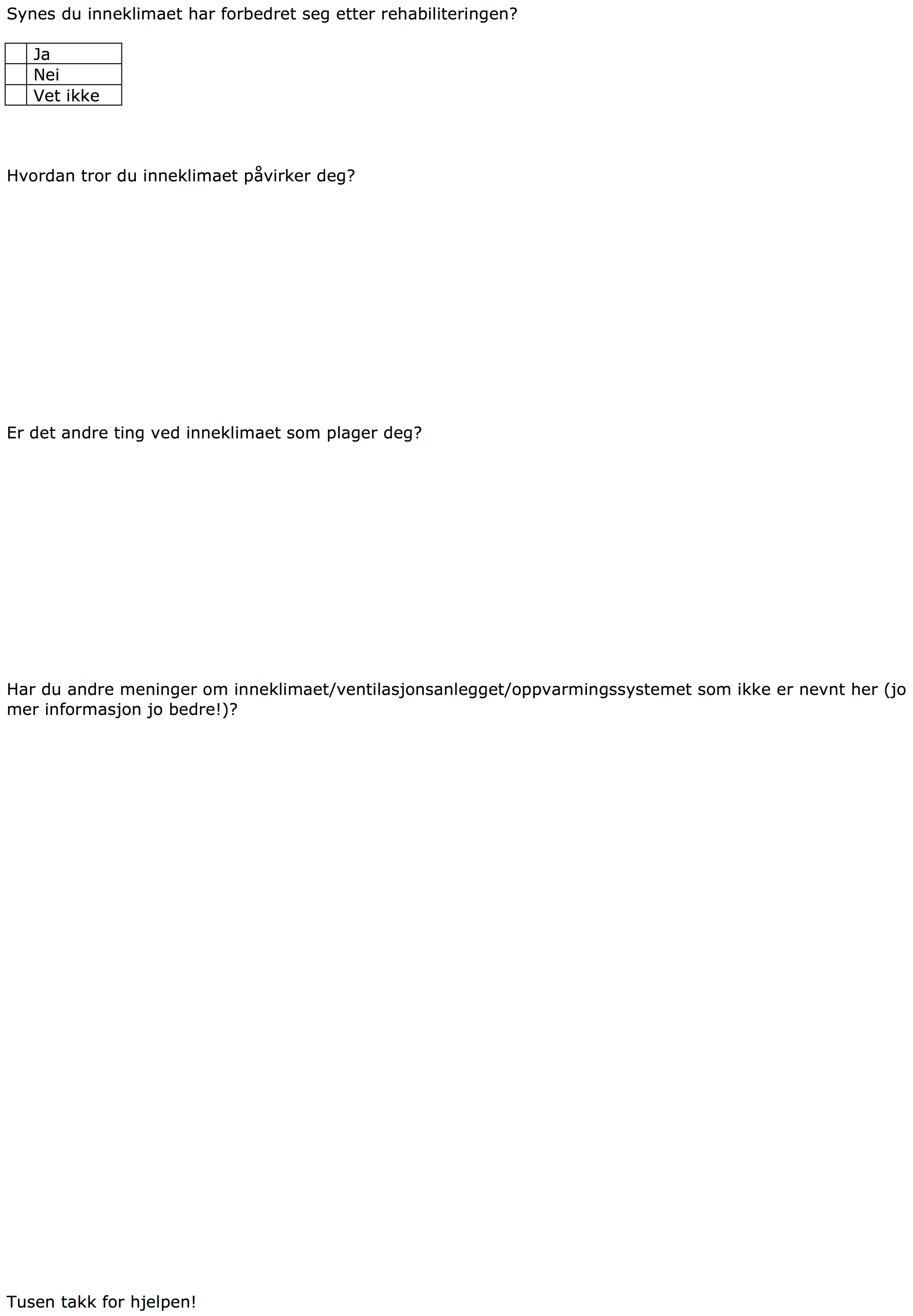
Var du fornøyd med inneklimaet slik det var før rehabiliteringen?

☐	Ja
☐	Nei
☐	Vet ikke

Er du fornøyd med inneklimaet slik det er nå?

☐	Ja
☐	Nei
☐	Vet ikke

Figure A2: Survey, page two



Synes du inneklimaet har forbedret seg etter rehabiliteringen?

	Ja
	Nei
	Vet ikke

Hvordan tror du inneklimaet påvirker deg?

Er det andre ting ved inneklimaet som plager deg?

Har du andre meninger om inneklimaet/ventilasjonsanlegget/oppvarmingssystemet som ikke er nevnt her (jo mer informasjon jo bedre!)?

Tusen takk for hjelpen!

Figure A3: Survey, page three

Appendix B - User survey answers

Table B1: Answers from user survey, women

Question	Too low	A little too low	Appropriate	A little too high	Too high	Do not know	No Answer
How was the temp. before rehab	1	6	1,50	0,50		3	1
How is temp. after rehab	2	5	6				
How was humidity before rehab		2,5	2,5			7	1
How is humidity after rehab		3	7			3	
How is temperature diff. Betw. Ancle and head	1	2	5	1		3	1
	Bad	Poor	Appropriate	Good	Very good	Do not know	No answer
How was indoor climate before rehab	4	5	1			2	1
How is indoor climate after rehab		2	9	1	1		
How is air quality at start of class		1	7	2		3	
How is air quality at end of class		1	8	1		3	
How is concentration after class		1	7	1	1	3	
How do you find the user friendliness of ventilation system	3		2			7	1
How do you find the user friendliness of heating system	3	1	2			6	1
How do you find the sound/noise level of the ventilation system			5	1	5	2	
How did you find the lighting before rehab		1	8		1	2	1
How do you find the lighting after rehab		1	11		1		

Table B2: Answers from user survey, women continued

	Yes	No	Do not know	No answer
Did you get tired at the end of class before rehab	1	5	5	2
Do you think this is because of the indoor climate	1	1	7	4
Do you get tired at the end of class now		9	3	1
Do you think this is because of the indoor climate		3	6	4
Were you satisfied with the indoor climate before rehab		9	3	1
Are you satisfied with the indoor climate now	10	2	1	
Do you think the indoor climate has improved	10		2	1

Table B3: Answers from user survey, men

Question	Too low	A little too low	Appropriate	A little too high	Too high	Do not know	No answer
How was the temp. before rehab	0,5	3	3		1,5	3	
How is temp. after rehab		4	5	1		1	
How was humidity before rehab	1	3	4			3	
How is humidity after rehab		1	9			1	
How is temperature diff. Betw. Ancle and head			7			2	2
	Bad	Poor	Appropriate	Good	Very good	Do not know	No answer
How was indoor climate before rehab	5	2	1			3	
How is indoor climate after rehab		1	6	1	2	1	
How is air quality at start of class			7		3	1	
How is air quality at end of class		1	6		2	2	
How is concentration after class			5	1	3	2	
How do you find the user friendliness of ventilation system	1		2	1	3	4	
How do you find the user friendliness of heating system	1		3	1	2	4	
How do you find the sound/noise level of the ventilation system			6	1	3	1	
How did you find the lighting before rehab		2	4	1	1	3	
How do you find the lighting after rehab		1	5	2	2	1	

Table B4: Answers from user survey, men continued

	Yes	No	Do not know
Did you get tired at the end of class before rehab	3	5	3
Do you think this is because of the indoor climate	3	3	5
Do you get tired at the end of class now	1	8	2
Do you think this is because of the indoor climate	5	3	3
Were you satisfied with the indoor climate before rehab		7	4
Are you satisfied with the indoor climate now	8	1	2
Do you think the indoor climate has improved	6	1	4

Appendix C - Blueprints

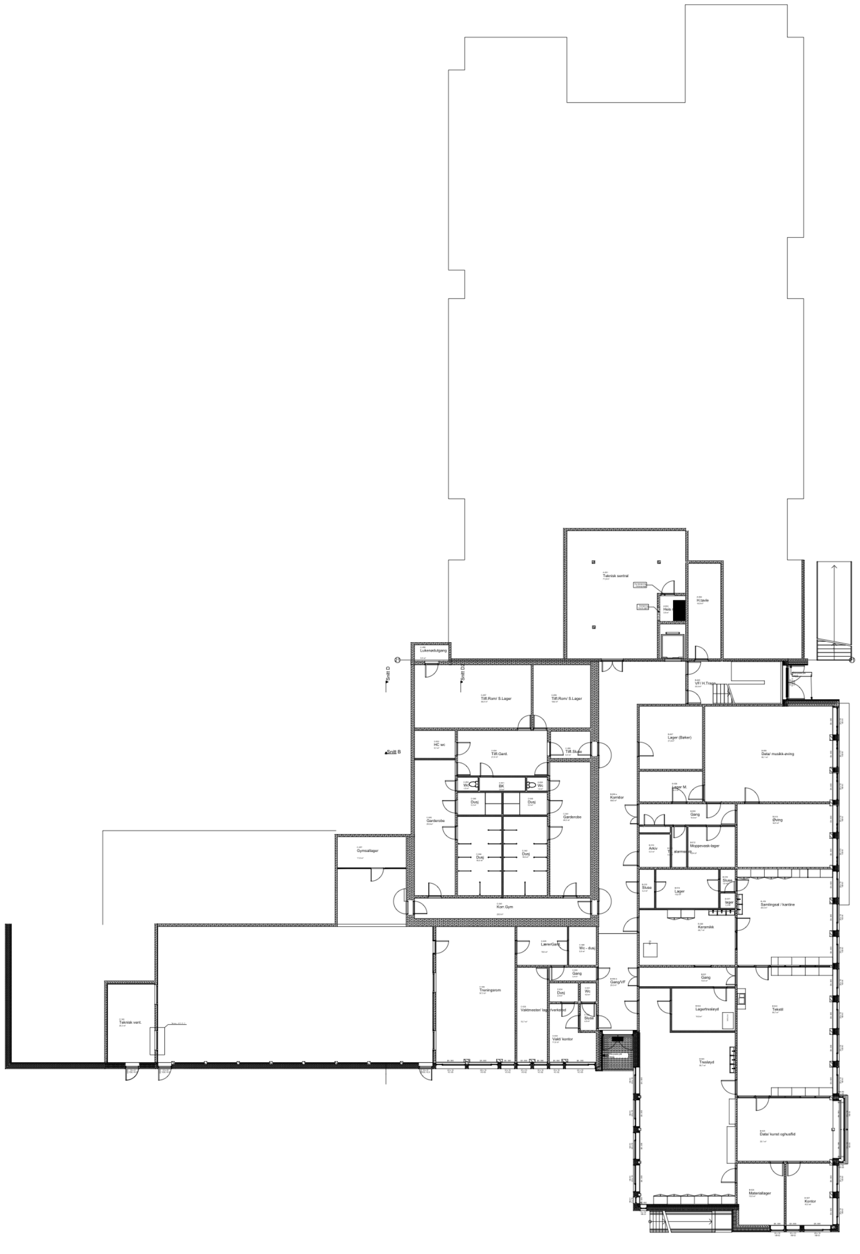


Figure C4: Blueprint of the basement floor

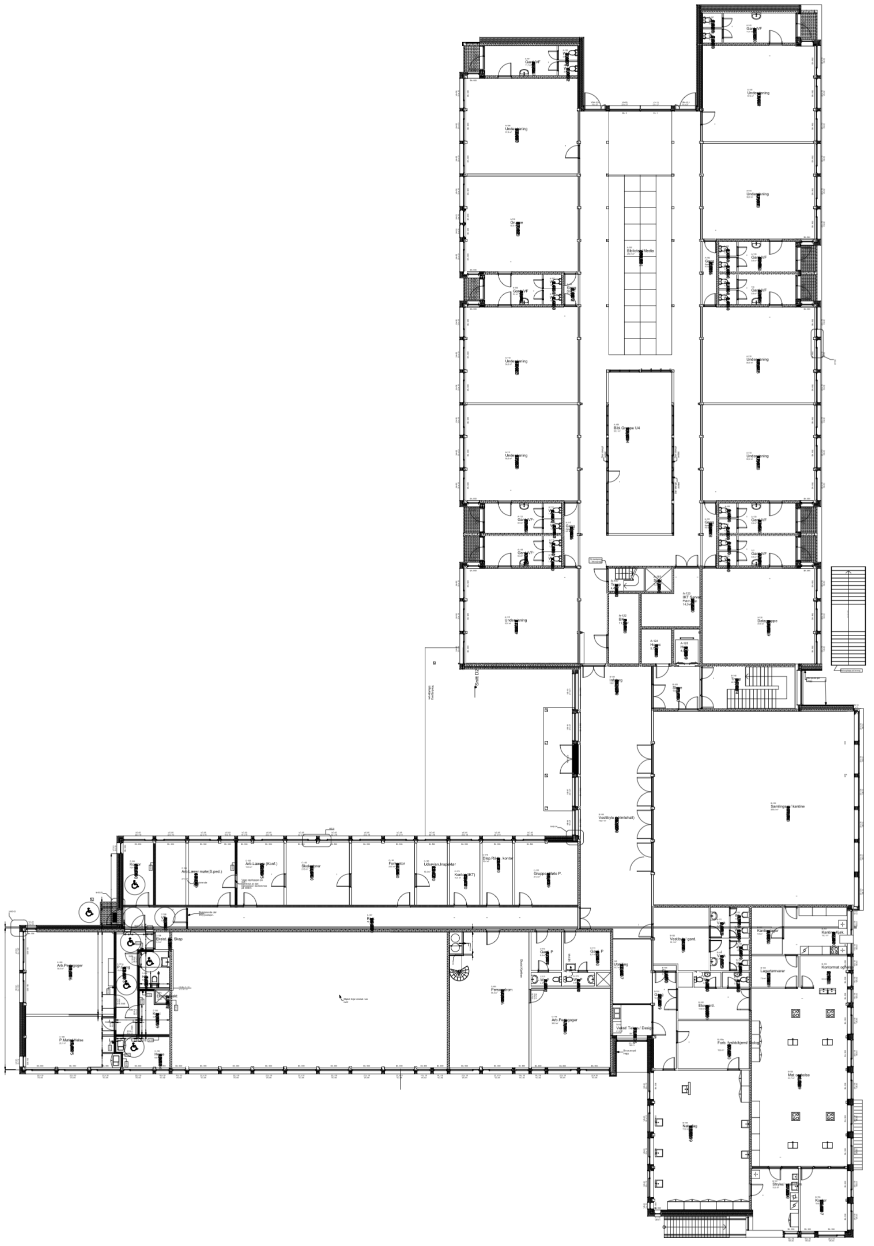


Figure C5: Blueprint of the first floor

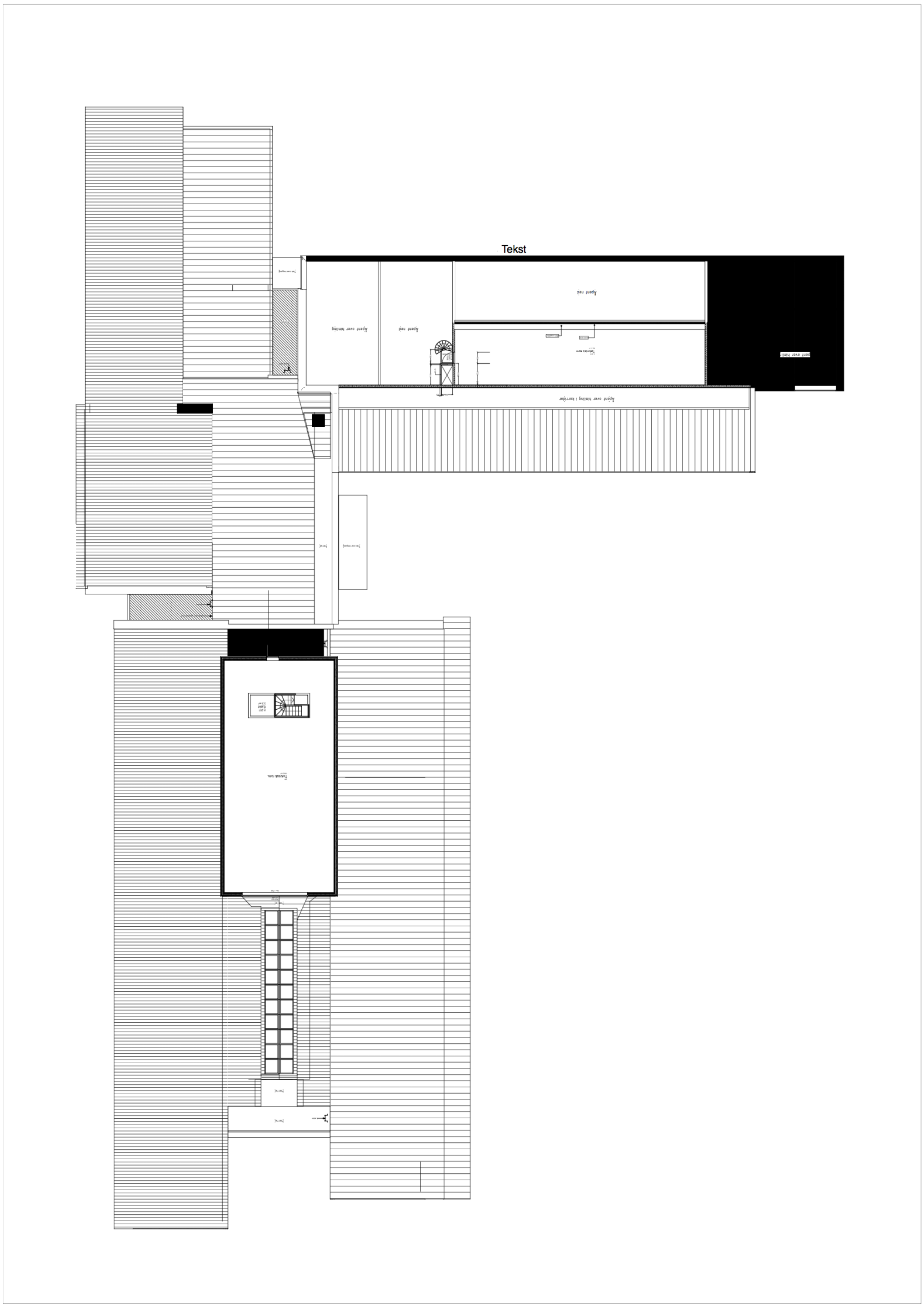


Figure C6: Blueprint of the technical floor

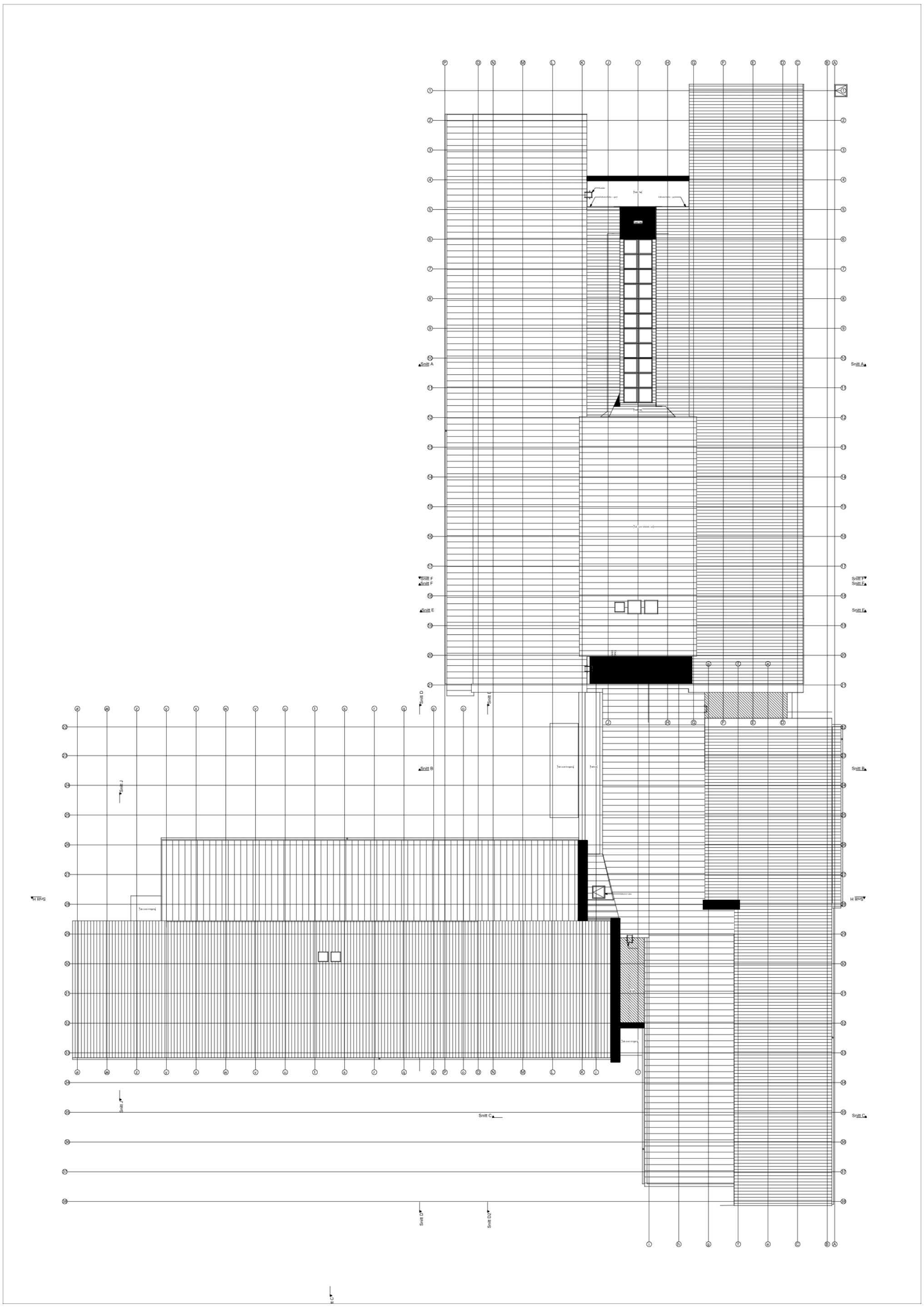


Figure C7: Blueprint of the roof

Appendix D - Section drawings

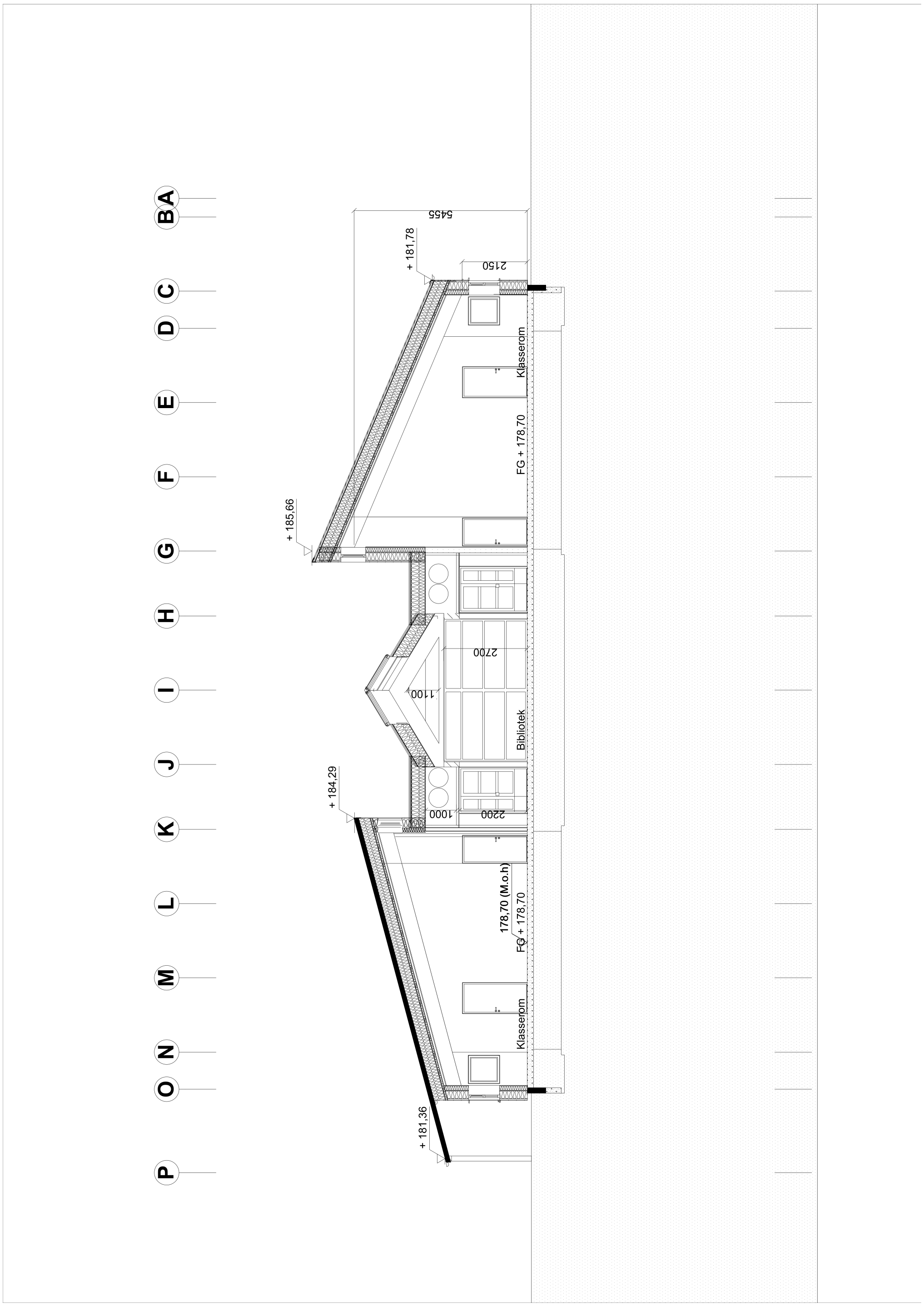


Figure D8: Section A: Through the A wing

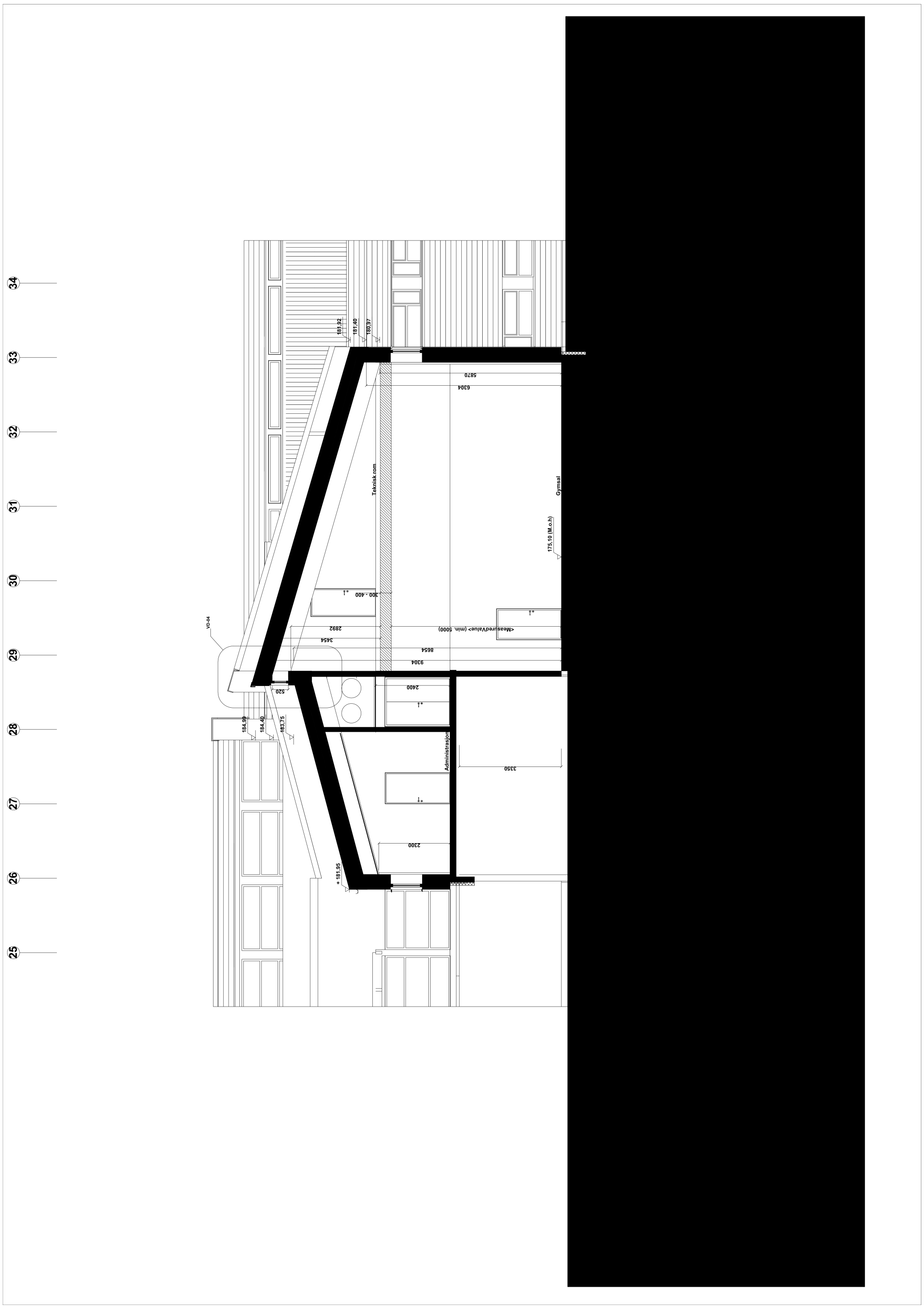


Figure D9: Section D: Through the C wing (short section)

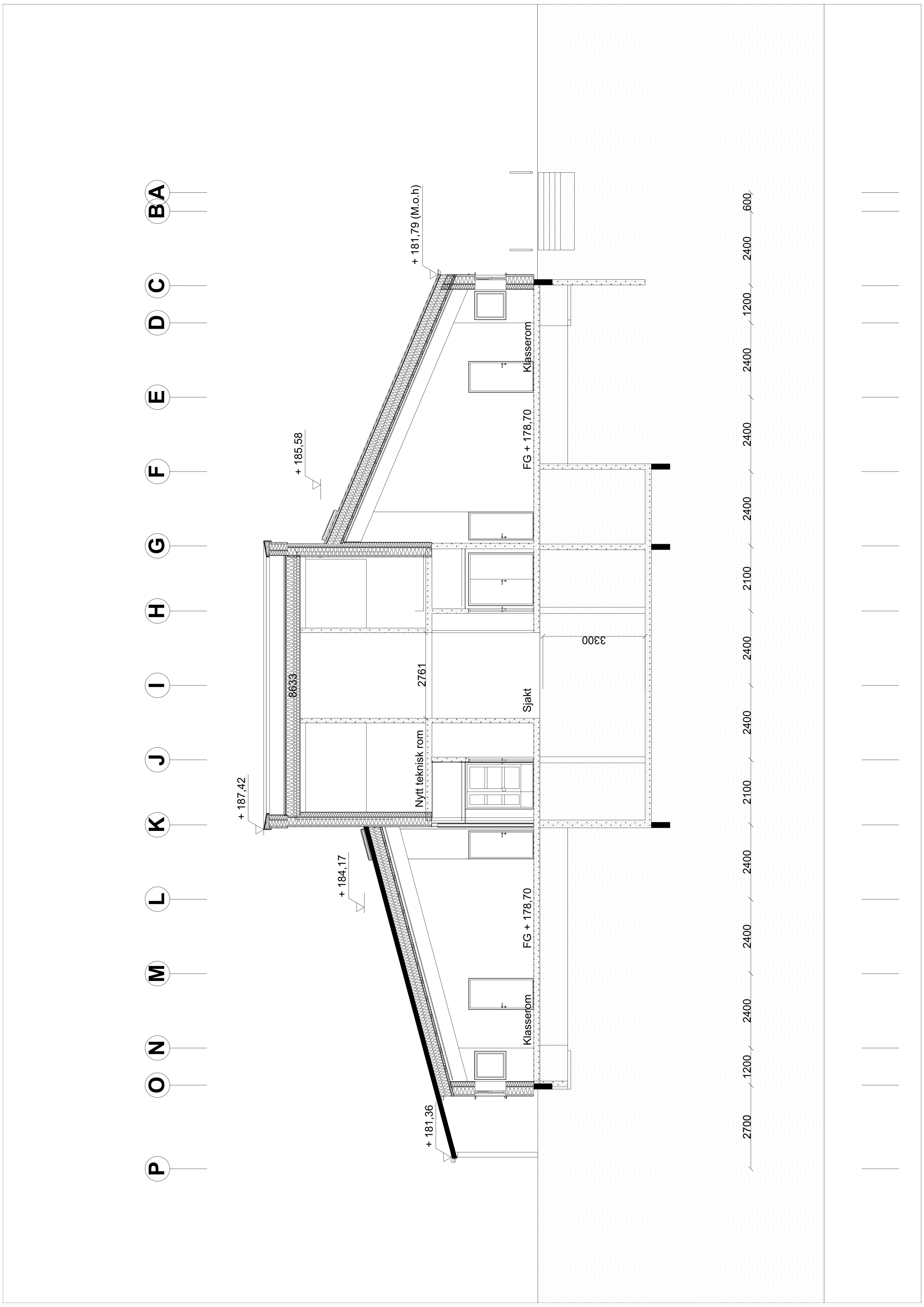


Figure D10: Section E: Through the A wing including the technical room

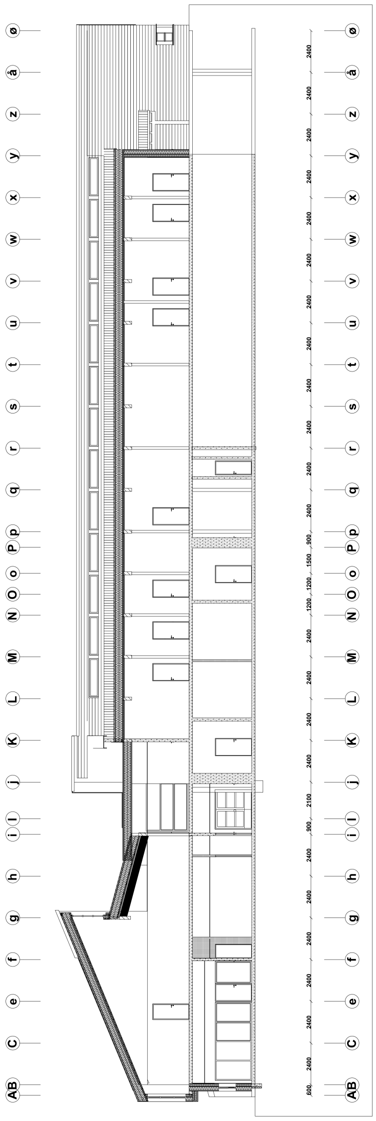


Figure D11: Section H: Through the C wing (long section)

Appendix E - Facade Drawings

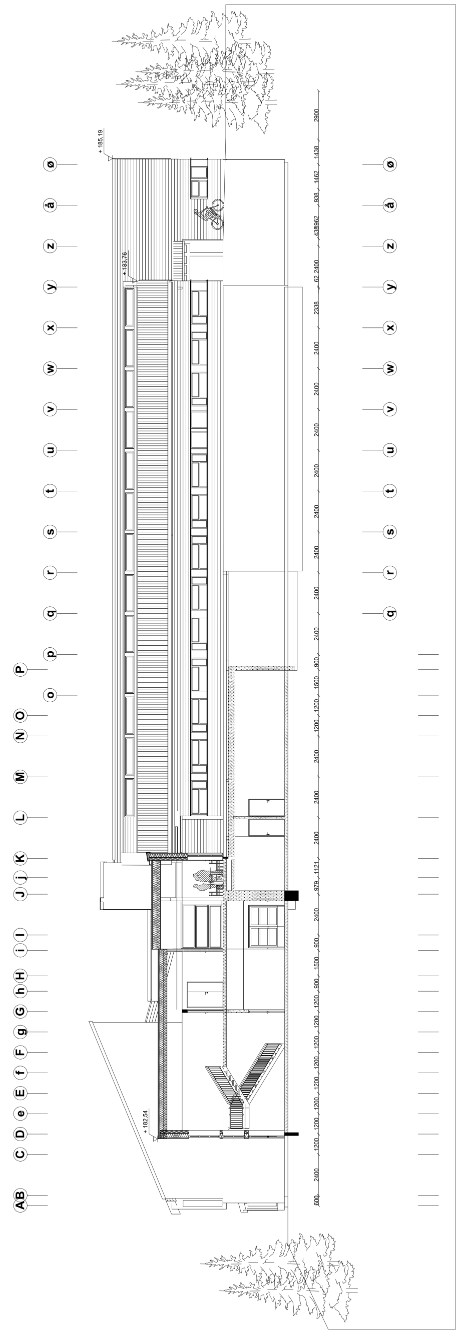


Figure E12: Facade North, through the foyer

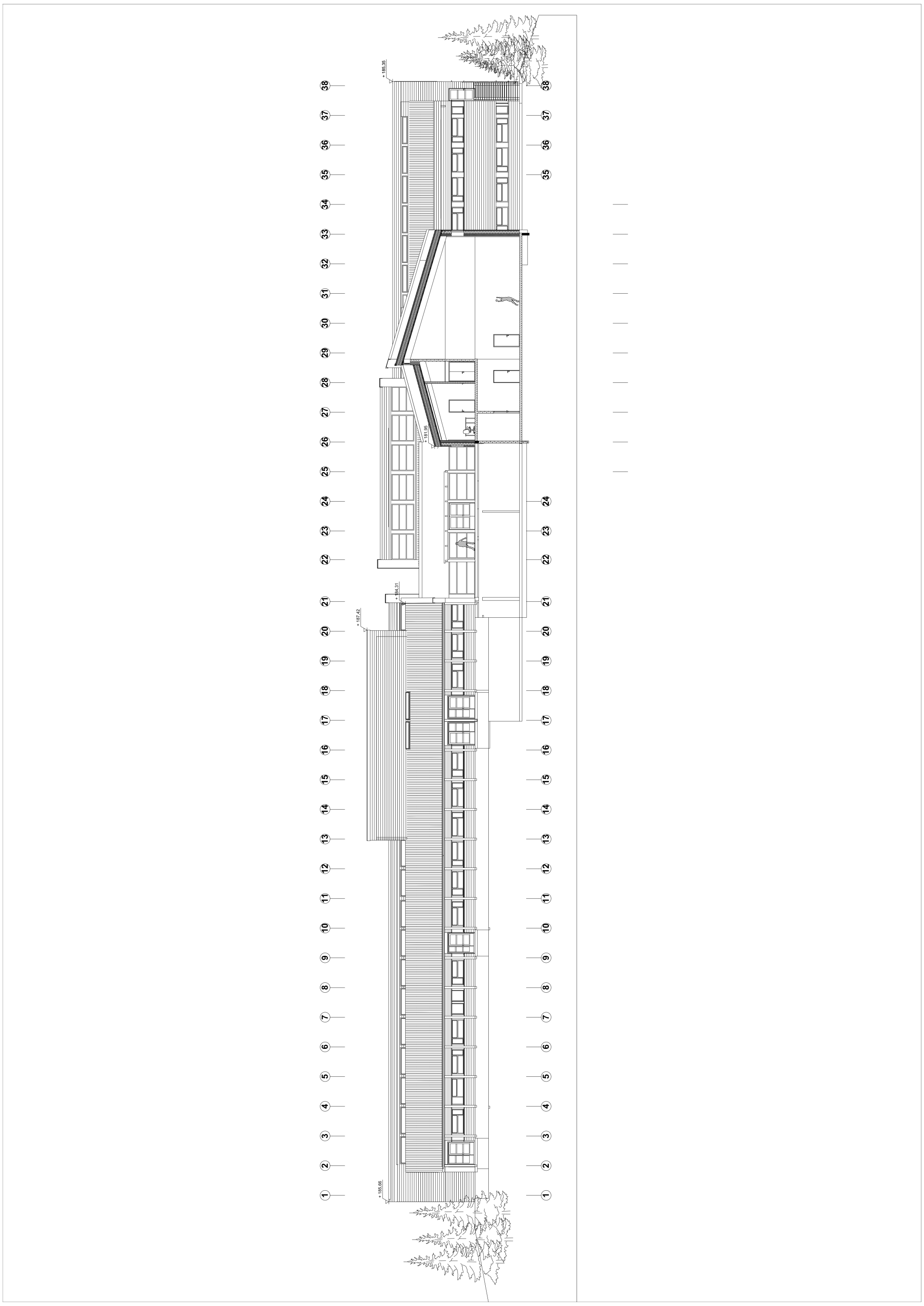
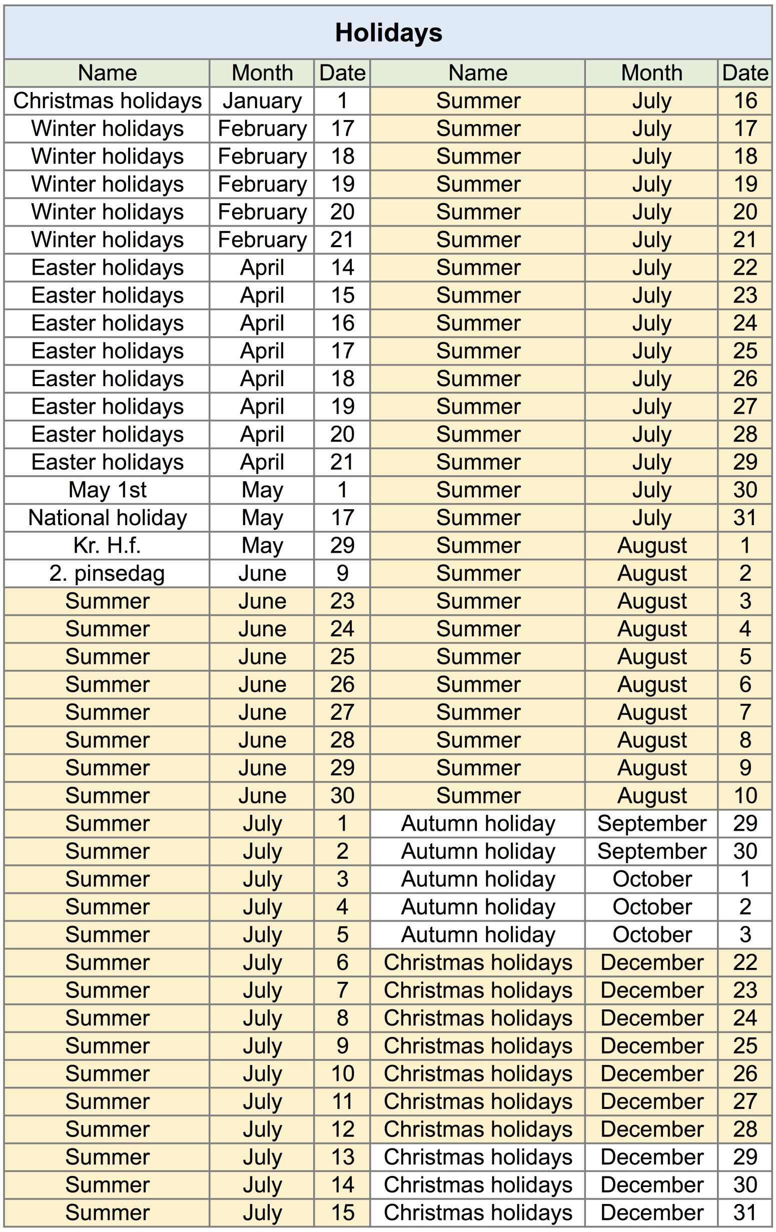


Figure E13: Facade West, through the gym

Appendix F - Holiday Schedule



Holidays

Name	Month	Date	Name	Month	Date
Christmas holidays	January	1	Summer	July	16
Winter holidays	February	17	Summer	July	17
Winter holidays	February	18	Summer	July	18
Winter holidays	February	19	Summer	July	19
Winter holidays	February	20	Summer	July	20
Winter holidays	February	21	Summer	July	21
Easter holidays	April	14	Summer	July	22
Easter holidays	April	15	Summer	July	23
Easter holidays	April	16	Summer	July	24
Easter holidays	April	17	Summer	July	25
Easter holidays	April	18	Summer	July	26
Easter holidays	April	19	Summer	July	27
Easter holidays	April	20	Summer	July	28
Easter holidays	April	21	Summer	July	29
May 1st	May	1	Summer	July	30
National holiday	May	17	Summer	July	31
Kr. H.f.	May	29	Summer	August	1
2. pinsedag	June	9	Summer	August	2
Summer	June	23	Summer	August	3
Summer	June	24	Summer	August	4
Summer	June	25	Summer	August	5
Summer	June	26	Summer	August	6
Summer	June	27	Summer	August	7
Summer	June	28	Summer	August	8
Summer	June	29	Summer	August	9
Summer	June	30	Summer	August	10
Summer	July	1	Autumn holiday	September	29
Summer	July	2	Autumn holiday	September	30
Summer	July	3	Autumn holiday	October	1
Summer	July	4	Autumn holiday	October	2
Summer	July	5	Autumn holiday	October	3
Summer	July	6	Christmas holidays	December	22
Summer	July	7	Christmas holidays	December	23
Summer	July	8	Christmas holidays	December	24
Summer	July	9	Christmas holidays	December	25
Summer	July	10	Christmas holidays	December	26
Summer	July	11	Christmas holidays	December	27
Summer	July	12	Christmas holidays	December	28
Summer	July	13	Christmas holidays	December	29
Summer	July	14	Christmas holidays	December	30
Summer	July	15	Christmas holidays	December	31

Figure F14: School Holidays

Appendix G - Elements of construction

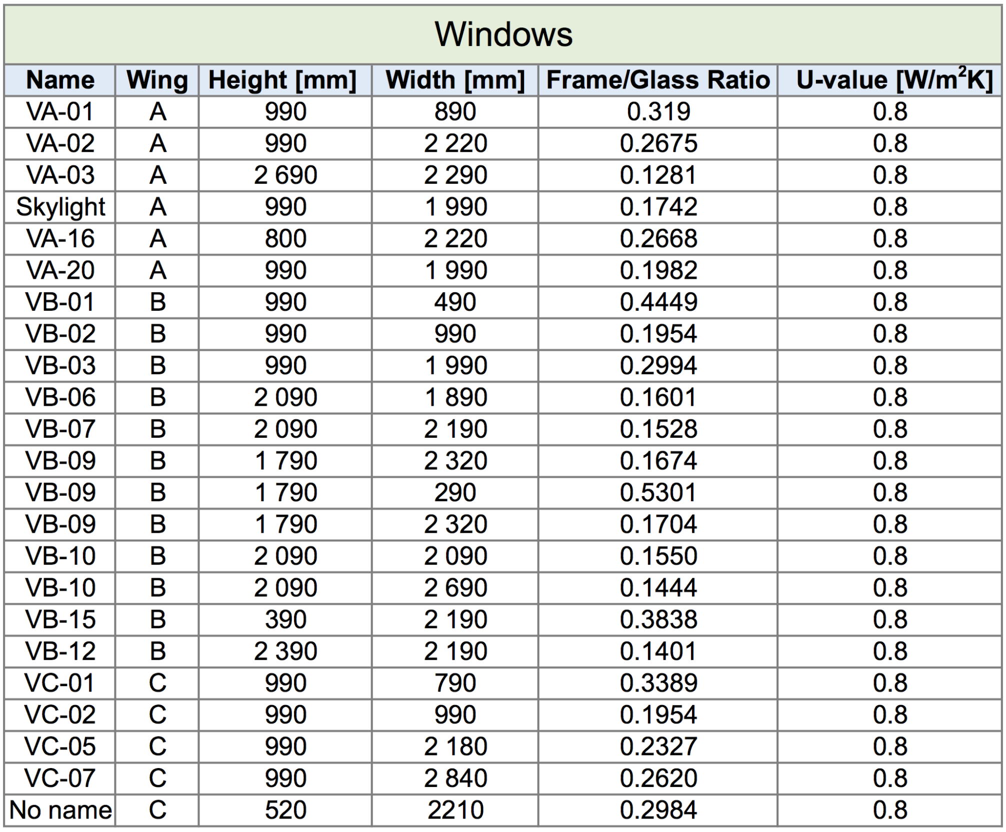
Table G1: Elements of construction

Element of Construction	Layer/material	Thickness	Heat Conductivity	Density	Specific Heat
External Wall	Gypsum	0.01 m	0.2 W/mK	970 kg/m^3	1090 J/kgK
	Vapor barrier	0.001 m	0.033 W/mK	1.0 kg/m^3	1.0 J/kgK
	Insulation	0.098 m	0.037 W/mK	20 kg/m^3	750 J/kgK
	Plywood	0.015 m	0.13 W/mK	500 kg/m^3	2300J/kgK
	Flex	0.25 m	0.048 W/mK	500 kg/m^3	1090 J/kgK
	Air in 30mm vert. Air gap	0.03 m	0.17 W/mK	1.2 kg/m^3	1006 J/kgK
Internal Wall	Gypsum	0.026 m	0.22 W/mK	970 kg/m^3	1090 J/kgK
	Air in 30 mm vert. Air gap	0.032 m	0.17 W/mK	1.2 kg/m^3	1006 J/kgK
	Light insulation	0.03 m	0.036 W/mK	20 kg/m^3	750 J/kgK
	Air in 30 mm vert. Air gap	0.032 m	0.17 W/mK	1.2 kg/m^3	1006 J/kgK
	Gypsum	0.026 m	0.22 W/mK	970 kg/m^3	1090 J/kgK
Internal floor	Floor coating	0.005 m	0.18 W/mK	1100 kg/m^3	920 J/kgK
	Concrete	0.02 m	0.15 W/mK	2300 kg/m^3	880 J/kgK
Roof	Wood wool	0.050 m	0.08 W/mK	500 kg/m^3	2300 J/kgK
	Gypsum	0.010 m	0.2 W/mK	970 kg/m^3	1090 J/kgK
	Vapor barrier	0.001 m	0.033 W/mK	1 kg/m^3	1 J/kgK
	Insulation	0.200 m	0.037 W/mK	20 kg/m^3	750 J/kgK
	Plywood	0.015 m	0.13 W/mK	500 kg/m^3	1090 J/kgK
	Insulation	0.300 m	0.037 W/mK	20 kg/m^3	750 J/kgK
	Wind barrier	0.001 m	0.033 W/mK	1000 kg/m^3	1300 J/kgK
	Air gap	0.096 m	0.17 W/mK	1.2 kg/m^3	1006 J/kgK
	Plywood	0.018 m	0.13 W/mK	500 kg/m^3	1090 J/kgK
	Asphalt roof	0.003 m	0.1 W/mK	500 kg/m^3	1090 J/kgK
External floor	Linoleum	0.005 m	0.17 W/mK	1100 kg/m^3	920 J/kgK
	Concrete	0.200 m	2.5 W/mK	2300 kg/m^3	880/kgK
	Diffusion barrier	0.001 m	0.033 W/mK	32 kg/m^3	750 J/kgK
	Expanded polystyrene	0.15 m	0.038 W/mK	32 kg/m^3	750 J/kgK

Appendix H - Descriptions of windows used

Following are descriptions for the different windows that were used in the building model. In the IDA ICE model, not all the different windows were used, as it was not always possible to differentiate between them all when consulting the blueprints and section views. Therefore, the windows that were used in the model are those that are listed here, including all data on the windows that was available from the descriptions provided by the architect. For all other values in IDA ICE glazings, default values were used.

Table H1: Windows

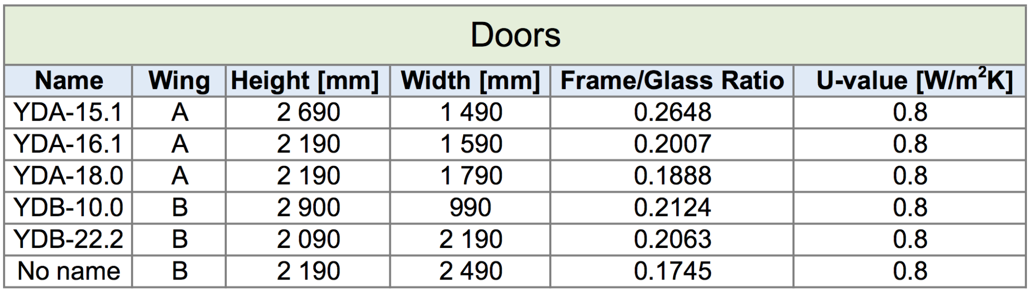


Windows					
Name	**Wing**	**Height [mm]**	**Width [mm]**	**Frame/Glass Ratio**	**U-value [W/m^2K]**
VA-01	A	990	890	0.319	0.8
VA-02	A	990	2 220	0.2675	0.8
VA-03	A	2 690	2 290	0.1281	0.8
Skylight	A	990	1 990	0.1742	0.8
VA-16	A	800	2 220	0.2668	0.8
VA-20	A	990	1 990	0.1982	0.8
VB-01	B	990	490	0.4449	0.8
VB-02	B	990	990	0.1954	0.8
VB-03	B	990	1 990	0.2994	0.8
VB-06	B	2 090	1 890	0.1601	0.8
VB-07	B	2 090	2 190	0.1528	0.8
VB-09	B	1 790	2 320	0.1674	0.8
VB-09	B	1 790	290	0.5301	0.8
VB-09	B	1 790	2 320	0.1704	0.8
VB-10	B	2 090	2 090	0.1550	0.8
VB-10	B	2 090	2 690	0.1444	0.8
VB-15	B	390	2 190	0.3838	0.8
VB-12	B	2 390	2 190	0.1401	0.8
VC-01	C	990	790	0.3389	0.8
VC-02	C	990	990	0.1954	0.8
VC-05	C	990	2 180	0.2327	0.8
VC-07	C	990	2 840	0.2620	0.8
No name	C	520	2210	0.2984	0.8

Appendix I - Descriptions of doors used

The doors that were used in the IDA ICE model are listed in the figure below. In wing B, there was an unspecified door in the blueprints, which was estimated to have the geometry and frame/glass-ratio as indicated in the table. In wing C, the external door was chosen to have the same values as the corresponding door found in the table. The values listed are all the information available from the architect, with default values being used for the remaining values.

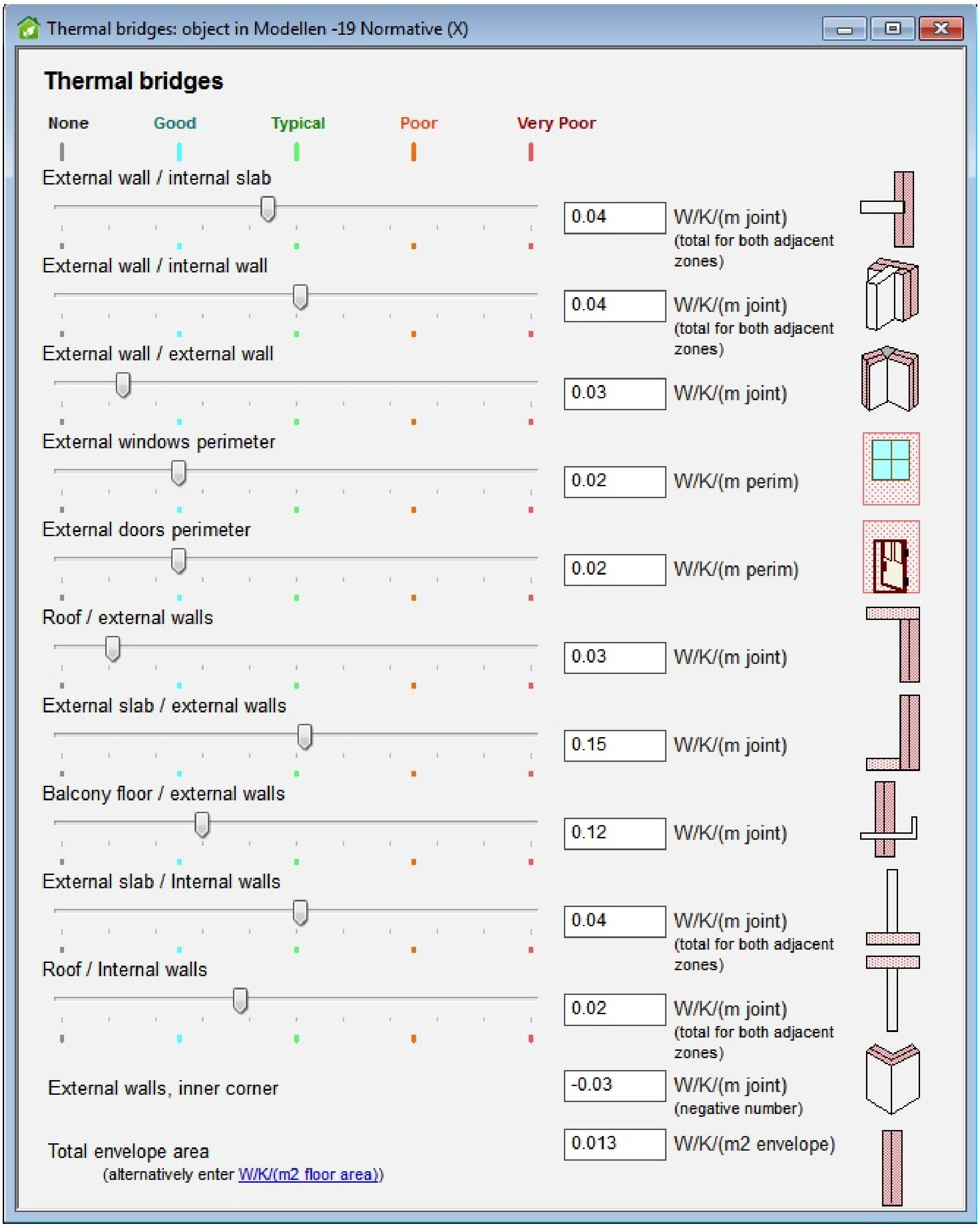
Table I1: Doors



Doors

Name	Wing	Height [mm]	Width [mm]	Frame/Glass Ratio	U-value [W/m^{2}K]
YDA-15.1	A	2 690	1 490	0.2648	0.8
YDA-16.1	A	2 190	1 590	0.2007	0.8
YDA-18.0	A	2 190	1 790	0.1888	0.8
YDB-10.0	B	2 900	990	0.2124	0.8
YDB-22.2	B	2 090	2 190	0.2063	0.8
No name	B	2 190	2 490	0.1745	0.8

Appendix J - Thermal Bridges



Thermal bridges: object in Modellen -19 Normative (X)

Thermal bridges

External wall / internal slab	0.04	W/K/(m joint) (total for both adjacent zones)
External wall / internal wall	0.04	W/K/(m joint) (total for both adjacent zones)
External wall / external wall	0.03	W/K/(m joint)
External windows perimeter	0.02	W/K/(m perim)
External doors perimeter	0.02	W/K/(m perim)
Roof / external walls	0.03	W/K/(m joint)
External slab / external walls	0.15	W/K/(m joint)
Balcony floor / external walls	0.12	W/K/(m joint)
External slab / Internal walls	0.04	W/K/(m joint) (total for both adjacent zones)
Roof / Internal walls	0.02	W/K/(m joint) (total for both adjacent zones)
External walls, inner corner	-0.03	W/K/(m joint) (negative number)
Total envelope area (alternatively enter W/K/(m2 floor area))	0.013	W/K/(m2 envelope)

Figure J15: Thermal bridges

Appendix K - System Overview

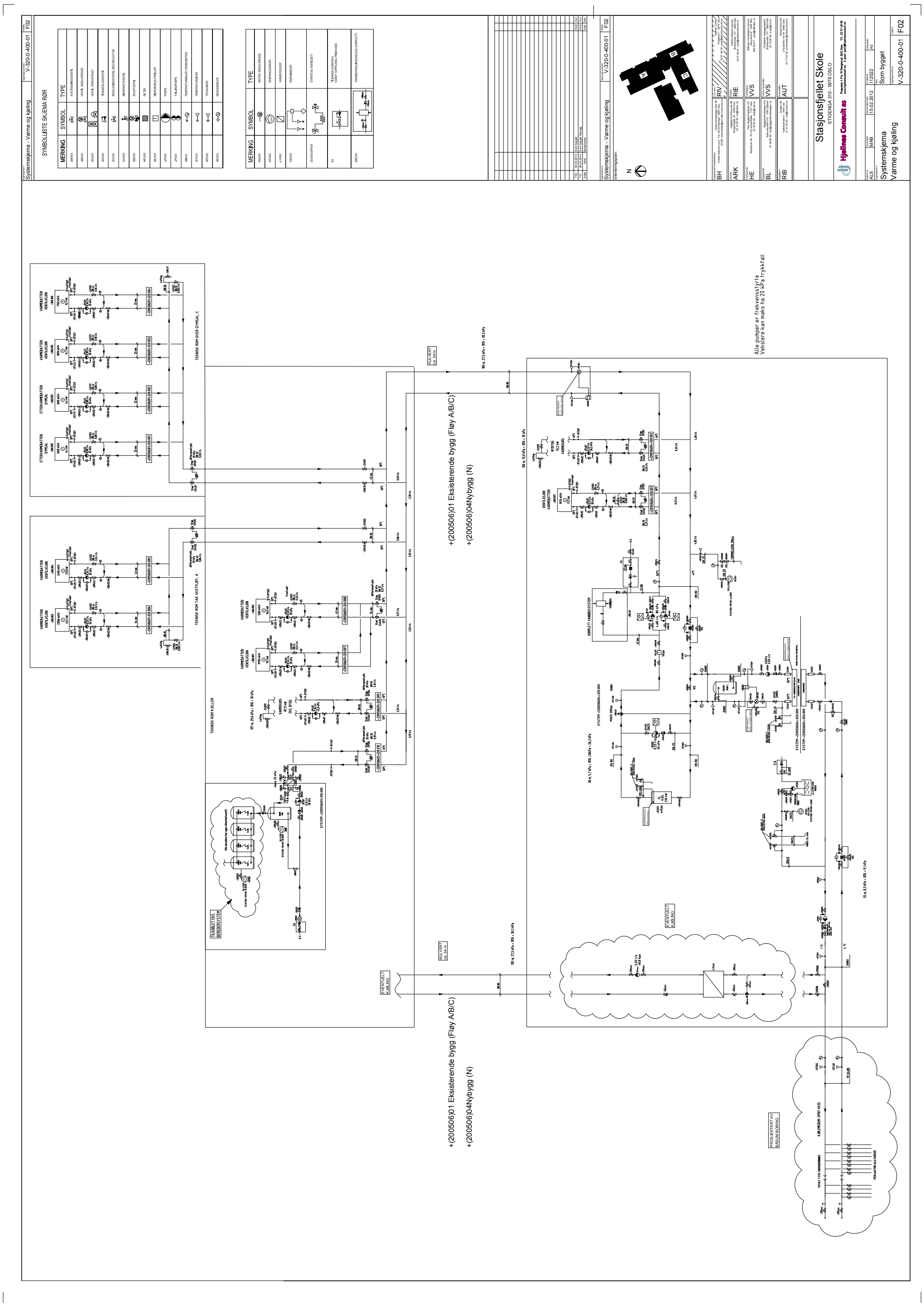
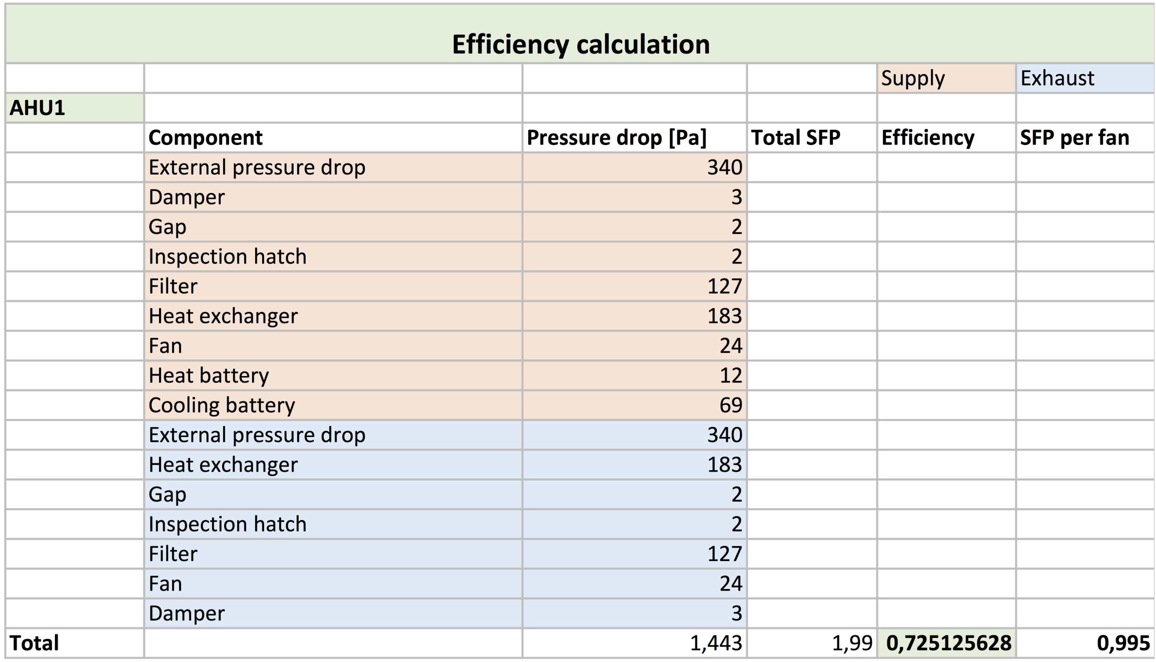


Figure K16: System Description

Appendix L - Air handling unit - SPF and efficiency

Table L1: Air handling unit 1



Efficiency calculation					
				Supply	Exhaust
AHU1					
	Component	**Pressure drop [Pa]**	**Total SFP**	**Efficiency**	**SFP per fan**
	External pressure drop	340			
	Damper	3			
	Gap	2			
	Inspection hatch	2			
	Filter	127			
	Heat exchanger	183			
	Fan	24			
	Heat battery	12			
	Cooling battery	69			
	External pressure drop	340			
	Heat exchanger	183			
	Gap	2			
	Inspection hatch	2			
	Filter	127			
	Fan	24			
	Damper	3			
Total		1,443	1,99	**0,725125628**	**0,995**

Table L2: Air handling unit 1

AHU2	**Component**	**Pressure drop [Pa]**	**Total SFP**	**Efficiency**	**SFP per fan**
	External pressure drop	270			
	Damper	9			
	Gap	0			
	Inspection hatch	3			
	Filter	145			
	Heat exchanger	159			
	Fan	31			
	Heat battery	38			
	Cooling battery	105			
	External pressure drop	270			
	Heat exchanger	159			
	Gap	0			
	Inspection hatch	3			
	Filter	145			
	Fan	31			
	Damper	9			
Total		1,377	1,98	**0,695454545**	**0,99**

Table L3: Air handling unit 1

AHU3	**Component**	**Pressure drop [Pa]**	**Total SFP**	**Efficiency**	**SFP per fan**
	External pressure drop	220			
	Damper	5			
	Gap	3			
	Inspection hatch	3			
	Filter	136			
	Heat exchanger	216			
	Fan	220			
	Heat battery	17			
	Cooling battery	94			
	External pressure drop	220			
	Heat exchanger	216			
	Gap	3			
	Inspection hatch	3			
	Filter	136			
	Fan	220			
	Damper	5			
Total		1,717	2	**0,8585**	**1**

Table L4: Air handling unit 1

AHU4	**Component**	**Pressure drop [Pa]**	**Total SFP**	**Efficiency**	**SFP per fan**
	External pressure drop	230			
	Damper	9			
	Gap				
	Inspection hatch	3			
	Filter	150			
	Heat exchanger	173			
	Fan	34			
	Heat battery	62			
	Cooling battery	114			
	External pressure drop	230			
	Heat exchanger	173			
	Gap				
	Inspection hatch	3			
	Filter	150			
	Fan	34			
	Damper	9			
Total		1,374	1,99	**0,690452261**	**0,995**

Table L5: Air handling unit 1

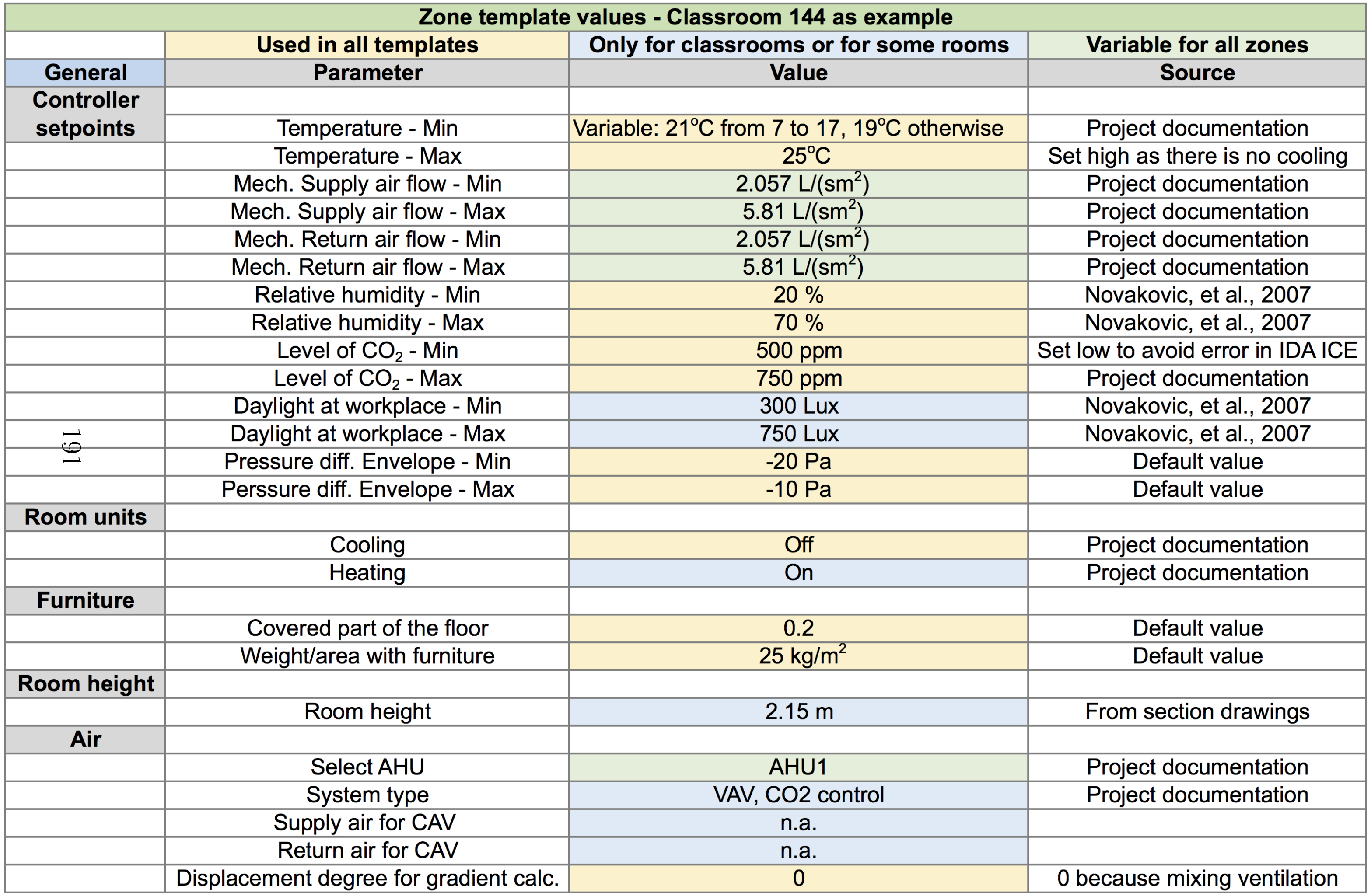
AHU5	Component	Pressure drop [Pa]	Total SFP	Efficiency	SFP per fan
	External pressure drop	300			
	Damper	4			
	Gap	0			
	Inspection hatch	3			
	Filter	137			
	Heat exchanger	191			
	Fan	25			
	Heat battery	15			
	Cooling battery	85			
	External pressure drop	300			
	Heat exchanger	191			
	Gap	0			
	Inspection hatch	3			
	Filter	137			
	Fan	25			
	Damper	4			
Total		1,42	1,98	**0,717171717**	**0,99**

Table L6: Air handling unit 1

AHU6	**Component**	**Pressure drop [Pa]**	**Total SFP**	**Efficiency**	**SFP per fan**
	External pressure drop	230			
	Damper	5			
	Gap				
	Inspection hatch	3			
	Filter	149			
	Heat exchanger	216			
	Fan	32			
	Heat battery	18			
	Cooling battery	103			
	External pressure drop	230			
	Heat exchanger	216			
	Gap				
	Inspection hatch	3			
	Filter	149			
	Fan	32			
	Damper	5			
Total		1,391	1,99	**0,698994975**	**0,995**

Appendix M - Zone Template Values

Table M1: Zone Template Values



Zone template values - Classroom 144 as example			
	Used in all templates	Only for classrooms or for some rooms	Variable for all zones
General	Parameter	Value	Source
Controller setpoints			
	Temperature - Min	Variable: 21°C from 7 to 17, 19°C otherwise	Project documentation
	Temperature - Max	25°C	Set high as there is no cooling
	Mech. Supply air flow - Min	2.057 $L/(sm^2)$	Project documentation
	Mech. Supply air flow - Max	5.81 $L/(sm^2)$	Project documentation
	Mech. Return air flow - Min	2.057 $L/(sm^2)$	Project documentation
	Mech. Return air flow - Max	5.81 $L/(sm^2)$	Project documentation
	Relative humidity - Min	20 %	Novakovic, et al., 2007
	Relative humidity - Max	70 %	Novakovic, et al., 2007
	Level of CO_2 - Min	500 ppm	Set low to avoid error in IDA ICE
	Level of CO_2 - Max	750 ppm	Project documentation
	Daylight at workplace - Min	300 Lux	Novakovic, et al., 2007
	Daylight at workplace - Max	750 Lux	Novakovic, et al., 2007
	Pressure diff. Envelope - Min	-20 Pa	Default value
	Perssure diff. Envelope - Max	-10 Pa	Default value
Room units			
	Cooling	Off	Project documentation
	Heating	On	Project documentation
Furniture			
	Covered part of the floor	0.2	Default value
	Weight/area with furniture	25 kg/m^2	Default value
Room height			
	Room height	2.15 m	From section drawings
Air			
	Select AHU	AHU1	Project documentation
	System type	VAV, CO2 control	Project documentation
	Supply air for CAV	n.a.	
	Return air for CAV	n.a.	
	Displacement degree for gradient calc.	0	0 because mixing ventilation

Table M2: Zone Template Values continued

	Parameter	Value	Source
Advanced			
Elements of construction	External walls	External wall	Self defined
	Internal walls	Internal wall	Self defined
	Internal floors	Internal floor	Self defined
	Roof	Roof	Self defined
	External floor	External floor	Self defined
Room unit power			
	Cooling	0 W/m2	Project documentation
	Heating	36.2 W/m2	Estimated value
Internal gains			
Occupants			
	no./m^2	0.5	Estimated value
	Schedule	Stasjonsfjellet - Use-time	Set to "Stasjonsfjellet - Classroom 6"
	Activity level	1.3 MET	Novakovic, et al., 2007
	Cloting level	Constant at 0.85 +- 0.25 CLO	Novakovic, et al., 2007
Equipment			
	no./m2	1	Estimated value - Standard Norge, 2012
	Emitted heat per unit	4W	Standard Norge, 2012
	Long wave radiation fraction	0	Default value
	Moisture emission per unit	0	Default value
	CO2 per unit	0	Default value
	Schedule	Stasjonsfjellet - Use-time	Set to "Stasjonsfjellet - Classroom 6"
	Energy meter	Equipment, facility	Default
Light			
	no./m2	1	Estimated value -Standard Norge, 2012
	Control strategy	Schedule	Presence sensors,schedule as approximation
	Rated input per unit	4.5 W	Standard Norge, 2012
	Luminous efficacy	12 lm/W	Default value
	Convective fraction	0.3	Default value
	Schedule	Stasjonsfjellet - Use-time	Set to "Stasjonsfjellet - Classroom 6"
	Energy meter	Lighting, facility	Default

Appendix N - Radiator overview

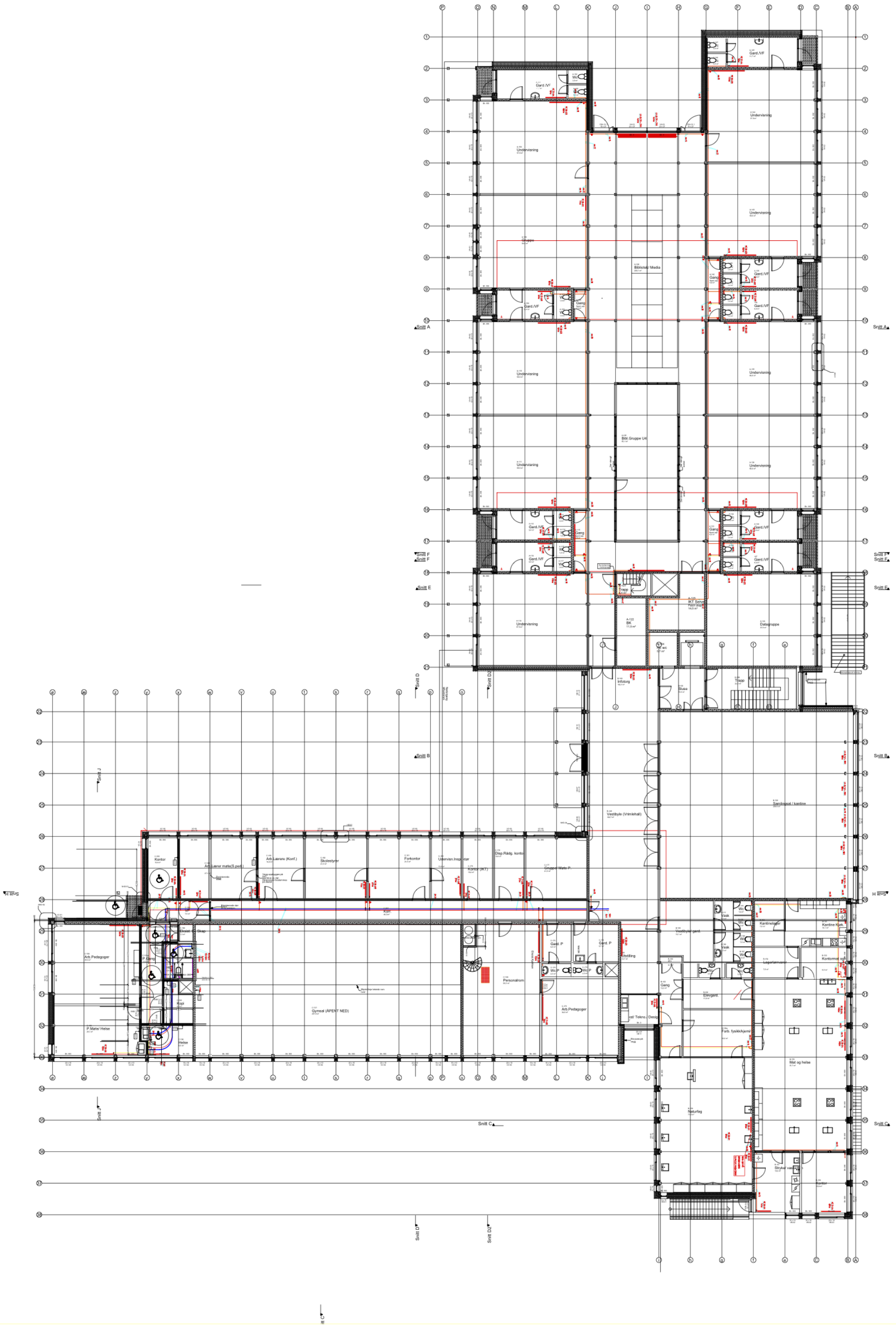


Figure N17: Radiators first floor

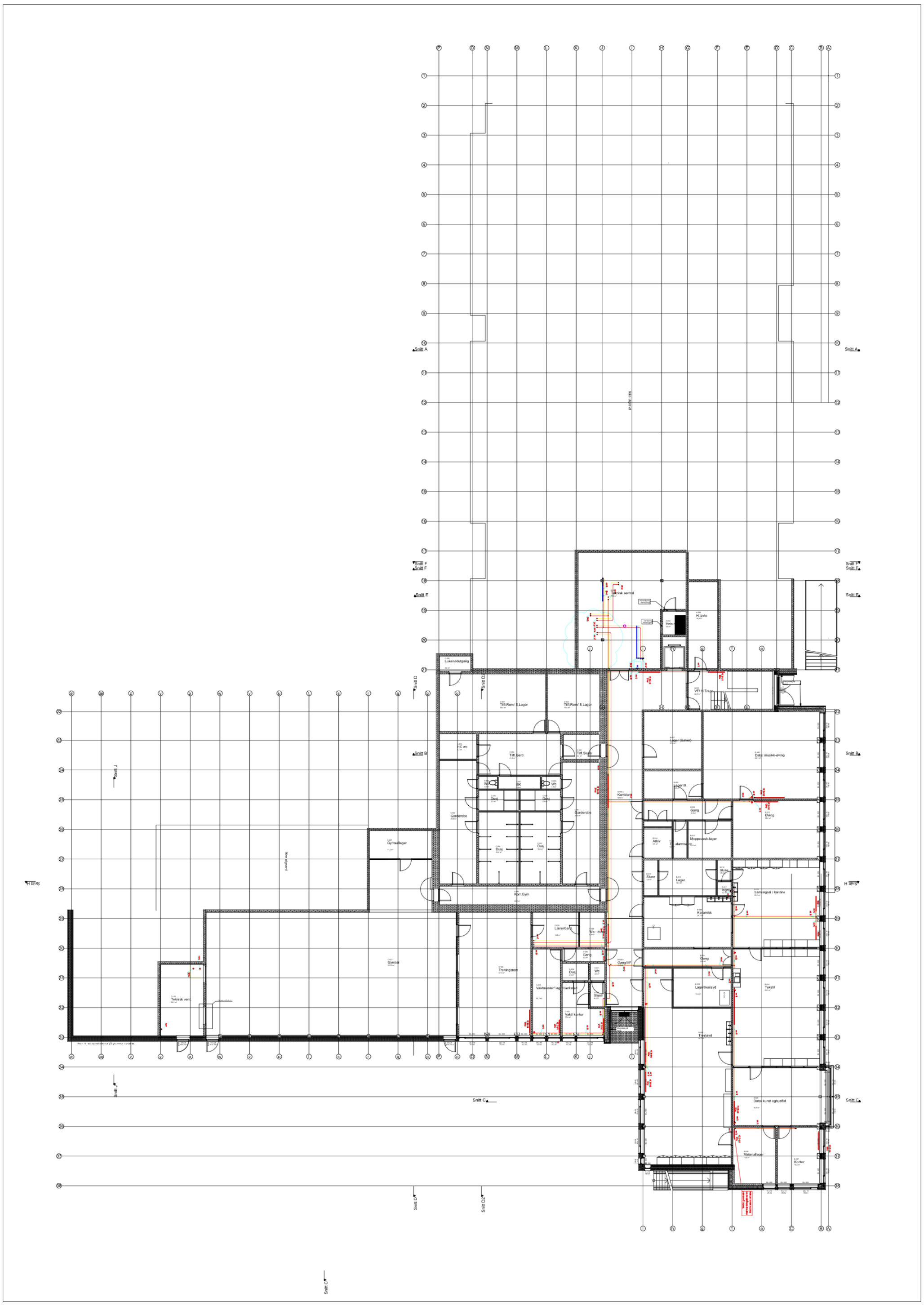


Figure N18: Radiators basement

Appendix O - Zone values

Table O1: Zone Values First Floor

Room values		Wing A	Wing B	Wing C
Room no.	**Room type**	**Floor area [m^2]**	**Pers.**	**Pers./m^2**
101	Gard./VF	11,7	0	0
102	WC	1,5	0	0
103	WC	1,5	0	0
104	Klasserom	57,6	30	0,520833
105A	Gruppe	28,3	15	0,530035
105B	Gruppe	28,2	15	0,531915
106	Gard./VF	9,4	0	0
107	WC	1,4	0	0
108	WC	1,4	0	0
109	Gang	2,3		0
110	Klasserom	57,8	30	0,519031
111	Klasserom	57,7	30	0,519931
112	Garderobe	9,4	0	0
113	WC	1,4	0	0
114	WC	1,4	0	0
115	Gang	4,8		0
116	WC	1,4	0	0
117	WC	1,4	0	0
118	Garderobe	9,4	0	0
119	Undervisning	57,2	30	0,524476
120	Bibl. Gruppe U4	43,9	12	0,273349
122	BK	11,5	0	0
10?	Trapp	4,4	0	0
10?	Sjakt	3,3		0
123	IKT Server Patch sk.	14	0	0
124	HC WC	5,7	0	0
125	Heis	4,9		0
126	Datagruppe	57,6	30	0,520833
127	Garderobe	9,4	0	0
128	WC	1,4	0	0
129	WC	1,4	0	0
130	Garderobe	9,4	0	0
131	WC	1,4	0	0
132	WC	1,4	0	0
133	Gang	4,8		0
134	Klasserom	57,7	30	0,519931
135	Klasserom	57,8	30	0,519031
136	Gard./VF	9,4	0	0
137	WC	1,4	0	0
138	WC	1,4	0	0
139	Gard./VF	9,4	0	0
140	WC	1,4	0	0
141	WC	1,4	0	0
142	Gang	4,8		0
143	Klasserom	57,7	30	0,519931
144	Klasserom	57,4	30	0,522648
145	Gard./VF	11,7	0	0
146	WC	1,5	0	0
147	WC	1,5	0	0

Table O2: Zone Values First Floor continued

Room no	Room type	Floor area [m^2]	Pers.	Pers./m^2
148	Trapp	21,6	0	0
150	Sluse	10,6		0
149	Vestibyle	122,3	0	0
151	Kjøkken	16	5	0,3125
152	Kantinelager	7,8	0	0
153	Kontor Mat og hels.	7,9	2	0,253165
154	Lager tørrvarer	8	0	0
155	Mat og helse	91,3	30	0,328587
156	Kontor Mat og hels.	15,5	4	0,258065
157	Stryke/vaskerom	15,6	8	0,512821
158	Naturfag	71,4	30	0,420168
158a	Forb. Fysikk/kjemi/	18,6	9	0,483871
159	Saml. Sal/kant.	209,7	103	0,491178
160	Elevgard.	11,8	0	0
161	WC	2,2	0	0
162	WC	2,2	0	0
163	Jakkegard.	5,9	0	0
164	Vekst/Tekno./Design	7	0	0
165	Vestibyle/Gard.	18,1	0	0
166	Vask	3,3	0	0
167	WC	1,6	0	0
168	WC	1,6	0	0
169	WC	1,6	0	0
170	WC	1,6	0	0
171	Vask	3,2	0	0
172	Gard. P.	9,7	0	0
173	WC P	2,3	0	0
174	WC P	2,3	0	0
175	Arb. Pedagoger	34	8	0,235294
176	Gard. P.	6,4	0	0
177	Gruppe/MøteP.	21,3	6	0,28169
178	Disp.-rådg.	10,3	1	0,097087
179	Kontor (IKT)	10,3	1	0,097087
180	Undervisn. Insp.	10,3	1	0,097087
181	Forkontor	21,4	5	0,233645
182	Skolestyrer	21,4	9	0,420561
183	Arb. Lærere (Konf.)	15,8	4	0,253165
184	Arb. Lærer møte	26,9	7	0,260223
185 = 184a	Nytt kontor	10,1	1	0,09901
187	Korridor	46,8	1	0,021368
188	VF	8,1	0	0
189	Personalrom	51,6	30	0,581395
190	Bibliotek/Media	264	50	0,189394
191a	Gang	13,6	0	0
194	EL	1,3	0	0
192	HC WC	5,7	0	0
195	Kopi	6	0	0
196	Helse	8,5	2	0,235294
198	Møte/Helse	25,1	12	0,478088
199	Arbeidsrom	39	10	0,25641

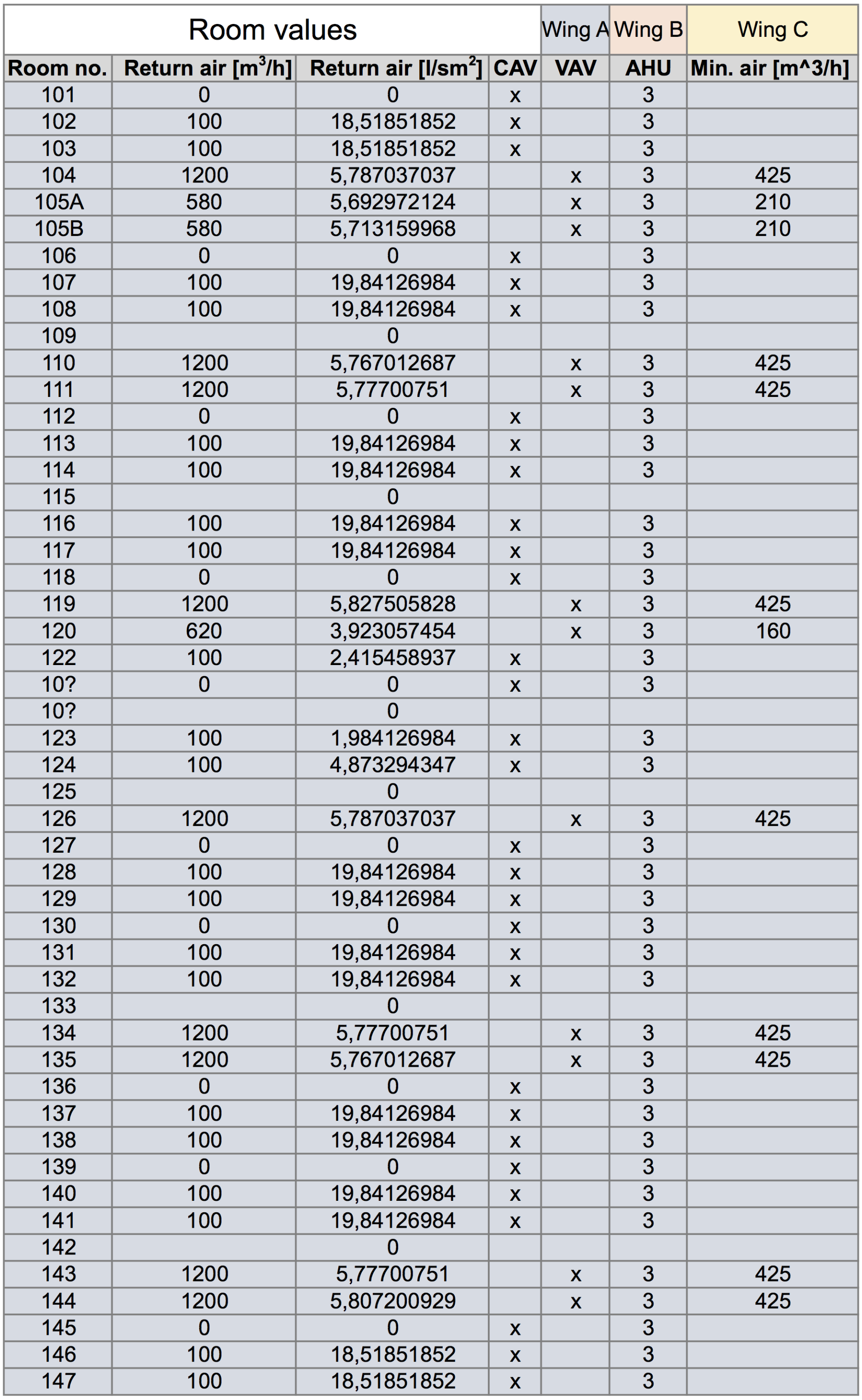
Table O3: Zone Values First Floor continued

Room values	Wing A	Wing B	Wing C
Room no.	**Supply air [m^3/h]**	**Supply air [L/s]**	**Supply air [l/sm^2]**
101	200	55,55555556	3,779289494
102	0	0	0
103	0	0	0
104	1200	333,3333333	5,787037037
105A	580	161,1111111	5,692972124
105B	580	161,1111111	5,713159968
106	200	55,55555556	4,553734062
107	0	0	0
108	0	0	0
109		0	0
110	1200	333,3333333	5,767012687
111	1200	333,3333333	5,77700751
112	200	55,55555556	3,805175038
113	0	0	0
114	0	0	0
115		0	0
116	0	0	0
117	0	0	0
118	200	55,55555556	5,910165485
119	1200	333,3333333	5,827505828
120	620	172,2222222	3,923057454
122	0	0	0
10?	100	27,77777778	6,313131313
10?		0	0
123	0	0	0
124	100	27,77777778	4,873294347
125		0	0
126	1200	333,3333333	5,787037037
127	200	55,55555556	3,805175038
128	0	0	0
129	0	0	0
130	200	55,55555556	5,910165485
131	0	0	0
132	0	0	0
133		0	0
134	1200	333,3333333	5,77700751
135	1200	333,3333333	5,767012687
136	200	55,55555556	4,553734062
137	0	0	0
138	0	0	0
139	200	55,55555556	5,910165485
140	0	0	0
141	0	0	0
142		0	0
143	1200	333,3333333	5,77700751
144	1200	333,3333333	5,807200929
145	200	55,55555556	3,779289494
146	0	0	0
147	0	0	0

Table O4: Zone Values First Floor continued

Room number	Supply air [m^3/h]	Supply air [L/s]	Supply air [l/sm^2]
148	100	27,77777778	0,862663906
150		0	0
149	920	255,5555556	2,089579359
151	520	144,4444444	9,027777778
152	0	0	0
153	130	36,11111111	4,571026723
154	0	0	0
155	2170	602,7777778	6,602166241
156	260	72,22222222	4,659498208
157	500	138,8888889	8,903133903
158	1580	438,8888889	6,146903206
158a	500	138,8888889	7,467144564
159	5600	1555,555556	7,418004557
160	200	55,55555556	4,29613936
161	0	0	0
162	0	0	0
163	50	13,88888889	2,354048964
164	100	27,77777778	3,968253968
165	130	36,11111111	1,995089012
166	200	55,55555556	16,83501684
167	0	0	0
168	0	0	0
169	0	0	0
170	0	0	0
171	200	55,55555556	17,36111111
172	100	27,77777778	2,683843264
173	0	0	0
174	0	0	0
175	450	125	3,676470588
176	100	27,77777778	4,340277778
177	310	86,11111111	4,04277517
178	110	30,55555556	2,966558792
179	110	30,55555556	2,966558792
180	110	30,55555556	2,966558792
181	280	77,77777778	3,634475597
182	380	105,5555556	4,932502596
183	220	61,11111111	3,867791842
184	370	102,7777778	3,820735233
185 = 184a	100	27,77777778	2,750275028
187	350	97,22222222	3,183699459
188	200	55,55555556	6,858710562
189	1140	316,6666667	6,136950904
190	3200	888,8888889	3,367003367
191a	250	69,44444444	5,10620915
194	0	0	0
192	0	0	0
195	0	0	0
196	110	30,55555556	3,594771242
198	480	133,3333333	5,312084993
199	540	150	3,846153846

Table O5: Zone Values First Floor continued



Room values				Wing A	Wing B	Wing C
Room no.	Return air [m^3/h]	Return air [l/sm^2]	CAV	VAV	AHU	Min. air [m^3/h]
101	0	0	x		3	
102	100	18,51851852	x		3	
103	100	18,51851852	x		3	
104	1200	5,787037037		x	3	425
105A	580	5,692972124		x	3	210
105B	580	5,713159968		x	3	210
106	0	0	x		3	
107	100	19,84126984	x		3	
108	100	19,84126984	x		3	
109		0				
110	1200	5,767012687		x	3	425
111	1200	5,77700751		x	3	425
112	0	0	x		3	
113	100	19,84126984	x		3	
114	100	19,84126984	x		3	
115		0				
116	100	19,84126984	x		3	
117	100	19,84126984	x		3	
118	0	0	x		3	
119	1200	5,827505828		x	3	425
120	620	3,923057454		x	3	160
122	100	2,415458937	x		3	
10?	0	0	x		3	
10?		0				
123	100	1,984126984	x		3	
124	100	4,873294347	x		3	
125		0				
126	1200	5,787037037		x	3	425
127	0	0	x		3	
128	100	19,84126984	x		3	
129	100	19,84126984	x		3	
130	0	0	x		3	
131	100	19,84126984	x		3	
132	100	19,84126984	x		3	
133		0				
134	1200	5,77700751		x	3	425
135	1200	5,767012687		x	3	425
136	0	0	x		3	
137	100	19,84126984	x		3	
138	100	19,84126984	x		3	
139	0	0	x		3	
140	100	19,84126984	x		3	
141	100	19,84126984	x		3	
142		0				
143	1200	5,77700751		x	3	425
144	1200	5,807200929		x	3	425
145	0	0	x		3	
146	100	18,51851852	x		3	
147	100	18,51851852	x		3	

Table O6: Zone Values First Floor continued

Room no.	Return air [m^3/h]	Return air [l/sm^2]	CAV	VAV	AHU
148	260	2,242926156	x		3
150		0			
149	970	2,203143454	x		5
151	400	6,944444444	x		4
152	60	2,109704641	x		4
153	130	4,571026723	x		4
154	60	2,083333333	x		4
155	2270	6,906413533		x	4
156	260	4,659498208	x		4
157	500	8,903133903		x	4
158	1680	6,535947712		x	4
158a	500	7,467144564	(x)	x	4
159	5600	7,418004557		x	3
160	0	0	x		5
161	100	12,62626263	x		5
162	100	12,62626263	x		5
163	0	0	x		5
164	100	3,968253968	x		5
165	130	1,995089012	x		5
166	0	0	x		5
167	100	17,36111111	x		5
168	100	17,36111111	x		5
169	100	17,36111111	x		5
170	100	17,36111111	x		5
171	0	0	x		5
172	0	2,683843264	x		5
173	100	12,07729469	x		5
174	100	12,07729469	x		5
175	450	3,676470588		x	5
176	0	0	x		5
177	310	4,04277517		x	5
178	110	2,966558792	x		5
179	110	2,966558792	x		5
180	110	2,966558792	x		5
181	280	3,634475597	x		5
182	380	4,932502596	x		5
183	220	3,867791842		x	5
184	370	3,820735233		x	5
185 = 184a	100	2,750275028	x		5
187	350	2,387774594	x		5
188	200	6,858710562	x		5
189	1140	6,136950904		x	5
190	3000	3,156565657		x	3
191a	0	0	x		5
194	50	10,68376068	x		5
192	100	4,873294347	x		5
195	100	4,62962963	x		5
196	110	3,594771242	x		5
198	480	5,312084993		x	5
199	540	3,846153846		x	5

Table O7: Zone Values First Floor continued

Room values		Wing A	Wing B	Wing C
Room number	**Min. air [l/sm^2]**	**Furniture [m^2]**	**MET**	**CLO**
101		0.7388	1.3	0.85 ± 0.25
102			1.3	0.85 ± 0.25
103			1.3	0.85 ± 0.25
104	2,049575617	25.35	1.3	0.85 ± 0.25
105A	2,061248528	25.35	1.3	0.85 ± 0.25
105B	2,06855792		1.3	0.85 ± 0.25
106		0.7388	1.3	0.85 ± 0.25
107			1.3	0.85 ± 0.25
108			1.3	0.85 ± 0.25
109		15.6	1.3	0.85 ± 0.25
110	2,04248366	25.35	1.3	0.85 ± 0.25
111	2,046023493	25.35	1.3	0.85 ± 0.25
112		1.4776	1.3	0.85 ± 0.25
113			1.3	0.85 ± 0.25
114			1.3	0.85 ± 0.25
115			1.3	0.85 ± 0.25
116			1.3	0.85 ± 0.25
117			1.3	0.85 ± 0.25
118			1.3	0.85 ± 0.25
119	2,063908314	25.35	1.3	0.85 ± 0.25
120	1,012401924	9.36	1.3	0.85 ± 0.25
122		Std. Values	1.3	0.85 ± 0.25
10?			1.3	0.85 ± 0.25
10?			1.3	0.85 ± 0.25
123			1.3	0.85 ± 0.25
124		0.5888	1.3	0.85 ± 0.25
125		0	1.3	0.85 ± 0.25
126	2,049575617	25.35	1.3	0.85 ± 0.25
127		1.4776	1.3	0.85 ± 0.25
128			1.3	0.85 ± 0.25
129			1.3	0.85 ± 0.25
130			1.3	0.85 ± 0.25
131			1.3	0.85 ± 0.25
132			1.3	0.85 ± 0.25
133			1.3	0.85 ± 0.25
134	2,046023493	25.35	1.3	0.85 ± 0.25
135	2,04248366	25.35	1.3	0.85 ± 0.25
136		1.4776	1.3	0.85 ± 0.25
137			1.3	0.85 ± 0.25
138			1.3	0.85 ± 0.25
139			1.3	0.85 ± 0.25
140			1.3	0.85 ± 0.25
141			1.3	0.85 ± 0.25
142		-	1.3	0.85 ± 0.25
143	2,046023493	25.35	1.3	0.85 ± 0.25
144	2,056716996	25.35	1.3	0.85 ± 0.25
145		0.7388	1.3	0.85 ± 0.25
146		-	1.3	0.85 ± 0.25
147		-	1.3	0.85 ± 0.25

Table O8: Zone Values First Floor continued

Room number	Min. air [l/sm^2]	Furniture [m2]	MET	CLO
148		0	1.3	0.85 ± 0.25
150		0	1.3	0.85 ± 0.25
149		0	1.3	0.85 ± 0.25
151	9,027777778	4.815	2.4	0.85 ± 0.25
152		5.538	1.3	0.85 ± 0.25
153	4,571026723	2.45	1.3	0.85 ± 0.25
154		-	1.3	0.85 ± 0.25
155	2,038456858	34.349	2.4	0.85 ± 0.25
156		3.55	1.3	0.85 ± 0.25
157	8,903133903	5.965	1.3	0.85 ± 0.25
158	2,061935885	31.161	1.3	0.85 ± 0.25
158a	7,467144564	Std. Values	1.3	0.85 ± 0.25
159	1,986965506	73.08	1.3	0.85 ± 0.25
160		2.15	1.3	0.85 ± 0.25
161		-	1.3	0.85 ± 0.25
162		-	1.3	0.85 ± 0.25
163		0	1.3	0.85 ± 0.25
164		1.35	1.3	0.85 ± 0.25
165		-	1.3	0.85 ± 0.25
166		-	1.3	0.85 ± 0.25
167		-	1.3	0.85 ± 0.25
168		-	1.3	0.85 ± 0.25
169		-	1.3	0.85 ± 0.25
170		-	1.3	0.85 ± 0.25
171		-	1.3	0.85 ± 0.25
172		1.379	1.3	0.85 ± 0.25
173		-	1.3	0.85 ± 0.25
174		-	1.3	0.85 ± 0.25
175	2,04248366	12.84	1.3	0.85 ± 0.25
176		-	1.3	0.85 ± 0.25
177	2,086593636	4.16	1.3	0.85 ± 0.25
178		2.64	1.3	0.85 ± 0.25
179		2.64	1.3	0.85 ± 0.25
180		2.64	1.3	0.85 ± 0.25
181		4.4	1.3	0.85 ± 0.25
182		8.04	1.3	0.85 ± 0.25
183	2,109704641	5.76	1.3	0.85 ± 0.25
184	2,065262288	10.08	1.3	0.85 ± 0.25
185 = 184a		2.52	1.3	0.85 ± 0.25
187		0	1.3	0.85 ± 0.25
188		0	1.3	0.85 ± 0.25
189	2,045650301	20.8	1.3	0.85 ± 0.25
190	2,025462963	23.4	1.3	0.85 ± 0.25
191a		0	1.3	0.85 ± 0.25
194		0	1.3	0.85 ± 0.25
192		0.5888	1.3	0.85 ± 0.25
195		Std. Values	1.3	0.85 ± 0.25
196		2.52	1.3	0.85 ± 0.25
198	2,213368747	7.182	1.3	0.85 ± 0.25
199	2,136752137	12.84	1.3	0.85 ± 0.25

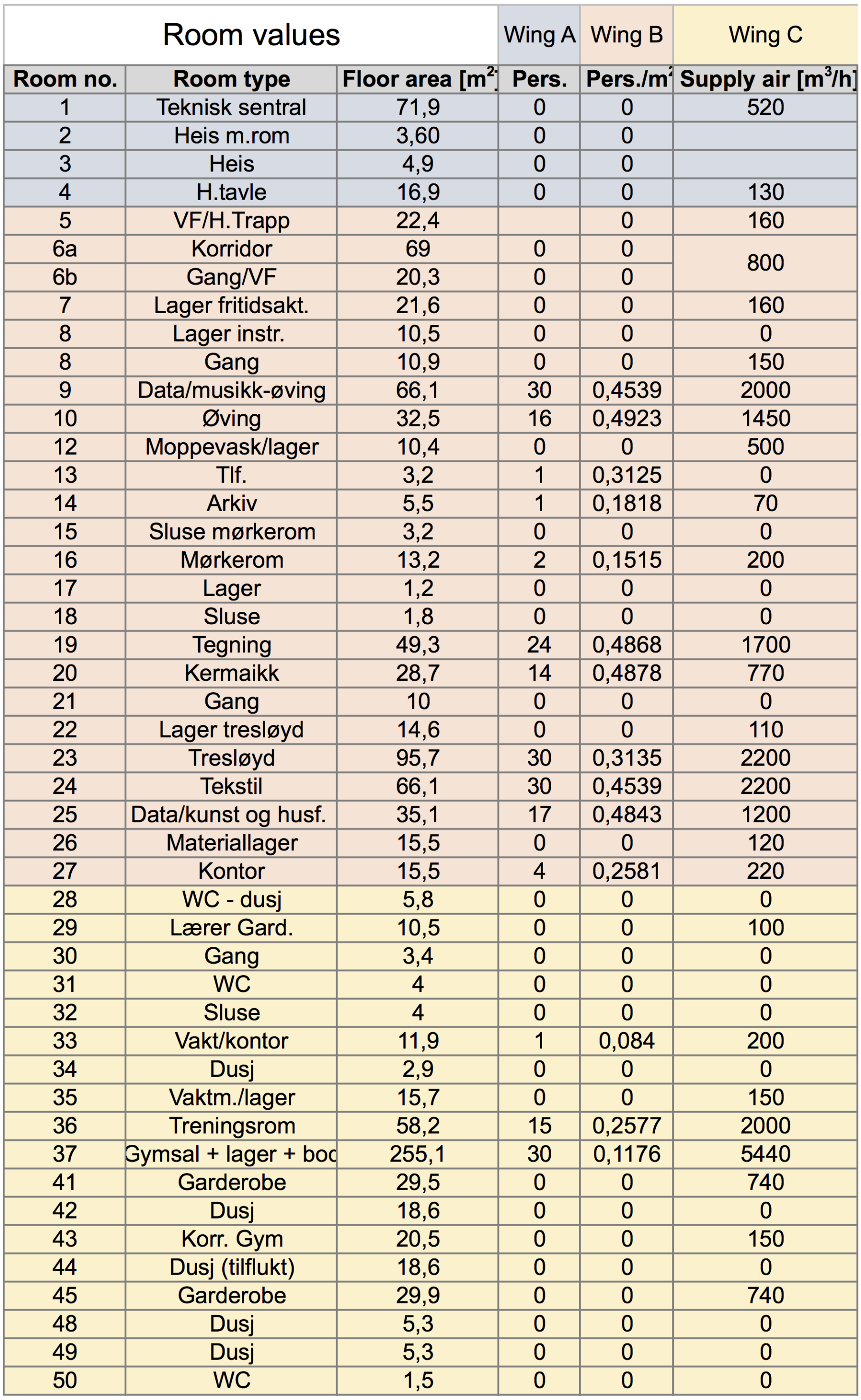
Table O9: Zone Values First Floor continued

Room values	Wing A	Wing B Wing C
Room number	**Daylight min. [Lux]**	**Daylight max. [Lux]**
101	50	100
102	50	100
103	50	100
104	300	750
105A	300	750
105B	300	750
106	50	100
107	50	100
108	50	100
109	300	750
110	300	750
111	300	750
112	50	100
113	50	100
114	50	100
115	75	150
116	50	100
117	50	100
118	50	100
119	50	100
120	300	750
122	75	150
10?	75	150
10?	75	150
123	75	150
124	500	100
125	75	150
126	300	750
127	50	100
128	50	100
129	50	100
130	50	100
131	50	100
132	50	100
133	75	150
134	300	750
135	300	750
136	50	100
137	50	100
138	50	100
139	50	100
140	50	100
141	50	100
142	300	750
143	300	750
144	300	750
145	50	100
146	50	100
147	50	100

Table O10: Zone Values First Floor continued

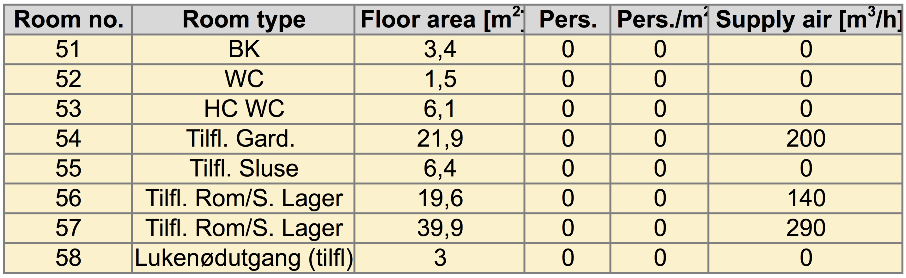
Room number	Daylight min. [Lux]	Daylight max. [Lux]
148	75	150
150	75	150
149	75	150
151	150	300
152	15	30
153	300	750
154	15	30
155	300	750
156	300	750
157	15	30
158	300	750
158a	50	100
159	150	300
160	50	100
161	50	100
162	50	100
163	75	150
164	300	750
165	50	100
166	50	100
167	50	100
168	50	100
169	50	100
170	50	100
171	50	100
172	50	100
173	50	100
174	50	100
175	300	750
176	50	100
177	300	750
178	300	750
179	300	750
180	300	750
181	300	750
182	300	750
183	300	750
184	300	750
185 = 184a	300	750
187	75	150
188	75	150
189	150	300
190	300	750
191a	75	150
194	75	150
192	50	100
195	50	100
196	300	750
198	300	750
199	300	750

Table O11: Zone Values Ground Floor



Room values			Wing A	Wing B	Wing C
Room no.	Room type	Floor area [m^2	Pers.	Pers./m^2	Supply air [m^3/h]
1	Teknisk sentral	71,9	0	0	520
2	Heis m.rom	3,60	0	0	
3	Heis	4,9	0	0	
4	H.tavle	16,9	0	0	130
5	VF/H.Trapp	22,4		0	160
6a	Korridor	69	0	0	800
6b	Gang/VF	20,3	0	0	
7	Lager fritidsakt.	21,6	0	0	160
8	Lager instr.	10,5	0	0	0
8	Gang	10,9	0	0	150
9	Data/musikk-øving	66,1	30	0,4539	2000
10	Øving	32,5	16	0,4923	1450
12	Moppevask/lager	10,4	0	0	500
13	Tlf.	3,2	1	0,3125	0
14	Arkiv	5,5	1	0,1818	70
15	Sluse mørkerom	3,2	0	0	0
16	Mørkerom	13,2	2	0,1515	200
17	Lager	1,2	0	0	0
18	Sluse	1,8	0	0	0
19	Tegning	49,3	24	0,4868	1700
20	Kermaikk	28,7	14	0,4878	770
21	Gang	10	0	0	0
22	Lager tresløyd	14,6	0	0	110
23	Tresløyd	95,7	30	0,3135	2200
24	Tekstil	66,1	30	0,4539	2200
25	Data/kunst og husf.	35,1	17	0,4843	1200
26	Materiallager	15,5	0	0	120
27	Kontor	15,5	4	0,2581	220
28	WC - dusj	5,8	0	0	0
29	Lærer Gard.	10,5	0	0	100
30	Gang	3,4	0	0	0
31	WC	4	0	0	0
32	Sluse	4	0	0	0
33	Vakt/kontor	11,9	1	0,084	200
34	Dusj	2,9	0	0	0
35	Vaktm./lager	15,7	0	0	150
36	Treningsrom	58,2	15	0,2577	2000
37	Gymsal + lager + boc	255,1	30	0,1176	5440
41	Garderobe	29,5	0	0	740
42	Dusj	18,6	0	0	0
43	Korr. Gym	20,5	0	0	150
44	Dusj (tilflukt)	18,6	0	0	0
45	Garderobe	29,9	0	0	740
48	Dusj	5,3	0	0	0
49	Dusj	5,3	0	0	0
50	WC	1,5	0	0	0

Table O12: Zone Values Ground Floor continued

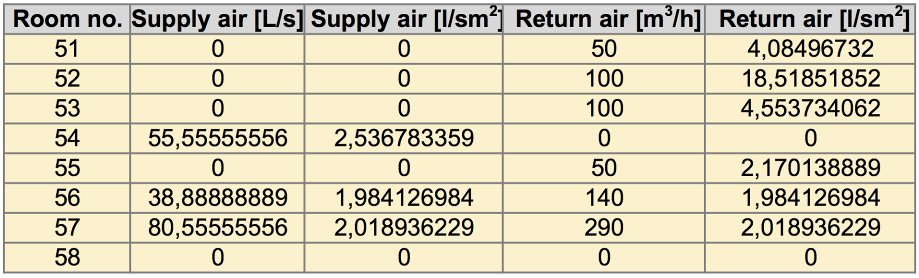


Room no.	Room type	Floor area [m^2	Pers.	Pers./m^2	Supply air [m^3/h]
51	BK	3,4	0	0	0
52	WC	1,5	0	0	0
53	HC WC	6,1	0	0	0
54	Tilfl. Gard.	21,9	0	0	200
55	Tilfl. Sluse	6,4	0	0	0
56	Tilfl. Rom/S. Lager	19,6	0	0	140
57	Tilfl. Rom/S. Lager	39,9	0	0	290
58	Lukenødutgang (tilfl)	3	0	0	0

Table O13: Zone Values Ground Floor continued

Room values		Wing A	Wing B	Wing C
Room no.	**Supply air [L/s]**	**Supply air [l/sm^2]**	**Return air [m^3/h]**	**Return air [l/sm^2]**
1	144,4444444	1,85565833	520	1,85565833
2	0	0		0
3	0	0		0
4	36,11111111	2,136752137	130	2,136752137
5	44,44444444	2,32528909	0	1,675884029
6a	222,2222222	3,220611916	650	2,616747182
6b	0	0		0
7	44,44444444	1,384562132	160	2,076843198
8	0	0	80	2,116402116
8	41,66666667	3,822629969	0	0
9	555,5555556	8,404773912	2000	8,404773912
10	402,7777778	12,39316239	1450	12,39316239
12	138,8888889	5,555555556	500	6,060606061
13	0	0	70	6,076388889
14	19,44444444	3,535353535	70	3,535353535
15	0	0	100	8,680555556
16	55,55555556	4,208754209	0	0
17	0	0	100	23,14814815
18	0	0	0	0
19	472,2222222	9,578544061	1700	9,578544061
20	213,8888889	7,452574526	770	7,452574526
21	0	0	150	4,166666667
22	30,55555556	2,092846271	110	2,092846271
23	611,1111111	6,385696041	2200	6,385696041
24	611,1111111	9,245251303	2200	9,245251303
25	333,3333333	9,496676163	1200	9,496676163
26	33,33333333	2,150537634	120	2,150537634
27	61,11111111	3,94265233	220	3,94265233
28	0	1,04427736	100	4,69924812
29	27,77777778	2,645502646	0	0
30	0	0	150	12,25490196
31	0	0	100	6,944444444
32	0	0	0	0
33	55,55555556	3,494060098	0	0
34	0	0	100	9,578544061
35	41,66666667	2,653927813	0	0
36	555,5555556	9,545628102	2000	9,545628102
37	1511,111111	5,923602944	5440	5,923602944
41	205,5555556	6,967984934	0	0
42	0	0	540	8,064516129
43	41,66666667	2,032520325	150	2,032520325
44	0	0	540	8,064516129
45	205,5555556	6,874767744	0	0
48	0	0	100	5,241090147
49	0	0	100	5,241090147
50	0	0	100	18,51851852

Table O14: Zone Values Ground Floor continued



Room no.	Supply air [L/s]	Supply air [l/sm^2]	Return air [m^3/h]	Return air [l/sm^2]
51	0	0	50	4,08496732
52	0	0	100	18,51851852
53	0	0	100	4,553734062
54	55,55555556	2,536783359	0	0
55	0	0	50	2,170138889
56	38,88888889	1,984126984	140	1,984126984
57	80,55555556	2,018936229	290	2,018936229
58	0	0	0	0

Table O15: Zone Values Ground Floor continued

Room values			Wing A	Wing B	Wing C
Room no.	**CAV**	**VAV**	**AHU**	**Min. air [m^3/h]**	**Min. air [l/sm^2]**
1	x		1		
2					
3					
4	x		1		
5	x		1		
6a	x		1		
6b	x		1		
7	x		1		
8	x		1		
8	x		1		
9		x	1	500	2,101193478
10		x	1	250	2,136752137
12	x		1		
13	x		1		
14	x		1		
15	x		1		
16	x		1		
17	x		1		
18	x		1		
19		x	1	750	4,225828262
20		x	2	500	4,839334108
21	x		1		
22	x		2		
23		x	2	700	2,031812377
24		x	1	1000	4,202386956
25		x	1	530	4,194365305
26	x		1		
27		x	1	220	3,94265233
28	x		6		
29	x		6		
30	x		6		
31	x		6		
32	x		6		
33	x		6		
34	x		6		
35	x		6		
36		x	6	450	2,147766323
37		x	6	1840	2,003571584
41	x		2		
42	x		2		
43	x		2		
44	x		2		
45	x		2		
48	x		2		
49	x		2		
50	x		2		

Table O16: Zone Values Ground Floor continued

Room no.	CAV	VAV	andling	Min. air [m^3/h]	Min. air [l/sm^2]
51	x		2		
52	x		2		
53	x		2		
54	x		2		
55	x		2		
56	x		2		
57	x		2		
58	x		2		

Table O17: Zone Values Ground Floor continued

Room values			Wing A	Wing B	Wing C
Room no	**Furniture [m^2]**	**MET**	**CLO**	**Daylight min. [Lux]**	**Daylight max. [Lux]**
1	4.41	1.3	0.85 ± 0.25	75	150
2		1.3	0.85 ± 0.25	75	150
3		1.3	0.85 ± 0.25	75	150
4		1.3	0.85 ± 0.25	75	150
5	0	1.3	0.85 ± 0.25	75	150
6a		1.3	0.85 ± 0.25	75	150
6b		1.3	0.85 ± 0.25	75	150
7	13.44	1.3	0.85 ± 0.25	50	100
8		1.3	0.85 ± 0.25	50	100
8	-	1.3	0.85 ± 0.25	75	150
9	44.753	1.3	0.85 ± 0.25	300	750
10	12.48	1.3	0.85 ± 0.25	300	750
12	13.08	1.3	0.85 ± 0.25	50	100
13		1.3	0.85 ± 0.25	50	100
14		1.3	0.85 ± 0.25	50	100
15		1.3	0.85 ± 0.25	50	100
16		1.3	0.85 ± 0.25	50	100
17		1.3	0.85 ± 0.25	50	100
18		1.3	0.85 ± 0.25	50	100
19	26.22	1.3	0.85 ± 0.25	500	1000
20	15.44	1.3	0.85 ± 0.25	300	750
21	-	1.3	0.85 ± 0.25	75	150
22	4.5	1.3	0.85 ± 0.25	50	100
23	44.753	1.3	0.85 ± 0.25	300	750
24	29.7	1.3	0.85 ± 0.25	500	1000
25	14.86	1.3	0.85 ± 0.25	500	1000
26	4.41	1.3	0.85 ± 0.25	50	100
27	3.55	1.3	0.85 ± 0.25	300	750
28	7.5616	1.3	0.85 ± 0.25	50	100
29		1.3	0.85 ± 0.25	50	100
30		1.3	0.85 ± 0.25	50	100
31		1.3	0.85 ± 0.25	50	100
32	2.64	1.3	0.85 ± 0.25	300	750
33		1.3	0.85 ± 0.25	300	750
34	-	1.3	0.85 ± 0.25	50	100
35	6.4	1.3	0.85 ± 0.25	50	100
36	10	3.5	0.5 ± 0.25	150	300
37	11	5	0.5 ± 0.26	150	300
41	10	1.3	0.85 ± 0.25	50	100
42		1.3	0.85 ± 0.25	50	100
43	0	1.3	0.85 ± 0.25	50	100
44	-	1.3	0.85 ± 0.25	50	100
45	-	1.3	0.85 ± 0.25	50	100
48	-	1.3	0.85 ± 0.25	50	100
49	-	1.3	0.85 ± 0.25	50	100
50	-	1.3	0.85 ± 0.25	50	100

Table O18: Zone Values Ground Floor continued

Room no	Furniture [m^2]	MET	CLO	Daylight min. [Lux]	Daylight max. [Lux]
51	-	1.3	0.85 ± 0.25	50	100
52	-	1.3	0.85 ± 0.25	50	100
53	-	1.3	0.85 ± 0.25	50	100
54	-	1.3	0.85 ± 0.25	50	100
55	-	1.3	0.85 ± 0.25	50	100
56	12.425	1.3	0.85 ± 0.25	50	100
57		1.3	0.85 ± 0.25	50	100
58		1.3	0.85 ± 0.25	50	100

Table O19: Zone Values Roof Floor

Room values				Wing A	WingC
Room no.	**Room type**	**Supply air [m^3/h]**	**Return air [m^3/h]**	**CAV**	**AHU**
201	Tekn. Rom	1100	1200	x	3
202	Tekn. Rom	680	680	x	6
Room no.	**Furniture [m^2]**	**Daylight min. [Lux]**	**Daylight max. [Lux]**		
201	100	75	150		
202	100	75	150		

Appendix P - Time schedules for specific rooms

Table P20: Time schedules for specific rooms

Schedules

Room	Zone	Monday	Tuesday	Wednesday	Thursday	Friday	Sat.-Sun. + holidays	All days (avg.)
Classroom 1	119	10-11.30, 12-13.30	8-11.30, 12-13	9-11.30, 12-15	10-11.30, 13.30-14.30	10-11.30, 12-15	-	9-11.30, 12-14.30
Classroom 2	111	9-11.30, 12-13	8-11.30, 12-13.30	9-11.30, 12-15	10.30-11.30, 12-14.30	10-10.30, 12-13	-	9-11.30, 12-13.30
Classroom 3	110	9-11.30	9-11.30, 12-13.30	8-10, 10.30-11.30	13.30-14.30	13-30	-	9-11.30
Classroom 4	105	8-11.30, 12-12.30	10-11.30, 12-15	8-10, 14-15.30	-	-	-	9-11.30
Classroom 5	104	8-11.30	8-11.30, 12-13.30	9-11.30, 12-15	9-10, 12-14.30	10-11.30	-	9-11.30, 12-13.30
Classroom 6	144	8-11.30, 12-12.30	9-10.30, 12-15	9-11.30	10-11.30	8-11.30, 12-12.30	-	9-11.30, 12-12.30
Classroom 7	143	8-11.30, 12-13.30	10-11.30, 12-15	8-10, 12-13.30	11-11.30, 12-13.30	10.30-11.30, 12-14.30	-	9-11.30, 12-13.30
Classroom 8	135	8-10.30	9-11.30, 12-15	8-9, 12-14.30	9-11.30, 12-13.30	8-11.30, 13.30-15	-	9-11.30, 12-13.30
Classroom 9	134	8-9, 10-11.30	8-11.30, 12-12.30	10-11.30, 12-15	9-11.30, 12-13.30	8-11.30	-	8-11.30, 12-12.30
Computerlab 10	126	-	-	-	-	-	-	10-11.30, 12-13.30
Gym	37	9-10.30, 12-13.30	9-10.30, 13.30-15	8-11.30, 12-13.30	10-11.30, 12-13.30	8-11.30, 12-15	-	9-11.30, 12-13.30
Arts and Crafts	19,24,25	8-10.30, 12-13.30	8-10.30, 13-15.30	10-11.30, 13-14.30	9-10.30, 12-13.30	9-10.30, 13-15-30	-	9-11.30, 12-13.30
Food and Health	155	10.30-11.30, 12-13.30	-	9-11.30, 12-14.30	8-10.30, 12-14.30	8-10.30	-	9-11.30, 12-12.30
Lab	158	10-11, 13-13.30	8-10.30, 13-13.30, 14.30-15.30	8-9, 12-13.30	8-9, 14-14.30	8-10, 11-11.30, 12-15	-	10-11.30, 12-13.30
Group	177	9-10, 12-12.30	12.30-13.30	12-13	-	11-11.30, 12-13.30	-	12-13
Musicroom	9	10.30-11.30	9-9.30, 14-1 5.30	9-10, 12-12.30	8-9, 10-10.30, 13.30-14.30	8-10, 11-11.30, 12-15	-	9-11.30
Bandroom	10	10.30-11.30	9-10	9-10, 12-13	8-9, 10-10.30, 13.30-14.30	8-10, 10.30-11, 12-15	-	9-11.30