NTNU – Trondheim
Norwegian University of
Science and Technology

Simulation of indoor climate in ZEB in relation to heating and cooling system

Hans-Martin Midtbust

Master of Energy Use and Energy Planning
Submission date: September 2014
Supervisor: Hans Martin Mathisen, EPT

Norwegian University of Science and Technology
Department of Energy and Process Engineering

NTNU

Norwegian University
of Science and Technology

Department of Energy
and Process Engineering

EPT-M-2014-72

MASTER THESIS

for

Student Hans-Martin Midtbust

Spring 2014

Simulation of thermal indoor climate in a ZEB pilot building

Simulering av termisk inneklima i en ZEB pilotbygning

Background and objective

One efficient action to meet the climate change is to reduce energy use in the building sector. In zero emission buildings local renewable energy sources is used to produce heat and/or electricity to cover up for the buildings consumption and, for the most ambitious, emissions related to construction and production of construction materials.

The Research Centre on Zero Emission Buildings (ZEB) is an ongoing activity managed by NTNU and SINTEF with the objective to develop competitive products and solutions for existing and new buildings, which will lead to buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. The Centre encompasses both residential and commercial buildings, as well as public buildings.

A part of the research is done on so-called pilot buildings. Powerhouse Kjørbo in Bærum is an older office building that are renovated to become a zero emissions building.

Several new solutions for energy supply and ventilation are implemented at Kjørbo, e.g.:
- Low-pressure ventilation with very low specific fan power (SFP) and high heat recovery, - Central radiator heating without perimeter heating in office cells.
- Geothermal heat pump for heating with use of wells for moderate cooling in summer.
- PV systems.
- The building is well instrumented down to the particular energy purpose level.

One important issue are if these systems manage to maintain thermal comfort in all rooms of the building.

The objective of the thesis is to study how the heating, cooling and ventilation system influence on the temperature distribution between different neighboring zones/rooms inside the building. For calculation of thermal comfort and other relevant parameters for different occupancy and outdoor conditions, the student will preferably use the simulation tool IDA ICE. The results should be used to verify if the building satisfies requirements for indoor climate.

The thesis should be written in English.

The following tasks are to be considered:

1. Short description and comparison of relevant tools for simulating temperature distribution in buildings
2. Models of air flows through open doors
3. Description of different occupancies and internal/external loads to be used in the simulations
4. Implementing the building in IDA ICE
5. Simulations for the different conditions
6. Comparing results against standards and requirement for indoor climate

-- " --

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 2014

Olav Bolland
Department Head

Hans Martin Mathisen
Academic Supervisor

Research Advisor:
Laurent Georges

Preface

This master thesis has been developed as part of the civil engineering program in the Energy and Environment at the Department of Energy and Process Engineering at the Norwegian University of Science and Technology, NTNU in spring and summer of 2014.

The idea for the subject for this thesis was developed at the end of my project thesis in January 2014. The final formulation of the thesis was developed during April 2014, where I had the opportunity to influence the objective for the thesis.

The master thesis was carried out with the purpose of examining the temperature distribution from zones with radiator heating to zones without radiator heating. The simulation program IDA ICE was utilized in this examination.

I would like to thank my academic supervisor Hans Martin Mathisen (NTNU) for good help and guidance in the development of this thesis. I would also thank my research advisor Laurent Georges (NTNU) for help with the models for air flows, Jörgen Eriksson (EQUA) for technical support in IDA ICE and Helge Koppang (Skanska) for access to drawings of Powerhouse Kjørbo.

Trondheim 11.09.2014 Hans-Martin Midtbust

Place and date Hans-Martin Midtbust

Abstract

The purpose of this thesis was to study how the heating-, cooling- and ventilation systems affected the temperature distribution between the different zones in a building. Powerhouse Kjørbo is equipped with central radiator heating without radiators in the office cells. Temperature distribution in the office cells is therefore dependent on air flows through open doors and supply air from the ventilation.

Evaluations of temperatures and thermal indoor climate for the office cells would have to be conducted, in order to examine if the temperature distribution was sufficient. A simulation model was therefore created.

A Simulation model in IDA ICE was built as similar as possible compared to the actual building. Evaluations of the thermal indoor climate were done by analyzing the simulation results from IDA ICE. The simulations were performed with the aim of examining how different actions affect the temperature and thermal indoor climate in the office cells.

The winter simulations showed that the office cells achieved low temperatures and a bad thermal indoor climate by only keeping the doors open outside the residence time. This meant that the temperature distribution through the doors was insufficient. By performing actions like increasing the set point for heating and supplying hot ventilation air, good indoor temperatures and a good thermal indoor climate were achieved.

The summer simulations showed that the operative temperature exceeded 26 °C, when no actions to prevent high indoor temperatures were performed. Further, the simulation results showed that external window shading and increased supply of ventilation air was effective for preventing high indoor temperatures. Good results for temperatures and thermal indoor climate were achieved, when these actions were included in the simulation model.

The results from the simulations showed that a good thermal indoor climate can be achieved in the office cells, both summer and winter, if the correct actions are implemented.

Sammendrag

Formålet med denne masteroppgaven var å studere hvordan varme-, kjøle- og ventilasjonsystemene påvirket temperaturdistribusjonen mellom forskjellige soner i en bygning. Powerhouse Kjørbo er utstyrt med sentral radiator varme uten radiatorer i cellekontorene. Temperaturdistribusjonen til cellekontorene er derfor avhengig av luftstrømmer gjennom åpne dører og den tilførte ventilasjonsluften.

Evalueringer av temperaturer og termisk inneklima for cellekontorene måtte gjennomføres, for å undersøke om temperaturdistribusjonen var tilstrekkelig. En simuleringsmodell ble derfor laget.

Simuleringsmodellen i IDA ICE ble bygget så lik som mulig i forhold til det faktiske bygget. Evalueringer av termisk inneklima ble gjort ved analyseringer av simuleringsresultatene fra IDA ICE. Simuleringene ble utført med den hensikt av å undersøke hvordan ulike tiltak påvirker temperaturen og termisk inneklima i cellekontorene.

Vintersimuleringene viste at cellekontorene oppnådde lave temperaturer og et dårlig termisk inneklima ved å kun holde dørene åpne utenom brukstiden. Dette betydde at temperaturdistribusjonen gjennom dørene ikke var tilstrekkelig. Ved å utføre tiltak som å øke settpunkt for oppvarming og tilføre varm ventilasjonsluft om natten, kunne gode innetemperaturer og et godt termisk inneklima oppnås.

Sommersimuleringene viste at den operative temperaturen oversteg 26 °C, når ingen tiltak ble gjort for å forhindre høye innetemperaturer. Videre viste simuleringsresultatene at utvending solavskjerming og økt tilførsel av ventilasjonsluft hadde en god effekt for å forhindre høye temperaturer i bygningen. Det ble oppnådd gode resultater for temperaturer og termisk inneklima når disse tiltakene ble brukt i simuleringsmodellen.

Resultatene fra simuleringene viste at et godt termisk inneklima kan oppnås i cellekontorene, både sommer og vinter, hvis de rette tiltakene er iverksatt.

Table of Contents

1 Introduction

1.1 Background

One efficient action to meet the climate changes is to reduce energy use in the building sector. In zero emission buildings local renewable energy sources is used to produce heat and/or electricity to cover up for the buildings consumptions and, for the most ambitious, emissions related to construction and production of construction materials.

The Research Centre on Zero Emission Buildings (ZEB) is an ongoing activity managed by NTNU and SINTEF with the objective to develop competitive products and solutions for existing and new buildings, which will lead to buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. The Centre encompasses both residential and commercial buildings, as well as public buildings.

A part of the research is done on so-called pilot buildings. Powerhouse Kjørbo in Bærum is an older office building that is renovated to become a zero emissions building.

Several new solutions for energy supply and ventilation are implemented in Powerhouse Kjørbo. The building is equipped with radiator heating without perimeter heating in office cells.

Because of low ambient temperature during the winter in Norway, the standard has been to equip buildings with perimeter heating to prevent cold drafts from windows. However, the heating system at Powerhouse Kjørbo is based on central radiator heating without perimeter heating in open office landscapes and office cells.

Radiators are normally mounted on the wall under the windows to prevent cold drafts at low ambient temperatures. Because of stricter requirements in terms of insulation, thermal bridges and sealing in laws and regulations, the risk for cold drafts has been reduced. (NTNU SINTEF, 2007)

One important issue is if the technical systems manage to maintain a good thermal indoor climate in all rooms in the building, despite for the lack of perimeter heating.

1.2 Objective

The objective of the thesis is to study how the heating, cooling and ventilation system influence on the temperature distribution between different neighboring zones/rooms inside the building. The results shall be used to verify if the building satisfies the requirements for indoor climate.

1.3 Scope of the work

Chapter 2 describes the models used for air flows through open used in IDA ICE.

Chapter 3 discusses relevant simulation tools which can be used for simulating the temperature distribution in buildings. Simien and IDA ICE were the simulation tools which were given the most attention.

Chapter 4 describes the heating- and ventilation systems in the building.

Chapter 5 describes the requirements for the indoor climate.

Chapter 6 presents the key values used in the simulation model in IDA ICE. The full setup and procedures are presented in Attachment 1.

Chapter 7 presents the zones which were given the main focus in the evaluation of the thermal indoor climate.

Chapter 8 describes how the results from the simulations were used to evaluate the indoor climate.

The results from the various summer- and winter simulations are presented and discussed in chapter 9 and 10.

The thesis is summed up with a discussion and conclusion in chapter 11 and 12.

A proposal for further work is given in chapter 13

2 Models for air flows through open doors

The office cells and meeting rooms are not equipped with radiator heating. The radiators at Powerhouse Kjørbo are mounted in the open landscapes. The idea for heating the office cells and meeting rooms is to let heat in from the open landscapes and corridors.

Air flows through open doors were considered to be essential for the heat distribution to the office cells and meeting rooms. Various opening schedules for the doors were used in the simulations, to examine the effect open doors have on the heat distribution.

The model for air flows through large vertical openings used in IDA ICE, is the same model which is being used in the simulation program TRNSYS. TRNFLOW Manual defines equations used for determination of air flows through large vertical openings, such as doors.

"As the pressure difference between two air nodes with different air densities is a function of the height z, the flow in a large opening has a vertical velocity profile. A numerical integration of this profile results into an air mass flow for both flow directions." (TRNFLOW, 2009)

The equations for air flows through large vertical openings, given in the TRNFLOW Manual, are listed below.

$$\dot{m}_{12} = C_d \int_0^H \sqrt{2\rho(z) f_{12}(z)} \cdot w(z) \cdot dz$$

With:

$$f_{12}(z) = \begin{cases} \Delta p(z)\,, if\ \Delta p(z) > 0 \\ 0 \qquad\ , if\ \Delta p(z) < 0 \end{cases}$$

$$\dot{m}_{21} = C_d \int_0^H \sqrt{2\rho(z) f_{21}(z)} \cdot w(z) \cdot dz$$

With:

$$f_{21}(z) = \begin{cases} -\Delta p(z)\,, if\ \Delta p(z) < 0 \\ 0 \qquad\quad , if\ \Delta p(z) > 0 \end{cases}$$

Where:

C_d = Discharge coefficient [-]

w(z) = Width of the opening at the height z [m]

H = Height of the opening [m]

12 = Flow direction from air node 1 to 2

21 = Flow direction from air node 2 to 1

For rectangular openings, w(z) = W.

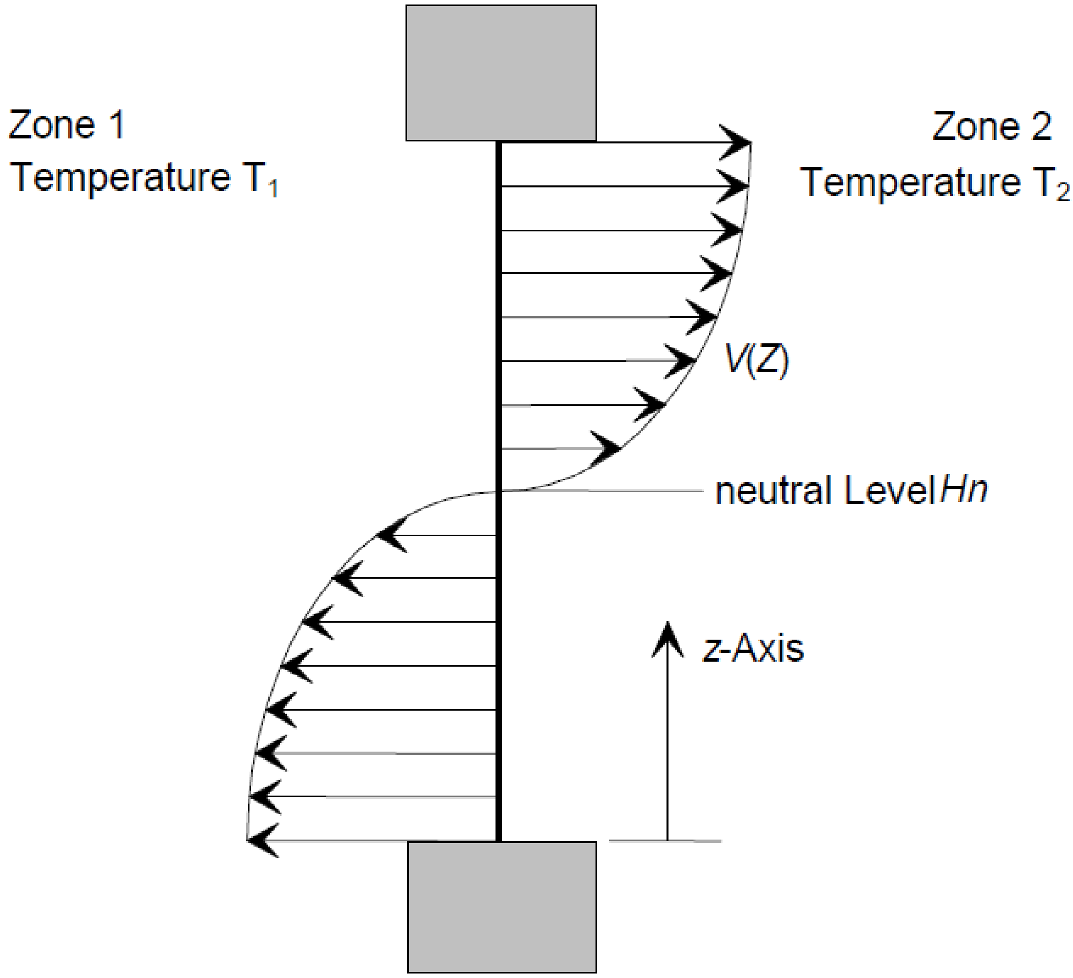


Figure 1: Velocity profiles in the large vertical opening. (TRNFLOW, 2009)

The discharge coefficient for openings is the ratio between the real air flow rate through the opening and the theoretical air flow rate, calculated with the Bernoulli equation. The discharge coefficient depends on the shape of the opening edges, the geometry of the opening and on the surrounding conditions on both sides of the opening. The discharge coefficient for doors between two air nodes (zones) depends on the ratio between the room height and the door height. The equations for determination of the discharge coefficient for internal doors between two zones are given in the TRNFLOW Manual as equation 16. (TRNFLOW, 2009)

For the simulation model in IDA ICE, the room height was set to 3.1 m (0.2 m slab dividing the floors), while the door height was set to 2.4 m. According to equation 16 in the TRNFLOW Manual, the discharge coefficient for the internal doors should be 0.405.

According to chapter 2.1.4 in Annex 20 written by the International Energy Agency (IEA), the discharge coefficient can vary from 0.25 to 0.75 for large openings. (International Energy Agency, 1992)

A discharge coefficient of 0.65 was used as standard for doors in IDA ICE. This value was applied to the internal doors in the simulation model.

The TRNFLOW Manual states that a discharge coefficient should be defined for completely opened and completely closed openings. (TRNFLOW, 2009)

Only one discharge coefficient can be applied to the doors in IDA ICE. This is shown in Figure 2.

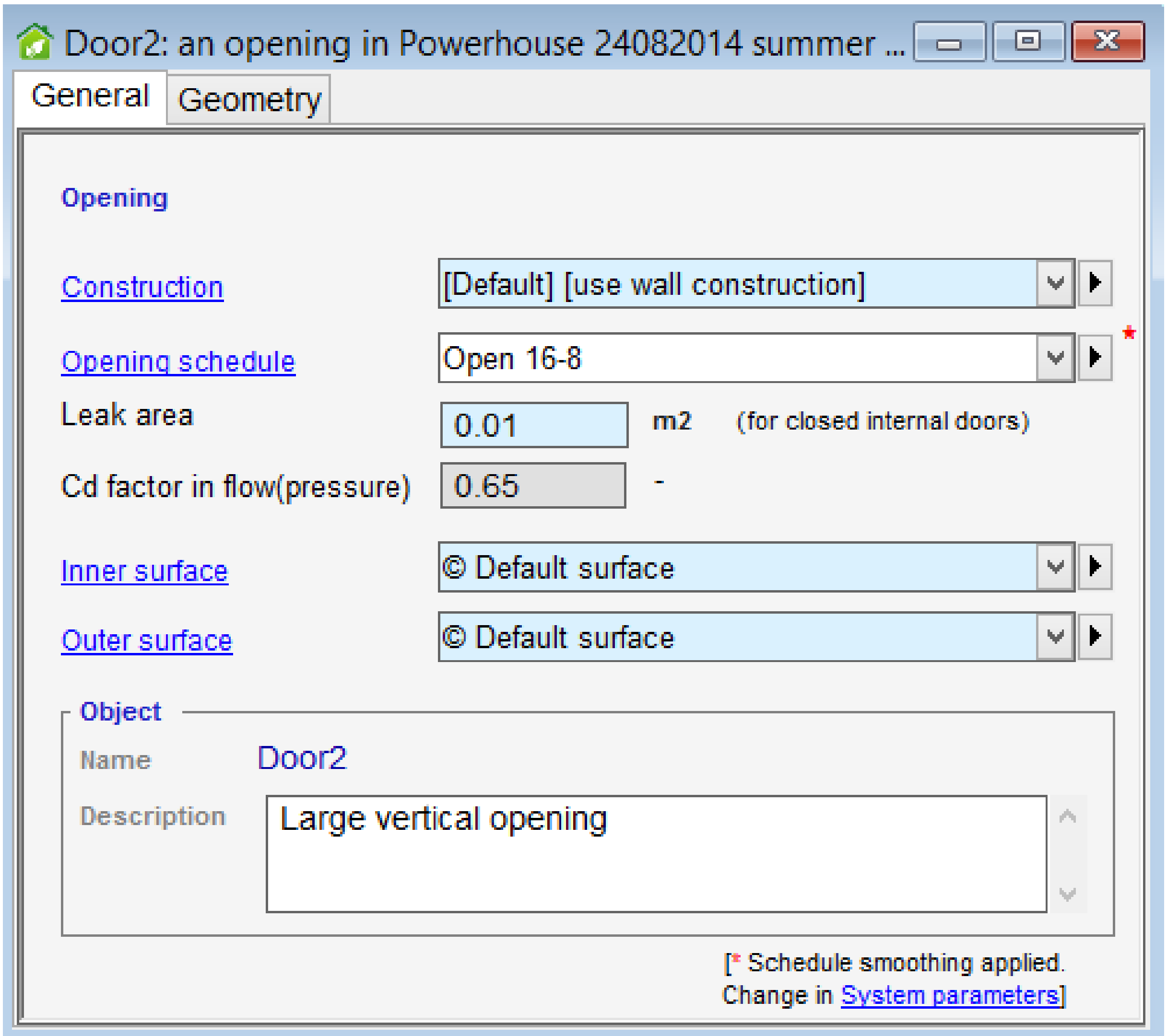


Figure 2: Design values for doors in IDA ICE. (Midtbust, 2014)

Displacement ventilation is the ventilation principle used at Powerhouse Kjørbo, where supply air is being supplied close to the floor. The office cells and meeting rooms are only equipped with air supply, which means there will be a constant flow of air going out of the office. This will influence on the natural air flow through the doors. This effect is shown in Figure 3, where the red arrow represents the supply air flowing out of the room. The constant flow of supply air flowing out of the room reduces the air flow going into the room, which causes a reduction in airborne heat supply to the room.

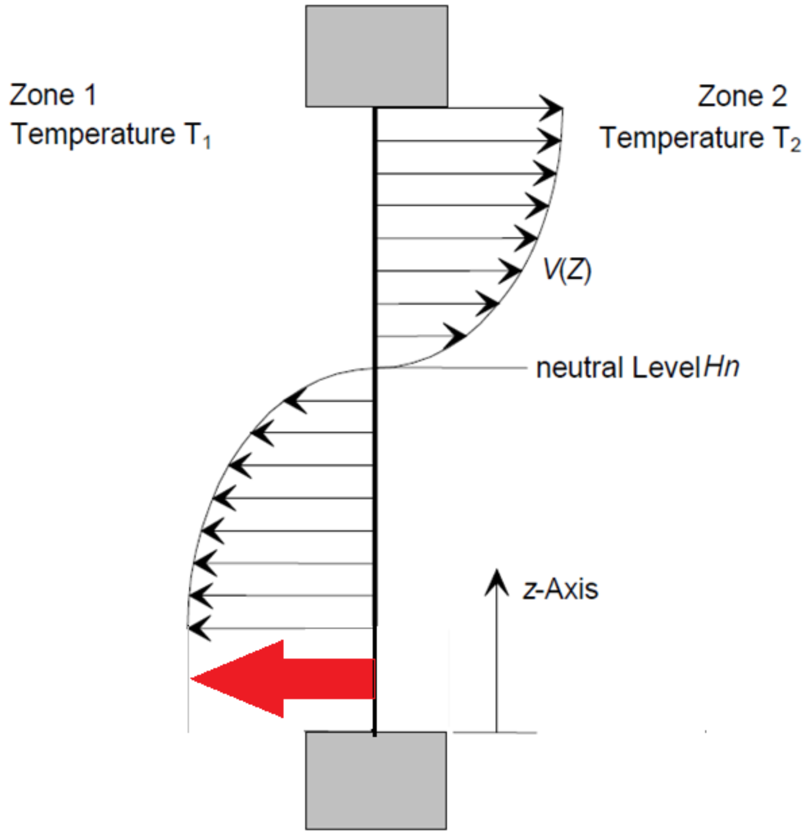


Figure 3: Air flow through open doors in meeting rooms and offices at Powerhouse Kjørbo (TRNFLOW, 2009) edited by Midtbust. H.M

The office doors was considered to be kept closed during residence time, which means that no airborne heat was supplied to the room during this period.

3 Tools for simulating the temperature distribution in buildings

This chapter will focus on describing and comparing relevant tools for simulating temperature distribution in buildings. The temperature distribution in office cells and meeting rooms at Powerhouse Kjørbo are dependent on air flows from one zone to another.

The Research Centre on Zero Emission Buildings (ZEB) has performed a survey of simulation tools used within SINTEF and NTNU. This survey led to a classification of the simulation tools based on program purposes and program possibilities.

Program name	Demand	System/ Components	Energy supply	CO2, Total energy use	LCA	Integration
USELOAD	x					x
eTransport				x		x
EnergyPlus	x	x	x	x		x
TRNSYS	x	x	x	possible to extend		x
Simulink/MATLAB	x	x	x	x	possible to extend	possible to extend
ESP-r	x	x	x	x		x
SIMIEN	x	x		x		
Modelica	Object-oriented, Equation-based					
ECOTECT	x				x	
GaBi 4					x	
COMSOL Multiphysics	x					x
VIP+	x	x		x		
PHPP	x					
IDA	x	x		x		x
SIMBAD	x	x	x	x	possible to extend	possible to extend
Bsim	x	x				
Apache	x	x	x			

Table 1: Classification of simulation programs surveyed by ZEB (Djuric et al., 2010)

Table 1 shows the purposes and the possibilities for the simulations programs.

Simien, IDA ICE, TRNSYS, EnergyPlus and ESP-r were considered to be the most relevant tools for simulating temperature distribution in buildings. According to Table 1 and **Error! Reference source not found.**, these programs are considered to have many of the same features.

According to the ZEB report, Simien is considered to be easy to learn and use, while EnergyPlus, TRNSYS and ESP-r may require some training and previous experience. (Djuric et al., 2010)

3.1 Simien

Simien is developed by Programbyggerne ANS and is a simulation program for calculating energy use, power demands and indoor climate in buildings. Simien uses dynamic simulations with 15 minute time steps, and can be used for designing buildings with several thermal zones. Simien is one of the most used energy simulation programs in Norway because it's well adapted to Norwegian conditions in terms of climate data, standards and check against Norwegian regulations. In addition to this, the program has a user friendly interface, which makes it easy to use. (Djuric et al., 2010)

Simien is validated in accordance with NS-EN 15265:2007, which is a standard method for evaluation of the accuracy for computer programs which calculates the energy demands in buildings. (Programbyggerne ANS)

Procedures for detailed modeling of natural and hybrid ventilation systems and advanced ventilation or lighting control algorithms, are not included in Simien. (Djuric et al., 2010)

The amount of different results which van be created in Simien, are relatively low compared to IDA ICE. The limited amount of input parameters prevents the program to create complex models.

The simulation model in Simien isn't created with shapes, just rectangular boxes where the floor area and room heights can be determined. The different zones are connected to each other by a determination of the shared floor-, ceiling- or wall area. In addition to this, the placing of doors, radiators etc. can't be placed exactly. The program is therefore unsuitable for simulations of buildings, where the shapes and placing of elements are important for the temperature distribution.

The air flows through doors are crucial for the temperature distribution in this thesis. When creating doors in Simien, the only options for the doors are the size and opening schedules. The door is placed somewhere on the wall between to connected zones.

Unlike IDA ICE, the simulation model in Simien can't be visualized in 3D. This may cause difficulties when creating a model consisting of many zones. The lack of visualization in 3D makes it difficult to maintain an overview of a model with many zones, and making it difficult for others to take over the simulation model.

3.2 IDA ICE

IDA Indoor Climate and Energy (IDA ICE) is a dynamic multi-zone simulation program, which can be used for examining the thermal indoor climate and energy consumptions in buildings. IDA ICE is developed by EQUA simulations AB. (Equa Simulation AB, 2014)

IDA ICE is validated in accordance with NS-EN 15265:2007. (Equa Simulation AB, 2010)

IDA ICE requires that a large amount of values must be added to the model. Despite this, the program provides a good overview of the model, by the use of tables for selected values and 3D visualization.

A simulation model in IDA ICE is created by drawing in 2D. The shapes of the rooms/zones are determined by the user, which means there is no issue of creating a complex model with many different zones. The simulation model can be created to be exactly like the actual building. Doors, radiators, windows etc. can be mounted exactly like they are in reality.

The accuracy of the simulation model is crucial, when the temperature distribution in some zones is dependent on air flow through open doors. The high accuracy in IDA ICE makes it more suitable for evaluation of the thermal indoor climate in complex simulation models, than for example Simien.

The models used for air flows through open doors in IDA ICE are the same as those used in TRNSYS.

3.3 TRNSYS

TRNSYS is a flexible graphically based software environment used to simulate the behavior of transient systems. The simulations in TRNSYS is most commonly used for evaluation of the performance of thermal and electrical energy systems, but can also be used to simulate other dynamic systems. TRNSYS contains different components, and it's up to the user to decide which components are included in a simulation model, and how they are connected to each other. The components can vary from a simple pump to a complex multi-zone building model. The user of the program can modify the components or write their own. (TRNSYS, 2014)

"As a weakness of TRNSYS, it can be mentioned that no assumptions about the building or system are made (although default information is provided). The user must have detailed information about the building and system and enter this information into the TRNSYS interface." (Djuric et al., 2010)

TRNSYS provides huge flexibility in creating a simulation model. Nevertheless, the program is considered to be complex in comparison to IDA ICE.

3.4 EnergyPlus

EnergyPlus is a building energy simulation program for simulation of heating, cooling, lighting, ventilation, other energy flows and water use. EnergyPlus simulations include sub-hourly time steps, modular systems and plant integrated with heat balance-based zone simulation, multi-zone air flow, thermal comfort, and photovoltaic systems. (U.S. Department of energy, 2013)

According to the report from Zeb, EnergyPlus requires some training and previous experience to use. The report furthers states, that EnergyPlus has several drawbacks. The program requires a huge amount of input and output parameters, has non-smooth models and has limited model flexibility of system control. (Djuric et al., 2010)

3.5 ESP-r

The program is an integrated modeling tool for simulating the thermal, visual and acoustic performance of buildings and the calculation of the energy and emissions associated with climate systems for indoor environment and building materials. The program includes tools for modeling heat, air, moisture and use of electric power in a user-controlled solution. (The Energy Systems Research Unit)

According to the report from ZEB, ESP-r is considered to require some training and previous experience. (Djuric et al., 2010)

4 Powerhouse Kjørbo

Powerhouse Kjørbo is a refurbishment project located in Bærum. The project consists of two older office buildings that are to be renovated to become zero emissions buildings. To obtain this, several new solutions for energy supply and ventilation are implemented in Powerhouse Kjørbo.

Figure 4: Powerhouse Kjørbo. (Snøhetta, 2014)

The systems that directly have an influence on the thermal indoor climate are the ventilation- and heating system.

The two buildings are called building 4 and building 5. Building 4 consists of four floors above ground, while building 5 consists of three floors above ground. The basements for the two buildings are not considered to be a part of the simulations.

4.1 Ventilation system

Powerhouse Kjørbo is implemented with a low-pressure ventilation system with very low specific fan power (SFP) and high heat recovery. This is obtained by transporting the supplied and extracted air through oversized shafts and staircases shown in Figure 5.

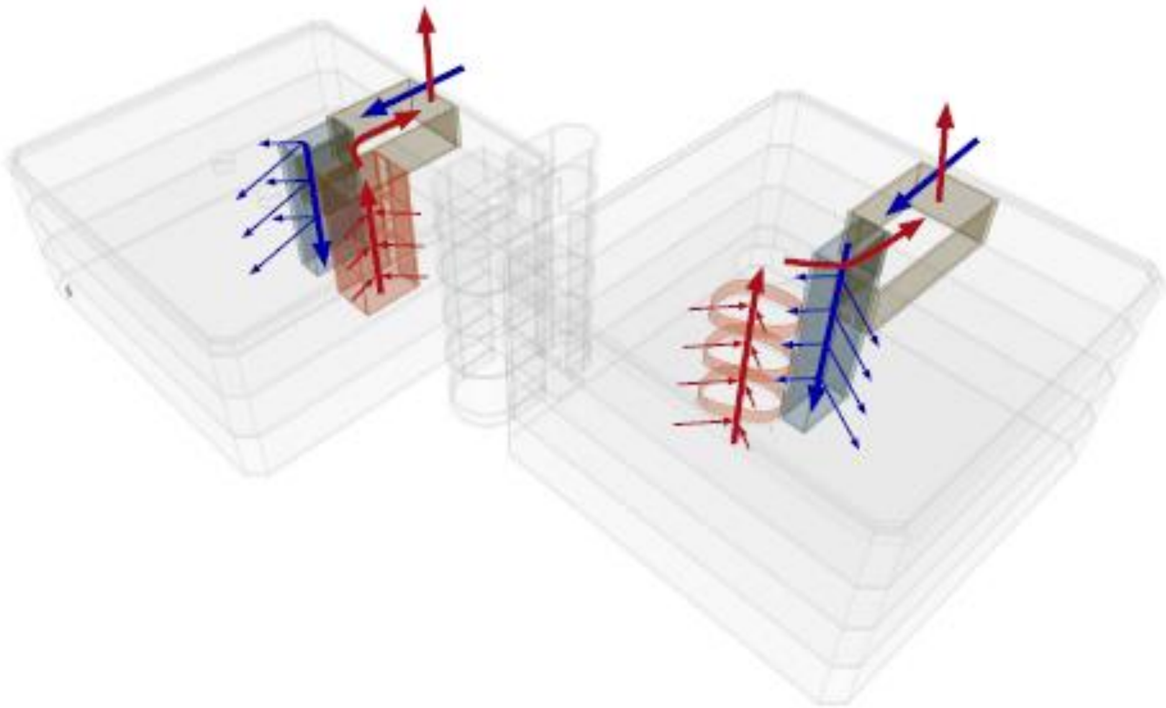


Figure 5: Main flow routes for the supplied and extracted air. (Powerhouse Alliansen, 2012)

The ventilation principle at Powerhouse Kjørbo is based on displacement ventilation for both the office cells and the open landscapes. The office cells are based on constant air volume (CAV), while open landscapes and larger meeting rooms are based on variable air volume (VAV).

Offices and meeting rooms are only equipped with supply air. The idea is that the extract air shall flow from these zones to zones with lower requirements to air quality, such as the corridors. (Powerhouse Alliansen, 2012)

Rooms, such as toilets and copy rooms are only equipped exhaust air diffusers.

The working spaces are placed near the façade, resulting in that the users have an opportunity to control the local indoor environment by using window ventilation and solar shading. (Powerhouse Alliansen, 2012)

Figure 6 shows how the air is supplied into the open landscapes. The supply air diffusers are placed inside the walls.

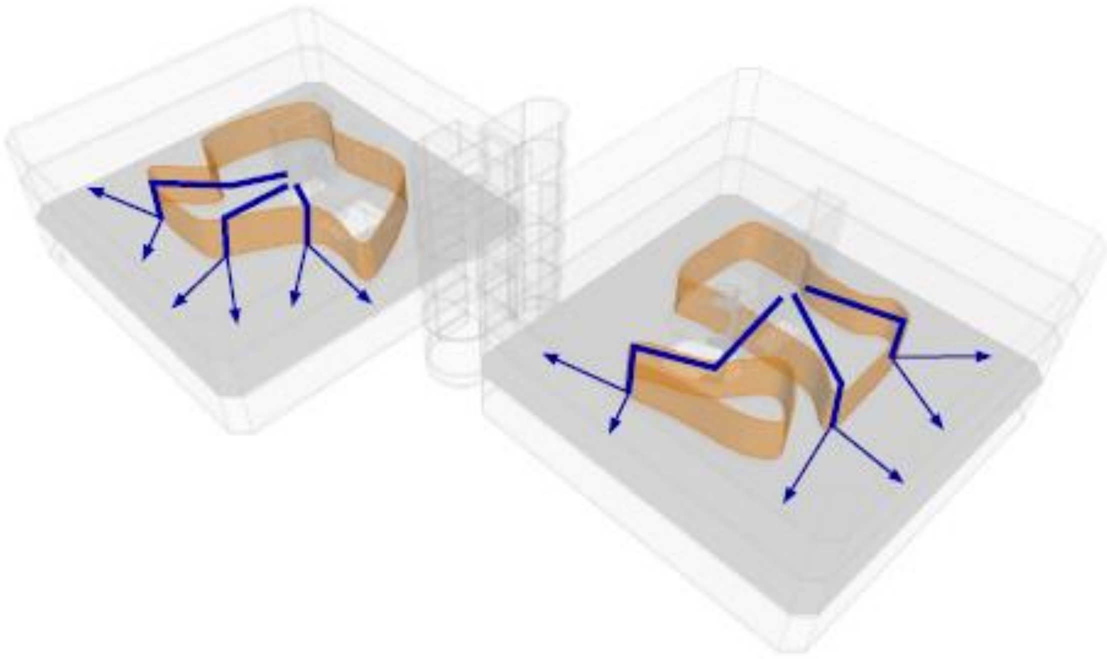


Figure 6: Air supply in open landscapes. (Powerhouse Alliansen, 2012)

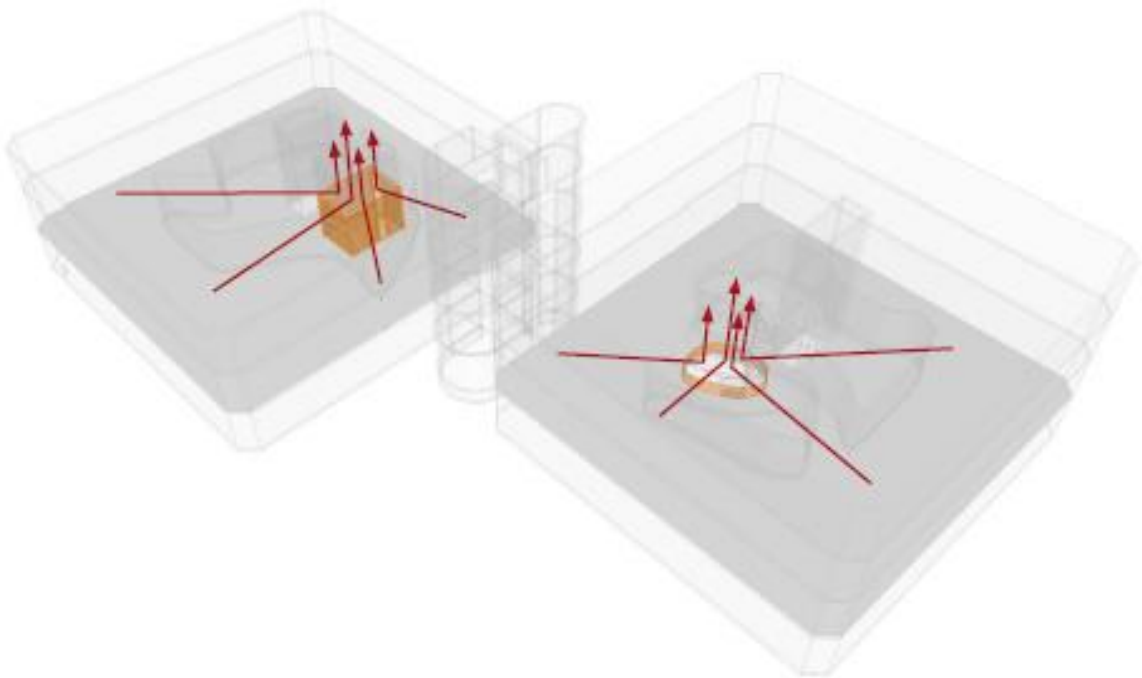


Figure 7: Exhaust ventilation through staircases. (Powerhouse Alliansen, 2012)

4.2 Heating system

Because of low ambient temperature during the winter in Norway, the standard has been to equip buildings with perimeter heating to prevent cold drafts from windows. However, the heating system at Powerhouse Kjørbo is based on central radiator heating without perimeter heating in open office landscapes and office cells.

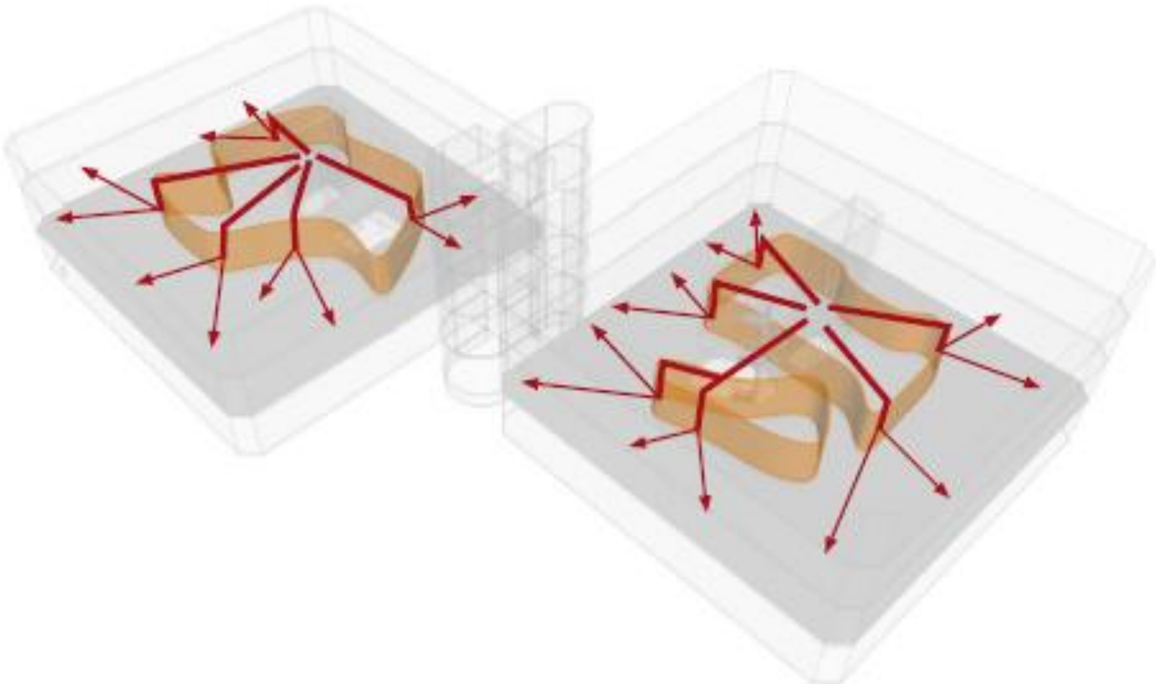


Figure 8: Radiators integrated in the walls. (Powerhouse Alliansen, 2012)

Radiators are normally mounted on the wall under the windows to prevent cold drafts at low ambient temperatures. Because of stricter requirements in terms of insulation, thermal bridges and sealing in laws and regulations, the risk for cold drafts has been reduced. (NTNU SINTEF, 2007)

5 Requirements for indoor climate

The Norwegian standard NS-EN 15251:2007 will be utilized to determine the indoor environmental input parameters in IDA ICE. This standard regards the indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal indoor climate, lighting and acoustics.

5.1 Criteria for thermal indoor climate

According to the feasibility study for Powerhouse Kjørbo, the operative temperature generally should satisfy the requirements of category 2 set out in Annex A.2 in NS-EN 15251:2007. Rooms with limited residence time, such as storage rooms and toilets, the operative temperature should satisfy the requirements of category 3. (Powerhouse Alliansen, 2012)

The annual mean temperature for Fornebu, which is located close to Powerhouse Kjørbo, is 5.9 °C. (Metereologisk institutt, 2013)

Annex A.2 in NS-EN 15251:2007 states that when the continuous mean values for the outdoor temperature is below 10 °C, the heating set points shall be taken from Annex A.1 in NS-EN 15251:2007.

Table A.2 in Annex A.1 in NS-EN 15251:2007 gives recommended design values for indoor temperatures. This Annex gives temperature set points for both heating and cooling for different categories. According to category II, the heating set point should be 20 °C and the cooling set point should be 26 °C for both office cells and open landscapes. This applies to a clothing level of 1.0 clo during the heating season and 0.5 clo during the cooling season. (Standard Norge, 2007a)

According to feasibility study for Powerhouse Kjørbo, the only requirement for the thermal indoor climate is that the operative temperature shall be kept between 20 °C and 26 °C.

The Norwegian technical regulation (TEK 10) recommends a temperature range for operative temperature between 19 °C and 26 °C for the light work activities. It further recommends that the air temperature is being kept below 22 °C, when there’s a need for heating. (Direktoratet for byggkvalitet, 2010)

Table A.1 in Annex A in NS-EN 15251:2007 give recommended values for PPD (Predicted Percentage Dissatisfied) and PMV (Predicted Mean Vote) for different categories. These categories were used in the evaluation of the thermal indoor climates in the simulations.

5.2 Indoor air quality and air volumes

The feasibility report for Powerhouse Kjørbo didn't set any requirements for the indoor air quality. However, the aim in the simulations was to keep the CO_2 concentration below 900 ppm (parts per million). This value qualifies for category II in Table B.4 in NS-EN 15251:2007.

Annex B.1 in NS-EN 15251 gives recommended design air quantities for commercial buildings. The standard gives several methods for calculating the necessary air quantity in commercial buildings. Method B.1.2 was chosen for calculating the air quantity for the simulation model in IDA ICE.

This method is based both on ventilation of contamination from the users of the building and ventilation of contaminations from the building itself and appurtenant systems. As for the criteria for thermal indoor climate in NS-EN 15251:2007, the air quantities are listed in different categories. For ventilation of contaminations from user of the building, category II gives an air quantity of 7 l/(s*person) and a PPD of 20%. For ventilation of contaminations from the building, category II gives an air quantity of 0.7 l/(s*m^2), given that the building is a low contaminating building. (Standard Norge, 2007a)

The equation for calculating the total air quantity for a room, given as equation B.1 in Annex B in NS-EN 15251:2007, is listed and described below.

$$q_{tot} = n \cdot q_p + A \cdot q_B$$

q_{tot} = the total air quantity for the room [l/s]

n = the dimensioned value for the number of persons in the room [-]

q_p = the air quantity for each person in the room [l/(s*person)]

A = the floor area for the room [m^2]

q_B= the air quantity for the contaminations by the building [l/(s*m^2)]

According to the Norwegian regulation (Byggteknisk forskrift), the average air supply should at least be 2.5 m^3 per hour per m^2 during residence time and 0.7 m^3 per hour per m^2 outside residence time. (Direktoratet for byggkvalitet, 2010)

6 Key values used in the Simulation model in IDA ICE

Parameter	Value/state	Comment
Location	Oslo (Fornebu)	
Climate	Oslo/Fornebu_ASHRAE	
Wind profile	Default urban	
U-value external walls	0.145 W/(m^2*K)	Thickness of 0.425 m
U-value internal walls	0.3168 W/(m^2*K)	Thickness of 0.146 m
U-value roof	0.07783 W/(m^2*K)	Thickness of 0.6522 m
U-value external floors	0.1173 W/(m^2*K)	Thickness of 0.6675 m
U-value windows	0.80 W/(m^2*K)	
Thermal bridge value	0.02 W/(m*K)	
Internal floors		200 mm concrete
Infiltration	0.5 ACH*	*Air changes per hour
Discharge coefficient (C_d) for internal doors	0.65	Leak area of 0.01 m^2
U-value ground properties	0.29 W/(m^2*K)	0.1 m insulation and 1.0 m soil
Ventilation strategy	VAV and CAV	VAV in meeting rooms and open landscapes. CAV in offices, copy rooms, toilets etc.
Ventilation principle	Displacement ventilation	IDA ICE did only support displacement ventilation in rectangular zones.
Supply air temperature	19 °C	
Supply air quantities	Building: 0.7 l/(s*m^2) Person: 7 l/(s*person)	Referred to as normal air quantity.
Ventilation control	Temperature	Maximum air supply when the indoor temperature exceeds 26 °C
Heating set point	20 °C	Originally set to 20 °C, changed to 22 °C in some of the simulations.
Cooling set point	26 °C	
Installed heating power	12 kW/floor	
Installed cooling power	0 kW/floor	
Lighting	3 W/m^2	
Equipment	6 W/m^2	
Occupants	0.052 occupants/m^2	
Operating time	06.00-18.00	
Residence time	06.00-18.00	
Ambient air CO_2 level	400 ppm	

7 Focus areas in the simulation model in IDA ICE

The simulations have been carried out using the simulation program IDA Indoor Climate and Energy (IDA ICE) with the purpose of simulate the temperature distribution between different neighboring zones in the building.

The office cells at Powerhouse Kjørbo are not equipped with radiator heating. By creating a simulation model, it could be possible to verify if the thermal indoor climate was acceptable in office cells and meeting rooms during summer- and winter conditions.

Since basements weren't included in the simulation model, the first floor was constructed to face the ground. To prevent the influence the ground may have on the temperatures at the first floor, the second floor was chosen as the main focus for the further work.

7.1 Meeting room.4206

Meeting room.4206 is located in the North West corner at the second floor in Building 4. The room is designed as a meeting room, with a designed capacity of ten occupants.

Meeting room.4206 was chosen because of the large façade areas. With the thermal indoor climate in mind, an office with a large façade area is more vulnerable than an office with a small façade area.

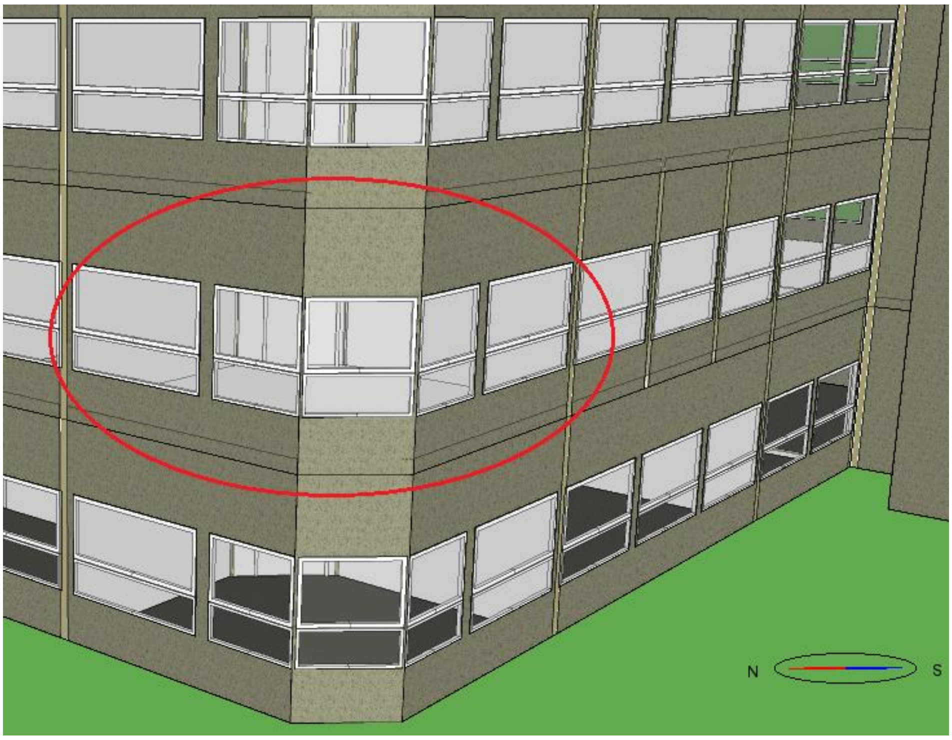


Figure 9: The façade of Meeting room.4206 in IDA ICE

The total façade area for Meeting room.4206 was measured to 18.01 m^2 (total external wall area = 31.06 m^2) and the total window area was measured to 13.05 m^2. For the rest of the office cells, the façade area was measured to 4.348 m^2 (total wall area = 7.768 m^2) and the window area was measured for each office cell.

The floor area for Meeting room.4206 was measured to 23.7 m^2, while the other office cells had a floor area measured to 8.828 m^2. Despite the fact that Meeting room.4206 had a larger floor area than the other offices, the wall area facing neighboring zones was smaller. The wall area which is facing neighboring zones in Meeting room.4206 was measured to 27.726 m^2. The same measurements for the rest of the office cells, showed an area of 29.66 m^2.

Because this office is a corner office with a façade facing south west and North West, the solar gains will be low during the winter. This is due to the orientation of the façades and because of the shading created by Building 5 and vegetation. Both the window area and the façade area in Meeting room.4206 are approximately three times larger than for rest of the office cells at the second floor. This is shown in Figure 10, where Meeting room.4206 is marked with red.

The rest of the office cells at the second floor are located below (3 offices) and to the right (5 offices) of Meeting room.4206. This is illustrated in Figure 10.

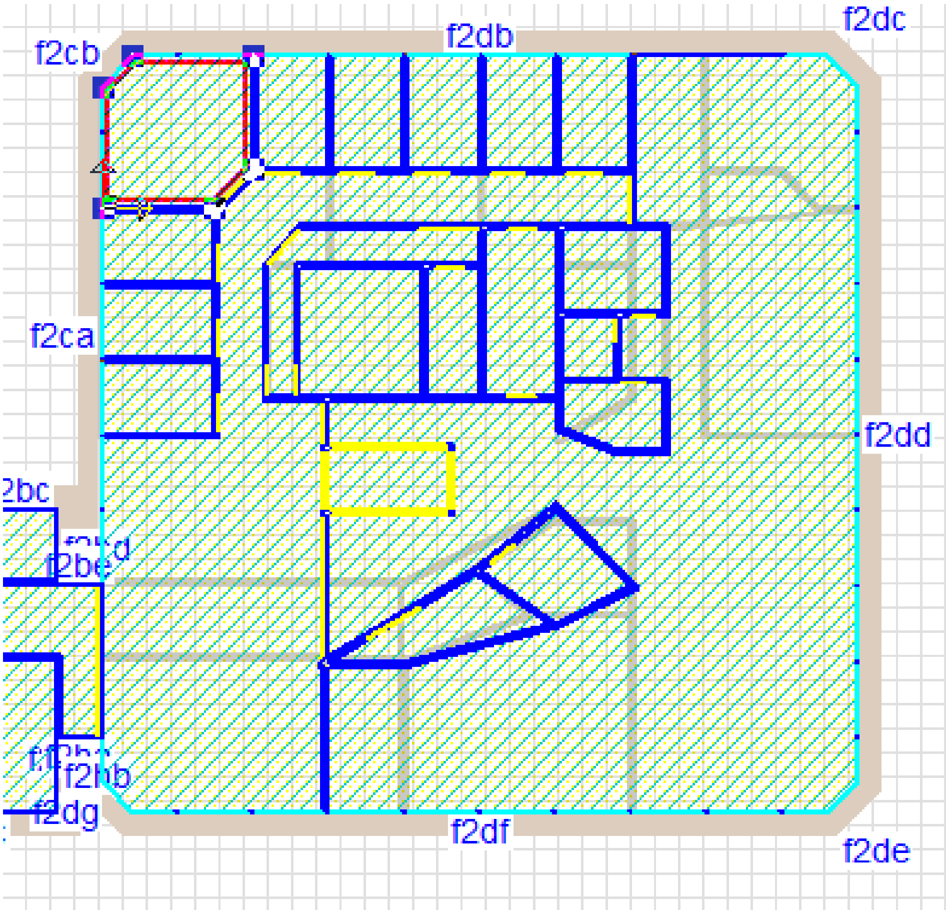


Figure 10: Location for Meeting room.4206 at the second floor in Building 4 from IDA ICE

7.2 Office.4203

Office.4203 is an office cell which is located nearby Meeting room.4206 at the second floor in Building 4. The room is designed for one occupant.

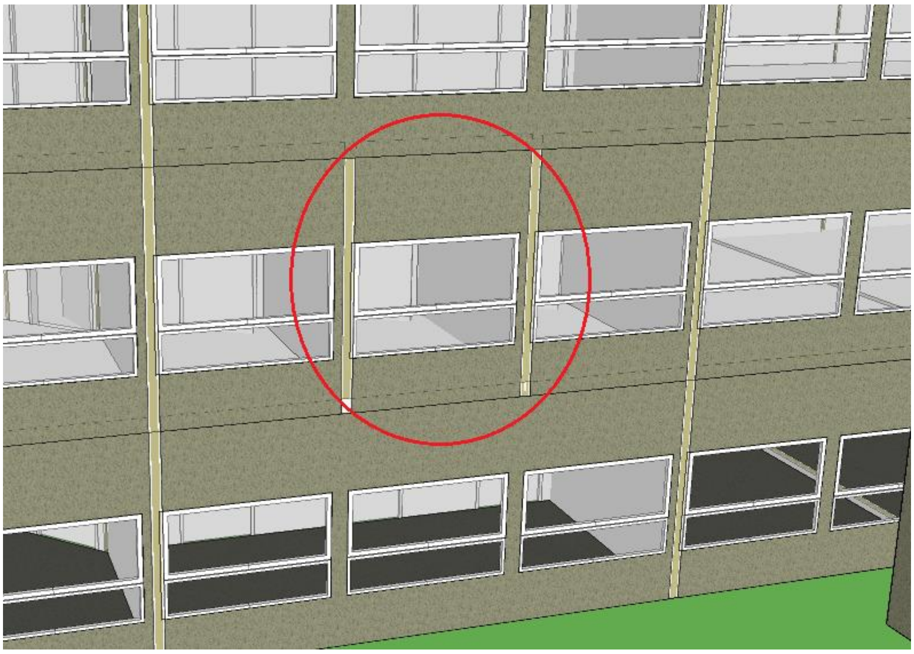


Figure 11: The façade of Office.4203 in IDA ICE

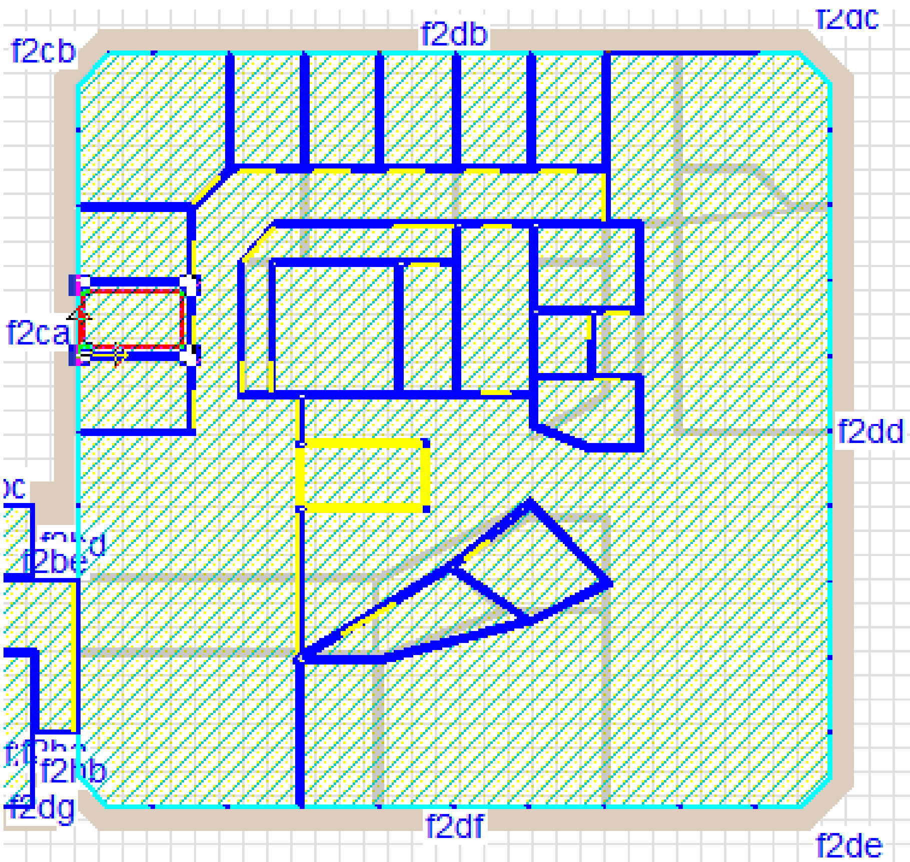


Figure 12: Location for Office.4203 at the second floor in Building 4 from IDA ICE

7.3 Landscape.4241

Landscape.4241 is located on the second floor in Building 4. The zone is designed to be used as open landscape with work spaces for 30 occupants.

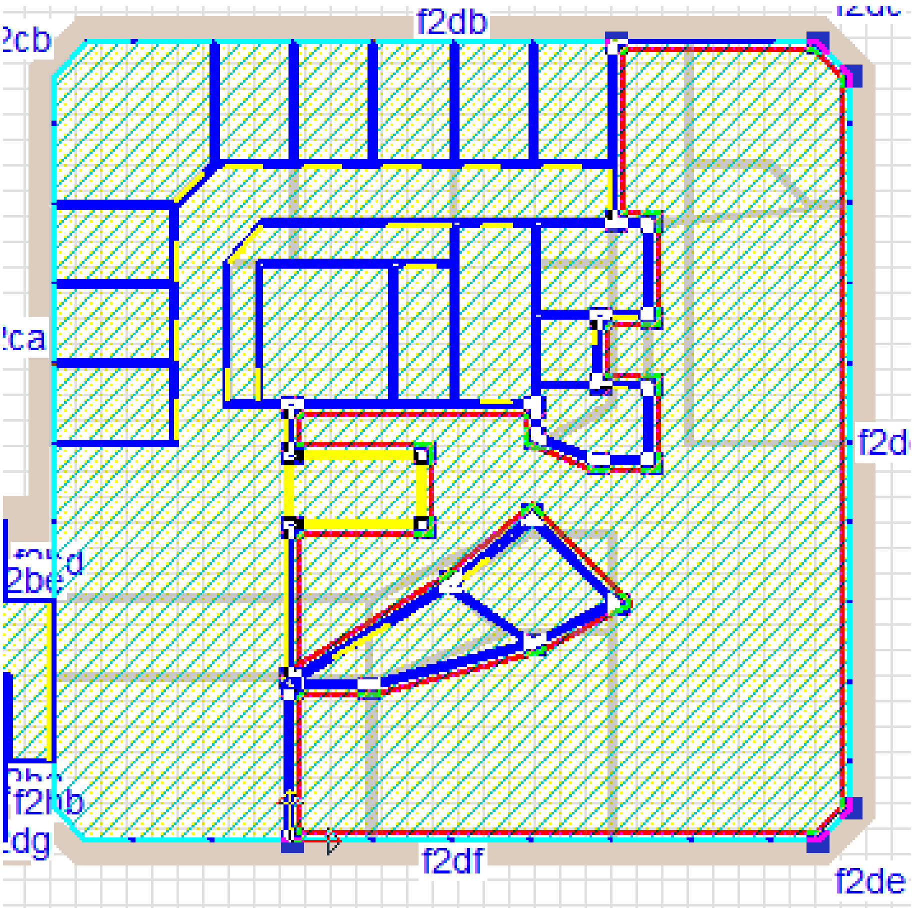


Figure 13: Location for Landscape.4241 at the second floor in Building 4 from IDA ICE

Most of the installed heating power at the second floor in Building 4 is placed in Landscape.4241.

8 Evaluations

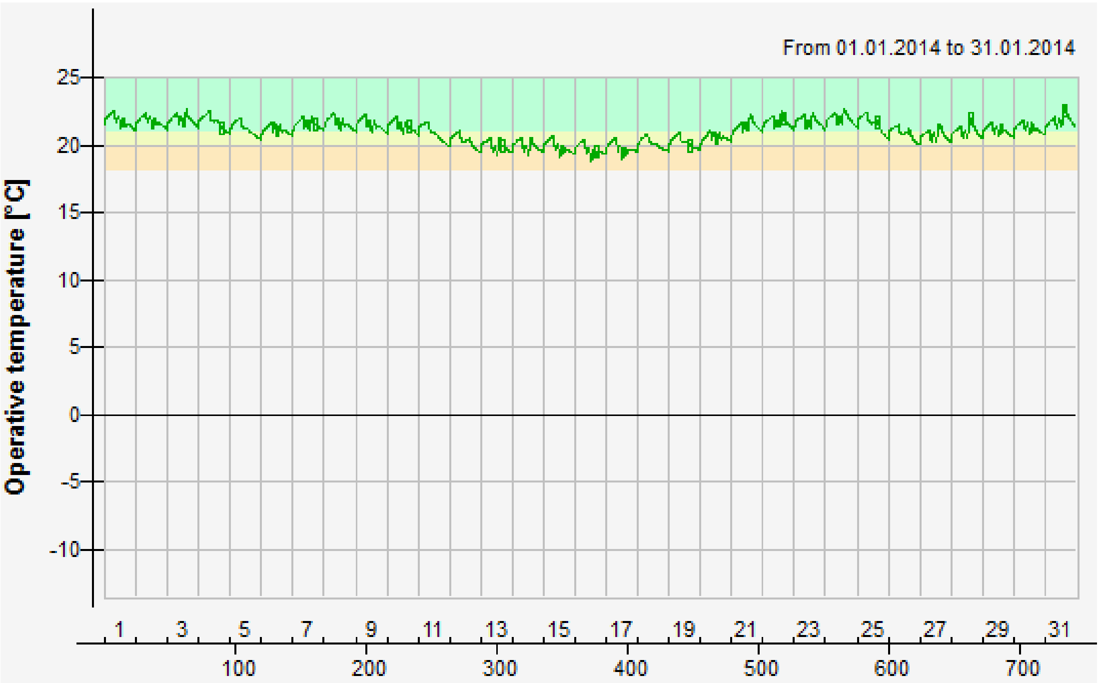
The simulations in IDA ICE were carried out with the purpose of examine the thermal indoor climate in chosen zones. The chosen zones were Meeting room.4206, Office.4203 and Landscape.4241.

Both winter- and summer simulations were carried out with the purpose of examining the thermal indoor climate. Results for main temperatures, PMV- and PPD values were used to evaluate the thermal indoor climate in the simulations. In some of the simulations, the indoor air quality was evaluated.

Various simulations were carried out with different action with the purposes of examining the effect each action or combinations of actions have on the thermal indoor climate.

8.1 Evaluation of the thermal indoor climate

The evaluation of the thermal indoor climate was performed in accordance with chapter I.2 in Annex I in NS-EN 15251:2007. This evaluation method is based on the percentage of occupancy hours in each comfort category. The comfort categories are based on PMV- and PPD values. The different comfort categories are defined in Table A.1 in Annex A in NS-EN 15251:2007. An example of the evaluation method is shown below.



Comfort category	No. of occupancy hours
I (best)	71
II (good)	85
III (Acceptable)	104
IV (Unacceptable)	0

Figure 14: Thermal comfort for Meeting room.4206 according to EN 15251 in Simulation 11

Figure 14 shows the number of occupancy hours in each comfort category. The evaluation of the thermal indoor climate was done by calculating the percentage for occupancy in each comfort category.

Percent of occupancy hours in each comfort category in Meeting room.4206				
Comfort category	Unacceptable (IV)	Acceptable (III)	Good (II)	Best (I)
Simulation 11	0 %	40 %	33 %	27 %

Figure 15: Evaluation of the thermal indoor climate in Meeting room.4206 in Simulation 11

The results from Figure 15 shows that the thermal indoor climate was considered to be acceptable in 40 % of the residence time, good in 33 % of the residence time and best in 27 % of the residence time.

By carrying out an evaluation for thermal indoor climate for each zone in every simulation, the different simulations can be compared in order to examine the influence that different used actions have on the thermal indoor climate.

An evaluation of the thermal indoor climate, for Meeting room.4206 and Office.4203, was carried out in every simulation. Landscape.4241 was equipped with radiator heating, and was considered to have a good thermal indoor climate during the winter. Therefore, an evaluation of the thermal indoor climate for Landscape.4241 was only carried out for the summer simulations. The evaluations of the thermal indoor climate can be found in Attachment 14.

8.2 Evaluation of main temperatures

Table E.3 in NS-EN ISO 7730:2005 gives PMV values for different operative temperatures, clothing levels and relative air velocity for an activity level of 1.2 met.

The clothing level in the winter simulations was set to 1.0 clo and it was assumed that the relative air velocity was < 0.10 m/s. The operative temperature which corresponds to a PMV value of 0 was found to be just below 22 °C.

The winter simulations were carried out with the goal of achieving a mean operative temperature of 22 °C. The main temperatures for each zone in every winter simulation was registered, and later compared to results from other simulations. In addition to the mean operative temperature, the minimum- and maximum operative temperature were registered.

The clothing level in the summer simulations was set to 0.5 clo and it was assumed that the relative air velocity was < 0.10 m/s. The operative temperature which corresponds to a PMV value of 0 was found to be just above 24 °C.

The summer simulations were carried out with the goal of achieving a mean operative temperature of 24 °C. The main temperatures for each zone in every summer simulation was registered, and later compared to results from other simulations. In addition to the mean operative temperature, the minimum- and maximum operative temperature were registered.

8.3 Evaluation of extreme values for PMV and PPD

Extreme values for PMV and PPD were registered for each zone in every simulation. This was done to show the influence that different used actions had on the extreme PMV- and PPD values. The winter simulations showed that the extreme values primarily occurred on the start of the residence time, while the summer simulations showed that the extreme values primarily occurred at the end of the residence time. This meant that the indoor temperatures were low in the morning for the winter simulations, while the indoor temperatures were high at the end of the residence time for the summer simulations. Figure 16 show the registered values for PMV and PPD for Meeting room.4206 in Simulation 11.

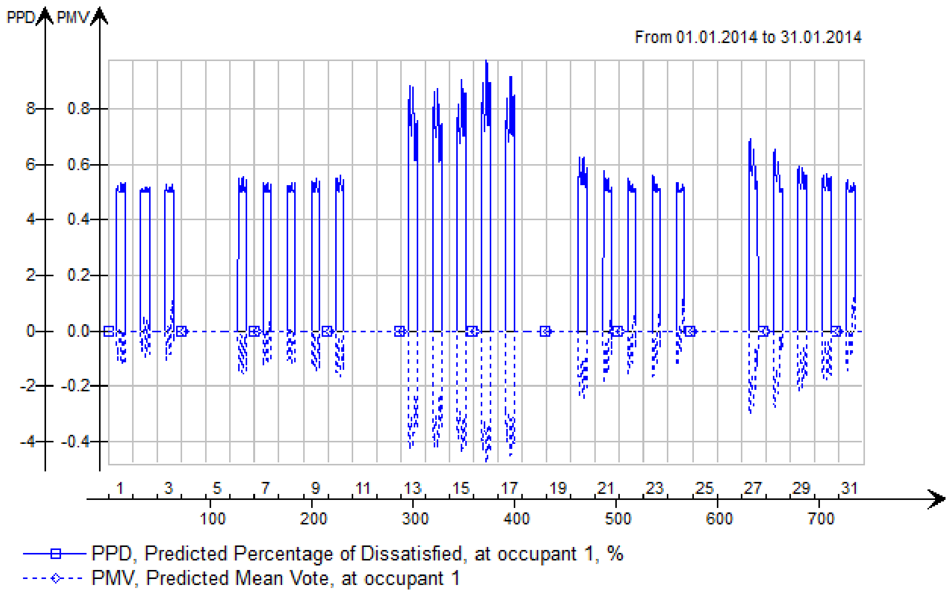


Figure 16: PPD and PMV for Meeting room.4206 in Simulation 11

8.4 Evaluation of the indoor air quality

The indoor air quality was measured in some of the simulations. The indoor air quality was considered to only be influenced by the supplied air into the zone and the presence from occupants, and it was therefore not necessary to collect results from every simulation, since the air supply and presence of occupants were equal for several simulations.

The results for indoor air quality were used to verify that the chosen zones were supplied with enough fresh air. The indoor air quality was also used for determining the ventilation control. The ventilation control was originally set to be temperature controlled.

The evaluation of the indoor air quality was carried out by using Table B.4 in NS-EN 15251:2007. This table specifies different categories for determination of the indoor air quality. Category II was set as an aim for the indoor air quality. This meant that the indoor air quality should be kept equal or below 900 ppm.

9 Winter simulations

January was considered to be the coldest period during the year. Therefore, the winter simulation was conducted from 01.01.2014 to 31.01.2014. Low values for residence time and presence were applied in the winter simulations, with the purpose of creating a "worst case scenario". By reducing the supplied heat from internal gains, the zones without radiator heating were more dependent on heat distribution from neighboring zones with radiator heating. The internal gains were minimized to examine if the indoor temperature became too low in the zones without radiator heating, such as Meeting room.4206 and Office.4203.

Figure 17, Figure 18 and Figure 19 show the residence time and presence for the occupants primarily used in the winter simulations.

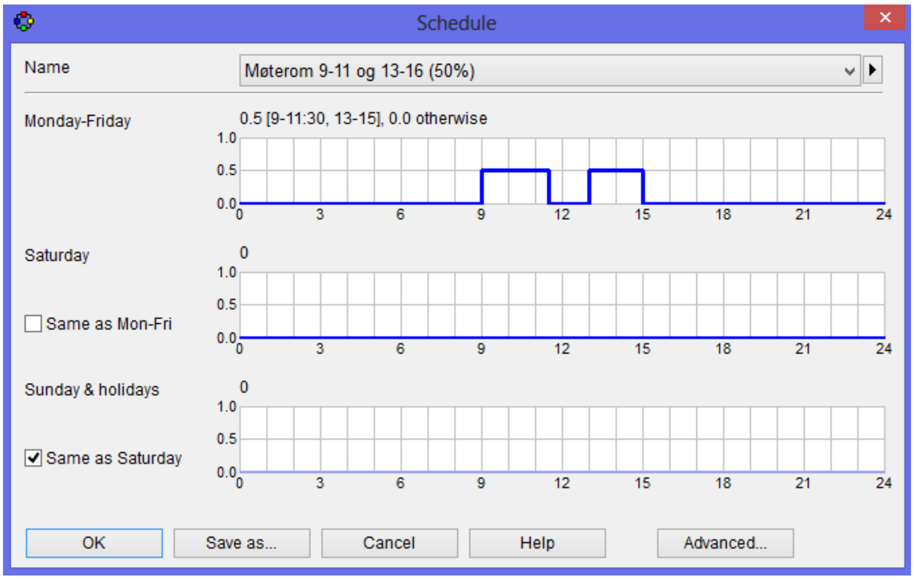


Figure 17: Schedule used in meeting rooms for winter simulations

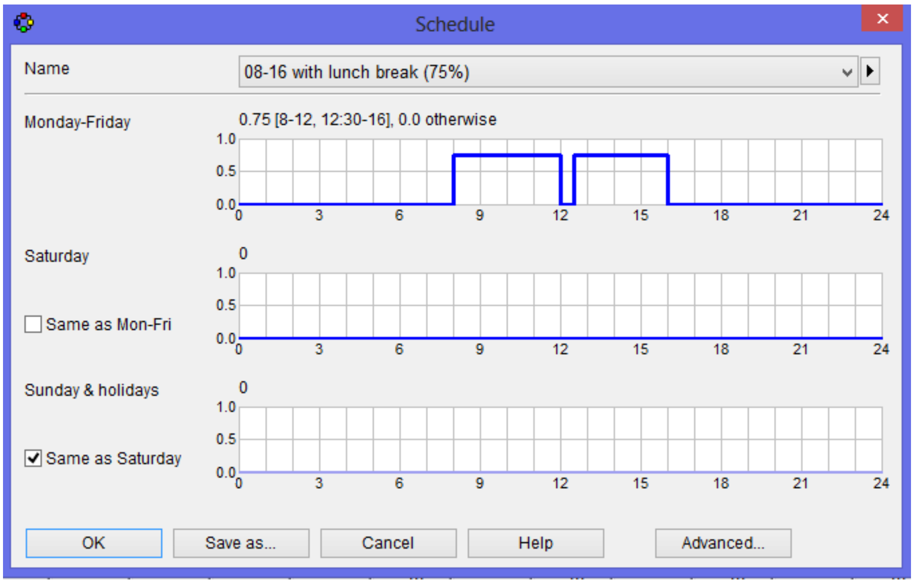


Figure 18: Schedule used in office cells for winter simulations

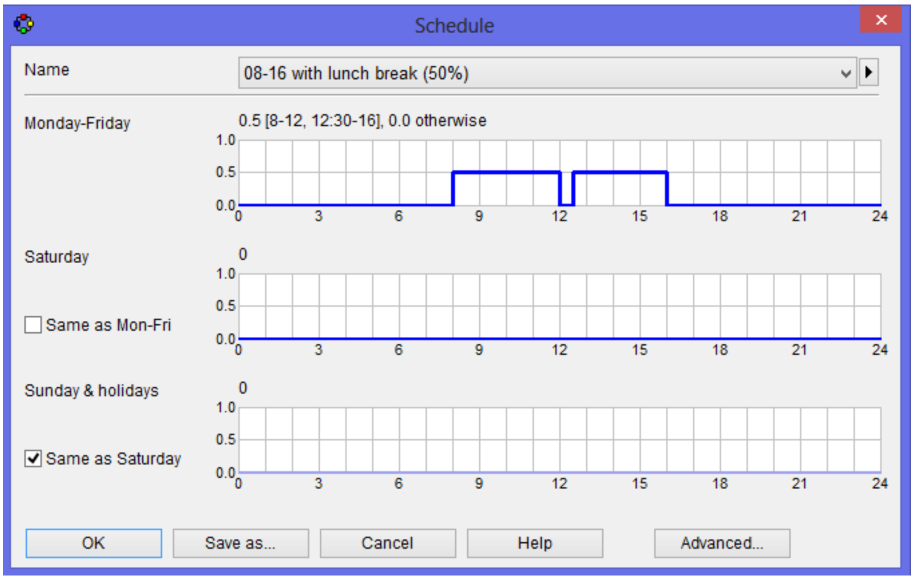


Figure 19: Schedule used in open landscapes for winter simulations

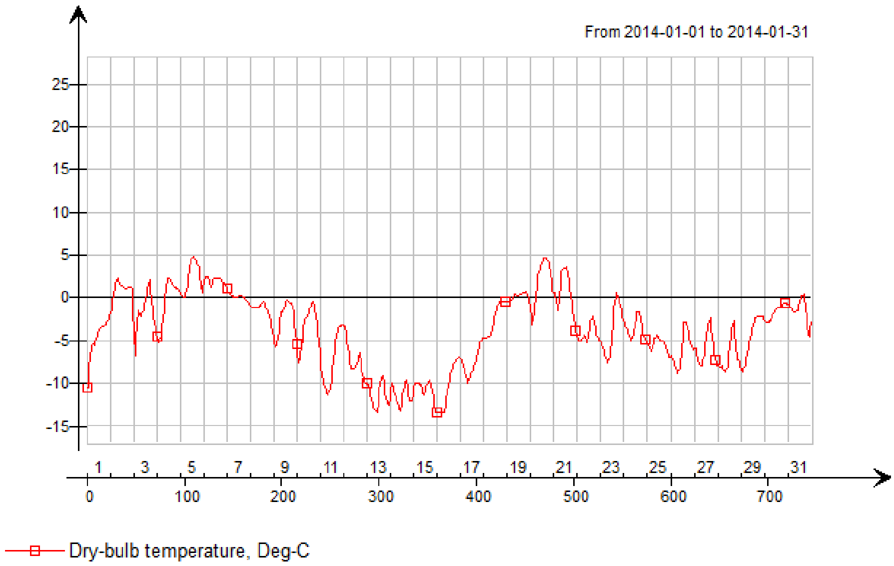


Figure 20: Ambient temperatures during the winter simulation

According to Figure 20, the lowest ambient temperatures were registered from 13.01.2014 to 16.01.2014. The ambient temperature was below -10 °C during this period. It was considered that the lowest indoor temperatures and the most extreme PMV- and PPD values would occur during this period.

9.1 Simulation 1

Simulation 1 was carried out to confirm that keeping the internal doors closed for the entire day, would result in a low indoor temperature in the meeting rooms and offices during the winter simulation. The parameters used in Simulation 1 can be found in Table 6 in Attachment 2.

9.1.1 Temperatures

The temperatures from Landscape.4241 showed that the installed heating power was sufficient to keep the indoor temperature for this zone equal or above the set point temperature of 20 °C.

For Meeting room.4206 and Office.4203, the mean temperatures were below the set point temperature. The minimum operative temperature was 16.2 °C in Office.4203, while the minimum operative temperature was 12.9 °C in Meeting room.4206. This difference in minimum operative temperature for the two zones was caused by a larger façade area and a lower presence from the occupants in Meeting room.4206. The mean operative temperatures were 15.2 °C for Meeting room.4206 and 17.7 °C for Office.4203. Results for achieved temperatures in Simulation 1 can be found in Attachment 2.

9.1.2 Thermal indoor climate

9.1.2.1 Meeting room.4206

According to Figure 31 in Attachment 2, the most extreme PMV value was measured to -1.6, while the corresponding PPD value was measured to 60 %.

According to Figure 32 in Attachment 2, 89 of 104 occupancy hours were defined as unacceptable according to simulation 1. The thermal indoor climate was considered to be acceptable or better in 14.4 % of the residence time. The operative temperature was below 20 °C during the whole simulation period.

The thermal indoor climate in Meeting room.4206 in Simulation 1 is presented in the table below, which is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 1	86 %	13 %	1 %	0 %

9.1.2.2 Office.4203

According to Figure 33 in Attachment 2, the most extreme PMV value was measured to -1.0, while the corresponding PPD value was measured to 25 %.

According to Figure 34 in Attachment 2, 78 of 180 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be acceptable or better in 56.7% of the residence time. In comparison to Meeting room.4206, the thermal comfort in

Office.4203 was slightly better. The operative temperature was below 20 °C during the whole simulation period.

The thermal indoor climate in Office.4203 in Simulation 1 is presented in the table below, which is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 1	43 %	52 %	4 %	0 %

9.1.3 Comments

The results from Simulation 1 shows that the temperatures achieved in Meeting room.4206 and Office.4203 were too low. The results showed that the thermal indoor climate was considered to be unacceptable in both Office.4203 and Meeting room.4206. The figures, that illustrate values for PMV and PPD, showed that the temperatures were too low in the beginning of the residence time.

Keeping the doors closed throughout the day resulted in a low indoor temperature and a bad thermal indoor climate.

9.2 Simulation 2

The second simulation was carried out to determine if keeping the office doors open outside the residence time, would result in a satisfying indoor temperature in the meeting rooms and office cells during the winter simulation. The parameters used in Simulation 2 can be found in Table 6 in Attachment 3.

9.2.1 Temperatures

In comparison to Simulation 1, the indoor temperatures for Meeting room.4206 and Office.4203 were increased in simulation 2. By keeping the doors open outside the residence time, the minimum operative temperature was increased from 12.9 °C to 16.7 °C for Meeting room.4206, and from 16.2 °C to 18.2 °C for Office.4203. The mean operative temperature was increased from 15.2 °C to 17.9 °C in Meeting room.4206, while the mean operative temperature in Office.4203 was increased from 17.7 °C to 18.9 °C. Results for achieved temperatures in Simulation 2 can be found in Attachment 3.

By keeping the doors open outside the residence time, instead of always closed, resulted in a major increase in minimum- and mean operative temperatures for Office.4203 and Meeting room.4206.

9.2.2 Thermal indoor climate

9.2.2.1 Meeting room.4206

According to Figure 35 in Attachment 3, the most extreme PMV value was measured to -0.9, while the corresponding PPD value was measured to 22 %. In comparison to simulation 1, both the PPD and PMV were improved in simulation 2. By keeping the door open outside the residence time, the most extreme PMV value increased from -1.6 to -0.9, while the highest PPD value decreased from 60 % to 22 %.

According to Figure 36 in Attachment 3, 34 of 106 occupancy hours were defined as unacceptable according to simulation 2. The thermal indoor climate was considered to be acceptable or better in 67.8 % of the residence time, which was an improvement from 14.4 % in simulation 1. The operative temperature was below 20 °C during the whole simulation period.

The table below presents the thermal indoor climate in Meeting room.4206 in Simulation 1 and Simulation 2. The table is based on the tables in Attachment 14.

	Percent of occupancy hours in each comfort category			
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 1	86 %	13 %	1 %	0 %
Simulation 2	32 %	65 %	3 %	0 %

The decision of keeping the door open outside residence time resulted in a massive improvement for the thermal indoor climate in Meeting room.4206.

9.2.2.2 Office.4203

According to Figure 37 in Attachment 3, the most extreme PMV value was measured to -0.65, while the corresponding PPD value was measured to 14.5 %. In comparison to simulation 1, both the PPD and PMV were improved in simulation 2. By keeping the door open outside the residence time, the most extreme PMV value increased from -1.0 to -0.65, while the highest PPD value decreased from 25 % to 14.5 %.

According to Figure 38 in Attachment 3, 4 of 181 occupancy hours were defined as unacceptable according to simulation 2. The thermal indoor climate was considered to be acceptable or better in 97.8 % of the residence time, which was an improvement from 56.7 % in simulation 1. The operative temperature was below 20 °C during the whole simulation period.

The table below presents the thermal indoor climate in Office.4203 in Simulation 1 and Simulation 2. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 1	43 %	52 %	4 %	0 %
Simulation 2	2 %	93 %	4 %	0 %

The decision of keeping the door open outside residence time resulted in a massive improvement for the thermal indoor climate in Office.4203.

9.2.3 Comments

The indoor temperatures increased for both Meeting room.4206 and Office.4203 compared to the results for Simulation 1. The thermal indoor climate was improved in Simulation 2, compared to Simulation 1. Despite this, the thermal indoor climate was considered to only be acceptable. The PMV- and PPD values showed that the temperatures at the beginning of the residence time were unacceptable.

The decisions of keeping the doors open outside the residence, instead of closed, resulted in an improvement for the thermal indoor climate. Nevertheless, the results from Simulation 2 showed that the temperatures in Meeting room.4206 and Office.4203 were lower than the set point for heating throughout the simulation period.

The set point for heating had to be increased in order to achieve higher temperatures in Meeting room.4206 and Office.4203.

9.3 Simulation 3

Simulation 3 was carried out with the purpose of showing the effect of always keeping the internal doors open, had on the temperature distribution in the office cells and meeting rooms. The parameters used in Simulation 3 can be found in Table 10 in Attachment 4.

9.3.1 Temperatures

The minimum operative temperature for Meeting room.4206 in Simulation 3 was calculated to 17.2 °C. This was an increase compared to the minimum operative temperature in Simulation 2, which was 16.7 °C. The mean operative temperature in Meeting room.4206 increased from 17.9 °C to 18.1 °C from Simulation 2 to Simulation 3.

The minimum operative temperature in Office.4203 was increased from 18.2 °C to 18.4 °C when the door was kept open during the residence time, instead of closed during the residence time. The mean operative temperature in Office.4203 increased from 18.9 °C to 19.0 °C.

Results for achieved temperatures in Simulation 3 can be found in Attachment 4.

Always keeping the doors open, instead of open just outside the residence time, had a small effect on the operative temperatures in Meeting room.4206. The changes in operative temperatures for Office.4203 were seen as insignificant.

9.3.2 Thermal indoor climate

9.3.2.1 Meeting room.4206

According to Figure 39 in Attachment 4, the most extreme PMV value was measured to -0.65, while the corresponding PPD value was measured to 19 % in Meeting room.4206. By comparing to the results from Simulation 2, the most extreme PMV value increased from -0.9 to -0.65, while the corresponding PPD-value decreased from 22 % to 19 %.

According to Figure 40 in Attachment 4, 18 of 108 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be acceptable or better in 83.3 % of the occupancy hours. This was an improvement from Simulation 2, which had a corresponding value of 67.8 %. The operative temperature was below 20 °C during the whole simulation period. The decision of always keeping the door open resulted in a significant improvement of the thermal indoor climate in Meeting room.4206.

The table below presents the thermal indoor climates for Meeting room.4206 in Simulation 2 and Simulation 3. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 2	32 %	65 %	3 %	0 %
Simulation 3	17 %	80 %	4 %	0 %

9.3.2.2 Office.4203

According to Figure 41 in Attachment 4, the most extreme PMV value was measured to -0.6, while the corresponding PPD value was measured to 13 % in Office.4203. In comparison to Simulation 2, the highest registered PPD value decreased from 14.5 % to 13 %, while the most extreme PMV value increased from -0.65 to -0.6. The changes that were performed from Simulation 2 to Simulation 3 resulted in an almost insignificant improvement on the extreme values for the PMV and PPD in Office.4203.

According to Figure 42 in Attachment 4, none of the occupancy hours in Office.4203 were defined as unacceptable, which implies that the thermal indoor climate was considered to be acceptable or better during the whole simulation period. This was a small improvement from Simulation 2, which had a corresponding value of 97.8 %. The operative temperature was below 20 °C throughout simulation period. The decision of always keeping the door open had a small effect on the thermal indoor climate in Office.4203, in comparison to only keeping the door open outside the residence time.

The table below presents an evaluation of the thermal indoor climate in Office.4203 in Simulation 2 and Simulation 3. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 2	2 %	93 %	4 %	0 %
Simulation 3	0 %	95 %	5 %	0 %

9.3.3 Comments

The results from Simulation 3 showed that always keeping the doors open had a small effect on the temperatures and thermal indoor climate in Meeting room.4206. The results for Office.4203 showed that the changes made from Simulation 2 to Simulation 3, had an almost insignificant influence on the temperatures and thermal indoor climate.

9.4 Simulation 4

Simulation 4 was carried out with the purpose of finding the effect a presence of 100 % had on temperatures and thermal indoor climate. The parameters used in Simulation 4 can be found in Table 14 in Attachment 5.

9.4.1 Temperatures

In comparison to Simulation 2, the minimum operative temperature increased from 16.7 °C to 17.1 °C, while the mean operative temperature increased from 17.9 °C to 18.1 °C for Meeting room.4206. For Office.4203, the minimum operative temperature increased from 18.2 °C to 18.3 °C, while the mean operative temperature was 18.9 °C for both simulations. Results for achieved temperatures in Simulation 4 can be found in Attachment 5.

Increased presence of occupants didn't result in a significant increase in the operative temperatures for Office.4203 and Meeting room.4206.

9.4.2 Thermal indoor climate

9.4.2.1 Meeting room.4206

According to Figure 43 in Attachment 5, the most extreme PMV value was measured to -0.85, while corresponding PPD value was measured to 20 % in Meeting room.4206. In comparison to Simulation 2, the PMV value decreased from -0.9 to -0.85, while the PPD value decreased from 22 % to 20 %. The increased presence from the occupants had a marginal effect on the most extreme PMV- and PPD values for Meeting room.4206. This result was expected, since these values occurred 09.00 on Mondays, which meant that the air temperatures were approximately the same for Simulation 2 and Simulation 4 at this point.

According to Figure 44 in Attachment 5, 9 of 118 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be acceptable or better in 92.4 % of the residence time, which was an improvement from 67.8 % in Simulation 2. The operative temperature was held below 20 °C during the most of the simulation period. The increased presence from the occupants resulted in a big improvement on the average thermal comfort for Meeting room.4206.

The table below presents an evaluation of the thermal indoor climate for Meeting room.4206 in Simulation 2 and Simulation 4. The table is based on the tables in Attachment 14.

	Percent of occupancy hours in each comfort category			
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 2	32 %	65 %	3 %	0 %
Simulation 4	8 %	70 %	19 %	3 %

9.4.2.2 Office.4203

According to Figure 45 in Attachment 5, the most extreme PMV value was measured to -0.65, while the highest PPD value was measured to 14 % in Office.4203. The corresponding values for Simulation 2 were measured to -0.65 and 14.5 %. The change in presence for the occupants didn't have an influence on the most extreme values for PMV and PPD in Office.4203. This result was expected, since these values occurred 08.00 on Mondays, which meant that the air temperatures were approximately the same for Simulation 2 and Simulation 4 at this point.

According to Figure 46 in Attachment 5, 2 of 185 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be acceptable or better in 98.1 % of the residence time. For Simulation 2, the corresponding value was calculated to 97.8 %. The operative temperature was held below 20 °C during the whole simulation period. The increased presence from the occupant wasn't considered having a big influence on the thermal indoor climate in Office.4203.

The table below presents an evaluation of the thermal indoor climate in Office.4203 in Simulation 2 and Simulation 4. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 2	2 %	93 %	4 %	0 %
Simulation 4	1 %	92 %	6 %	0 %

9.4.3 Comments

The results from Simulation 4 showed that an increased presence had a positive influence on the temperatures and thermal indoor climate in Meeting room.4206. The increased presence was considered to have insignificant improvement for the temperature and thermal indoor climate in Office.4203.

9.5 Simulation 5

Simulation 5 was carried out with the purpose of finding the effect of increasing the set point for heating from 20 °C to 22 °C, has on the thermal indoor climate in Meeting room.4206 and Office.4203. The parameters used in Simulation 5 can be found in Table 18 in Attachment 6.

According to Table E.3 in NS-EN ISO 7730:2005, the PMV value will never be 0 with a set point for heating of 20 °C. To get as close to a PMV value equal to 0 as possible, the set point for heating was set to 22 °C.

The results for main temperatures in Simulation 2 showed that the mean air temperatures in Office.4203 and Meeting room.4206 were 19.0 °C and 17.9 °C. By increasing the set point for heating to 22 °C, the mean air temperatures would most likely exceed 19 °C. If so, the air supply from the ventilation, with a temperature of 19 °C, would cool down the air temperature. This would counteract the effect of increasing the set point for heating.

9.5.1 Temperatures

In comparison to Simulation 2, the indoor temperatures for Meeting room.4206 and Office.4203 were increased in Simulation 5. By changing the set point for heating from 20 °C to 22 °C, the minimum operative temperature increased from 16.7 °C to 19.5 °C for Meeting room.4206, and from 18.2 °C to 19.5 °C for Office.4203. The mean operative temperature in Meeting room.4206 increased from 17.9 °C to 20.2 °C, while the mean operative temperature in Office.4203 increased from 18.9 °C to 20.1 °C. The results for achieved temperatures in Simulation 5 can be found in Attachment 6.

The decision of changing the set point for heating, from 20 °C to 22 °C, resulted in an increase for both the minimum- and mean operative temperature in Meeting room.4206 and Office.4203.

9.5.2 Thermal indoor climate

9.5.2.1 Meeting room.4206

According to Figure 47 in Attachment 6, the most extreme PMV value was measured to -0.5, while the highest PPD value was measured to approximately 10 % in Meeting room.4206. In comparison to Simulation 2, the most extreme PMV value increased from -0.9 to -0.5, while the highest measured PPD value decreased from 22 % to 10 %. The decision of changing the set point for heating from 20 °C to 22 °C resulted in a big improvement for the most extreme PMV- and PPD values in Meeting room.4206.

According to Figure 48 Attachment 6, 13 of 119 occupancy hours in were defined as unacceptable. The thermal indoor climate was considered to be acceptable or better in 89.1 % of the residence time, which was an improvement from 67.8 % in Simulation 2. The operative temperature was below 20 °C throughout the simulation period. The decision of changing the set point for heating from 20 °C to 22 °C resulted in a big improvement for the thermal indoor climate in Meeting room.4206.

The table below presents an evaluation of the thermal indoor climate for Meeting room.4206 in Simulation 2 and Simulation 5. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 2	32 %	65 %	3 %	0 %
Simulation 5	11 %	76 %	13 %	0 %

9.5.2.2 Office.4203

According to Figure 49 Attachment 6, the most extreme PMV value was measured to -0.5, while the highest PPD value was measured to approximately 10.5 % in Office.4203. In comparison to Simulation 2, the most extreme PMV value increased from -0.65 to -0.5, while the highest PPD value decreased from 14.5 % to 10.5 %. The decision of changing the set point for heating from 20 °C to 22 °C resulted in a small improvement for the most extreme values for PMV and PPD in Office.4203.

According to Figure 50 in Attachment 6, none of 228 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be good or better in 24.6 % of the residence time, while the corresponding value in Simulation 2 was 4.4 %. The operative temperature was held equal or above 20 °C during the whole simulation period. The decision of changing the set point for heating from 20 °C to 22 °C resulted in significant improvement on the thermal indoor climate in Office.4203.

The table below presents an evaluation of the thermal indoor climate for Office.4203 in Simulation 2 and Simulation 5. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 2	2 %	93 %	4 %	0 %
Simulation 5	0 %	75 %	24 %	0 %

9.5.3 Comments

The decision of changing the set point for heating resulted in a huge improvement for the temperatures and thermal indoor climate for Meeting room.4206 and Office.4203.

Nevertheless, the PMV- and PPD values showed that the temperatures still were too low at the beginning of the residence time.

9.6 Simulation 11

Simulation 11 was carried out with the purpose of examining the effect that hot ventilation air, supplied during the night to heat the building, has on the indoor temperatures. The supply air temperature was increased during the night, to avoid low temperatures in the office cells and meeting rooms during the residence time. The supply air temperature was set to 19 °C between 08.00 and 00.00, while it was set to 40 °C between 00.00 and 08.00. The schedule for the supply air temperature is shown in Figure 92 in Attachment 12. The parameters used in Simulation 11 can be found in Table 41 in Attachment 12.

The previous winter simulations showed that the temperatures in Meeting room.4206 and Office.4203 were too low. Despite the fact that the heating set point was increased from 20 °C to 22 °C in Simulation 5, the indoor temperatures were too low.

The supply air temperature was therefore increased during the night, to avoid low temperatures in the office cells and meeting rooms.

Hans Martin Mathisen stated that; "in reality, the supply air temperature can be increased in order to heat the building during the night in the winter. Depending on the outside temperature, the supply air temperature can be increased to temperatures up to 40 °C." (Mathisen, 2014)

This solution was therefore added to the simulation model in Simulation 11.

9.6.1 Temperatures

By using heated ventilation air during the night, the mean-, minimum- and maximum operative temperatures were increased in comparison to Simulation 5.

The mean operative temperature in Meeting room.4206 increased from 20.2 °C to 21.0 °C, while the increase in Office.4203 was from 20.1 °C to 22.3 °C.

The minimum operative temperature in Meeting room.4206 increased from 19.5 °C to 19.7 °C, while the increase in Office.4203 was from 19.5 °C to 21.4 °C.

The results for achieved temperatures in Simulation 11 can be found in Attachment 12.

The decision of using heated ventilation air to heat the building during the night resulted in a massive improvement for the operative temperatures in Meeting room.4206 and Office.4203.

9.6.2 Thermal indoor climate

9.6.2.1 Meeting room.4206

According to Figure 93 in Attachment 12, the most extreme PMV value was measured to -0.5, while the corresponding PPD value was measured to 10 % in Meeting room.4206. These results were approximately the same as the results in Simulation 5. However, the average PMV- and PPD values were reduced in comparison to Simulation 5. For most of the days in the simulation period, the PMV values were above -0.2. The decision of using heated ventilation air to heat the building during nighttime resulted in a small improvement for the extreme PMV- and PPD values.

According to Figure 94 in Attachment 12, none of 260 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be good or better in 60.0 % of the residence time. This result was a huge improvement in comparison to Simulation 5, which had a corresponding value of 12.6 %. The operative temperature was kept over 20 °C for most of the time during the simulation period. The decision of using heated ventilation air to heat the building during nighttime resulted in a massive improvement for the thermal indoor climate in Meeting room.4206.

The table below shows an evaluation of the thermal indoor climate in Meeting room.4206 for Simulation 2, Simulation 5 and Simulation 11. The table is based on the tables in Attachment 14.

	Percent of occupancy hours in each comfort category			
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 2	32 %	65 %	3 %	0 %
Simulation 5	11 %	76 %	13 %	0 %
Simulation 11	0 %	40 %	33 %	27 %

9.6.2.2 Office.4203

According to Figure 95 in Attachment 12, the most extreme PMV values in Office.4203 were measured to -0.2 and 0.3, while the corresponding PPD values were 6 % and 7%. This was an improvement in comparison to Simulation 5, where the most extreme PMV value was -0.5 and the highest PPD value was 10 %. The decision of using heated ventilation air to heat the building during nighttime resulted in a small improvement for the extreme PMV- and PPD values.

According to Figure 96 in Attachment 12, none of 516 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be good or better in 66.7 % of the residence time. This was a huge improvement in comparison to Simulation 5, which had a corresponding value of 4.4 %. The operative temperature was kept above 20 °C throughout the simulation period. The decision of using heated ventilation air to heat the building during nighttime resulted in a massive improvement for the thermal indoor climate in Office.4203.

The table below shows an evaluation of the thermal indoor climate in Office.4203 for Simulation 2, Simulation 5 and Simulation 11. The table is based on the tables in Attachment 14.

	Percent of occupancy hours in each comfort category			
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 2	2 %	93 %	4 %	0 %
Simulation 5	0 %	75 %	24 %	0 %
Simulation 11	0 %	33 %	33 %	33 %

9.6.3 Comments

The decision of using heated ventilation air to heat the building during nighttime resulted in a massive improvement for the thermal indoor climate in Meeting room.4206 and Office.4203.

The results from Simulation 11 showed that the mean operative temperature was kept close to 22 °C for both Meeting room.4206 and Office.4203. The thermal indoor climate was considered to be good or better during most of the residence time for both Meeting room.4206 and Office.4203.

10 Summer simulations

The summer simulation was conducted from 01.08.2014 to 31.08.2014. July was considered to be the warmest period during the year. Despite this, August was chosen as the summer simulation period, because most Norwegian workers are on holiday during the most of July. High values for residence time and presence were applied in the summer simulation, with the purpose of creating a “worst case scenario”. The internal gains were maximized to examine if the indoor temperature became too high. The residence time and presence for occupants are shown in Figure 21.

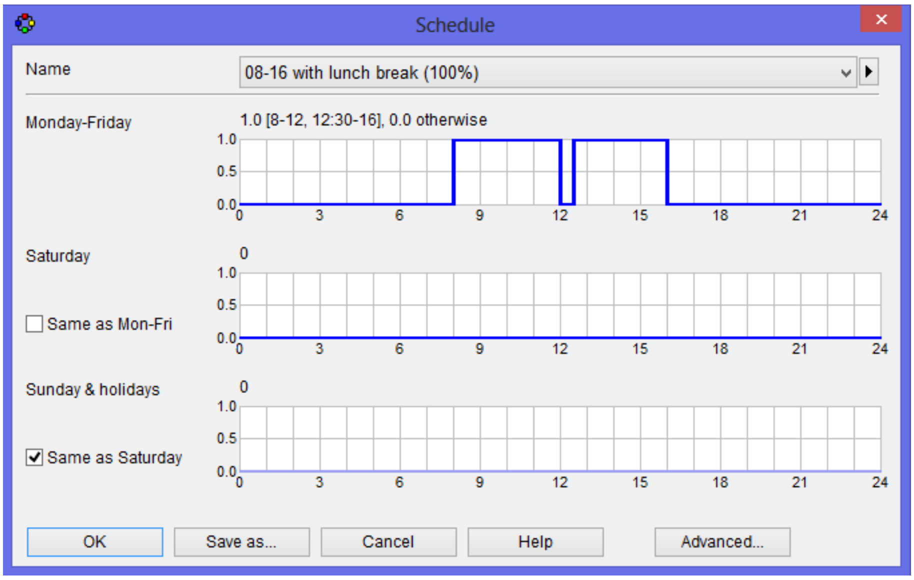


Figure 21: Schedule used in the summer simulations

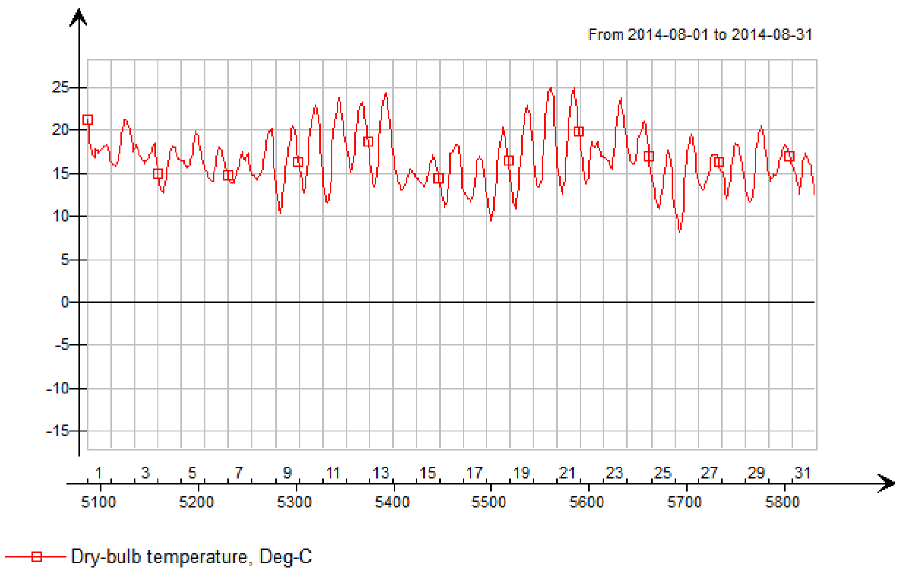


Figure 22: Ambient temperatures during the summer simulation

According to Figure 22, the highest ambient temperatures were registered from 20.08.2014 to 21.08.2014. The ambient temperature varied from 13 °C to 25 °C during this period. It was considered that the highest indoor temperatures and the most extreme PMV- and PPD values would occur during this period.

10.1 Simulation 6

Simulation 6 was carried out with the purpose of examine the thermal indoor climate in the simulation model during summer conditions. There wasn't made any actions to prevent high indoor temperatures, such as implementing exterior window shading, opening of windows or increased air volumes, for this simulation. The parameters used in Simulation 6 can be found in Table 22 in Attachment 7.

10.1.1 Temperatures

According to Table 23, Table 24 and Table 25, all zones experienced high maximum operative temperatures. The mean operative temperature in Meeting room.4206 was 26.1 °C, which was above the set point for cooling.

The maximum operative temperature in for Office.4203 was calculated to 27.1 °C, while the maximum operative temperature in Meeting room.4206 was calculated to 27.0 °C.

The results for achieved temperatures in Simulation 6 can be found in Attachment 7.

10.1.2 Thermal indoor climate

10.1.2.1 Meeting room.4206

According to Figure 51 in Attachment 7, the most extreme PMV value in Meeting.room.4206 was measured to 1.1, while the corresponding PPD value was measured to 30 %.

According to Figure 52 in Attachment 7, 5 of 284 occupancy hours in were defined as unacceptable. The thermal indoor climate was considered to be acceptable or better in 98.2% of the residence time, and good or better in 44.7 % of the residence time. The thermal indoor climate in Meeting room.4206 was considered to be acceptable during the simulation period, despite that no actions to prevent high indoor temperatures were included.

The table below presents an evaluation of the thermal indoor climate for Meeting room.4206 in Simulation 6. The table is based on the tables in Attachment 14.

	Percent of occupancy hours in each comfort category			
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	2 %	54 %	35 %	10 %

10.1.2.2 Office.4203

According to Figure 53 in Attachment 7, the most extreme PMV value in Office.4203 was measured to 0.9, while the corresponding PPD value was measured to 22.5 %.

According to Figure 54 in Attachment 7, 4 of 423 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be acceptable or better in 99.1 % of the residence time, and good or better in 62.6 % of the residence time. The thermal indoor climate in Office.4203 was considered to be acceptable during the simulation period, despite that no actions to prevent high indoor temperatures were included.

The table below presents an evaluation of the thermal indoor climate for Office.4203 in Simulation 6. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	1 %	36 %	34 %	28 %

10.1.2.3 Landscape.4241

According to Figure 55 in Attachment 7, the most extreme PMV value was measured approximately to 0.55, while the corresponding PPD value was measured to 11 % in Landscape.4241.

According to Figure 56 in Attachment 7, none of 405 occupancy hours were defined as unacceptable in Landscape.4241. The thermal indoor climate was considered to be good or better in 61 % of the residence time. The thermal indoor climate in Landscape.4241 was considered to be acceptable during the simulation period, despite that no actions to prevent high indoor temperatures were included.

The table below presents an evaluation of the thermal indoor climate for Landscape.4241 in Simulation 6. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	0 %	39 %	38 %	23 %

10.1.3 Comments

The thermal indoor climate in the chosen zones was considered to be acceptable during the simulation period, despite that no actions to prevent high indoor temperatures were included. Nevertheless, the all zones experienced temperatures above 26 °C, which was the set point for cooling.

Actions that prevent an increase in temperature would have to be included in the later simulations, in order to lower the maximum operative temperature in the chosen zones. Examples of actions to prevent an increase in temperature can be; opening of windows, external window shading or increased ventilation quantities.

10.2 Simulation 7

Simulation 7 was carried out with the purpose of finding the effect open windows have on the indoor temperature. The opening control of the windows was handled by a non-user defined PI temperature control and schedule in IDA ICE. The schedule was set from 09.00 to 11.00 and 13.00 to 16.00 with an opening of 50 % and is shown in Figure 23. The opening control for windows in IDA ICE was set to 50 % open when the indoor air temperatures in the zone exceeds 26 °C, and only open between 09.00 to 11.00 and 13.00 to 16.00. The parameters used in Simulation 7 can be found in Table 26 in Attachment 8.

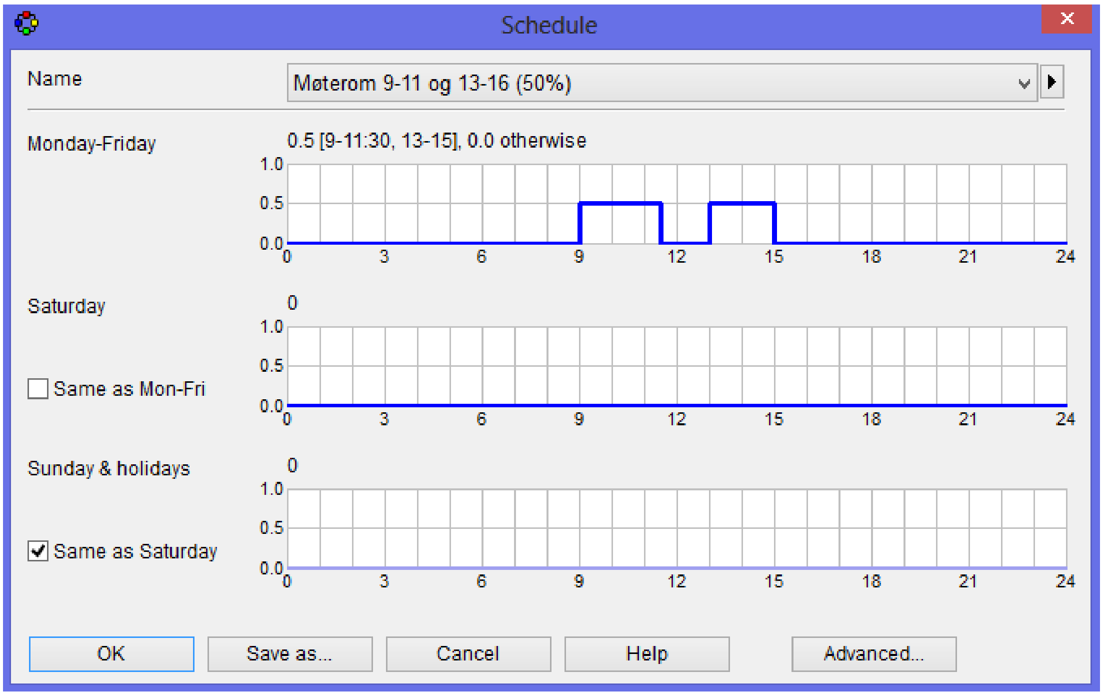


Figure 23: Schedule for opening of windows in Simulation 7

According to Hans Martin Mathisen, the users of the building aren't allowed to affect the local climate by opening windows. (Mathisen, 2014)

Nevertheless, this simulation was carried out to show the effect that open windows have on the maximum operative temperature and the thermal comfort.

10.2.1 Temperatures

In comparison to Simulation 6, the maximum operative temperature decreased from 27.7 °C to 27.4 °C for Meeting room.4206 and from 27.1 °C to 26.7 °C for Office.4203. The maximum operative temperature in Landscape.4241 increased from 26.4 °C to 27.7 °C.

The results for achieved temperatures in Simulation 7 can be found in Attachment 8.

There was a small decrease in the maximum operative temperatures in Meeting room.4206 and Office.4203, while there was an increase in the maximum operative temperature for Landscape.4241. To create a significant reducing of the maximum operative temperatures, the windows must be kept fully opened for a longer period than in this simulation.

10.2.2 Thermal indoor climate

10.2.2.1 Meeting room.4206

According to Figure 57 in Attachment 8, the most extreme PMV value was measured to 1.0, while the corresponding PPD value was measured to approximately 24.5 % in Meeting room.4206. In comparison to Simulation 6, the most extreme PMV value decreased from 1.1 to 1.0, while the highest measured PPD value decreased from 30 % to 24.5 %. These results show that the windows would have to be kept open more often, in order to reduce the PMV- and PPD values in Meeting room.4206.

According to Figure 58 in Attachment 8, 2 of 338 occupancy hours were defined as unacceptable. In Simulation 7, the thermal indoor climate was considered to be acceptable or better in 99.4 % of the residence time, while the corresponding value in Simulation 6 was 98.2 %. The changes made for opening of the windows had a small positive influence on the thermal indoor climate in Meeting room.4206.

The table below presents an evaluation of the thermal indoor climate in Meeting room.4206 for Simulation 6 and Simulation 7. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	2 %	54 %	35 %	10 %
Simulation 7	1 %	46 %	43 %	11 %

10.2.2.2 Office.4203

According to Figure 59 in Attachment 8, the most extreme PMV value was measured to approximately 0.75, while the highest PPD value was measured to approximately 16.5 %. In comparison to Simulation 6, the most extreme PMV value decreased from 0.9 to 0.75, while the highest measured PPD value decreased from 22.5 % to 16.5 %. The most extreme values for PMV and PPD were reduced, when the windows were opened for a period during the day. However, the windows must be kept open more often, in order to reduce these values further.

According to Figure 60 in Attachment 8, 3 of 443 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be acceptable or better in 99.3 % of the residence time, and good or better in 64.3 % of the residence time. The thermal indoor climate in Simulation 6 and 7 was considered to be quite similar, which meant that the opening of the windows had an insignificant effect on the thermal indoor climate. The windows must be kept open more often in order to have a large positive influence on the thermal indoor climate in Office.4203.

The table below presents an evaluation of the thermal indoor climate in Office.4203 for Simulation 6 and Simulation 7. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	1 %	36 %	34 %	28 %
Simulation 7	1 %	35 %	33 %	31 %

10.2.2.3 Landscape.4241

According to Figure 61 in Attachment 8, the most extreme positive PMV value was measured to 0.35, while the corresponding PPD value was measured to approximately 7.5 % in Landscape.4241. In comparison to Simulation 6, the most extreme PMV value decreased from 0.55 to 0.35, while the highest measured PPD value decreased from 11 % to 7.5 %. The most extreme values for PMV and PPD were reduced when the windows were opened for a period during the day. However, the windows must be kept open more often, in order to reduce these values further.

According to Figure 62 in Attachment 8, none of 433 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be good or better in 63.5 % of the residence time, which was a small improvement in comparison to Simulation 6. The operative temperature was kept below 27 °C during the whole simulation period. The thermal indoor climate in Landscape.4241 was slightly improved by keeping the windows open for some time during the day. By keeping the windows open for a longer period, the thermal indoor climate could be improved further.

The table below shows an evaluation of the thermal indoor climate in Landscape.4241 for Simulation 6 and Simulation 7. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	0 %	39 %	38 %	23 %
Simulation 7	0 %	36 %	36 %	28 %

10.2.3 Air supply and opening schedule for windows

During daytime in the period 04.08.2014 to 15.08.2014 and 17.08.2014 to 29.08.2014, the air temperature rose above 26 °C in Meeting room.4206, which is the set point for cooling. This is shown in Figure 63 in Attachment 8.

In IDA ICE, the windows were considered to be a part of the external wall. According to Figure 64 in Attachment 8, an inflow through windows happened when the air temperature in Meeting room.4206 rose above 26 °C. The highest total inflow into Meeting room.4206 was measured to 240 l/s. The corresponding air temperature was measured to almost 28 °C. These results show that the windows were opened when the air temperature in Meeting room.4206 exceeded 26 °C.

Meeting room.4206 was equipped with VAV ventilation, where the VAV airflows were temperature controlled. In simulation 7, the highest possible air supply was 86.6 l/s, while the lowest was 16.6 l/s. Figure 65 in Attachment 8 shows the air supply in Meeting room.4206 during the simulation period. Compared to Figure 63, maximum air supply occurred when the air temperature exceeded 26 °C.

10.2.4 Indoor air quality

According to Figure 66 in Attachment 8, the CO_2 concentration in Landscape.4241 was kept below 800 ppm during most of the simulation period. The outside CO_2 concentration in IDA ICE was set to 400 ppm.

According to Table B.4 in NS-EN 15251, the indoor air quality was considered to qualify for category II throughout the simulation period. The maximum CO_2 concentration to qualify for category I was 750 ppm, while for category II the corresponding value was 900 ppm.

10.2.5 Comments

The results from Simulation 7 showed that the windows weren't opened enough in order to create a huge reduction of the maximum temperatures in Meeting room.4206 and Office.4203. In order to lower the maximum temperatures further, the windows have to be opened more often.

The thermal indoor climates for the chosen zones were slightly improved, when the windows were opened for some time during the day.

10.3 Simulation 8

Simulation 8 was carried out with the purpose of showing the effect that increased air quantity has on maximum air temperature. The air quantities in simulation 8 were doubled in comparison to the air quantities used in Simulation 7. The used air quantities were 1.4 l/(s*m^2) for the building itself and 14 l/(s*person) for occupants. The parameters used in Simulation 8 can be found in Table 30 in Attachment 9.

10.3.1 Temperatures

In comparison to Simulation 6, the mean operative temperature in Meeting room.4206 was reduced from 26.1 °C to 24.8 °C. The reduction in Office.4203 was 25.2 °C to 22.9 °C, while it was 25.0 °C to 23.0 °C for Landscape.4241.

The maximum operative temperature in Meeting room.4206 was reduced from 27.7 °C to 26.2 °C. The reduction in Office.4203 was 27.1 °C to 24.5 °C, while it was 26.4 °C to 24.3 °C for Landscape.4241.

The results for achieved temperatures in Simulation 8 can be found in Attachment 9.

The decision of increasing the supplied air quantities resulted in a significant reduction of the maximum operative temperatures compared to the results in Simulation 6.

10.3.2 Thermal indoor climate

10.3.2.1 Meeting room.4206

According to Figure 67 in Attachment 9, the most extreme PMV value was measured to 0.6, while the corresponding PPD value was measured to approximately 11.5 %. In comparison to Simulation 6, the most extreme PMV value decreased from 1.1 to 0.6, while the highest measured PPD value decreased from 30 % to 11.5 %. These results show that an increase in the supply air quantities had a great positive effect on maximum values for PMV and PPD in Meeting room.4206.

According to Figure 68 in Attachment 9, none of 403 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be good or better in 61.0 % of the residence time, which was an improvement from 45.0 % in Simulation 6. The operative temperature was always kept below 28 °C. The thermal indoor climate in Meeting room.4206 was significantly improved when the supply air quantities were increased.

The table below shows an evaluation of the thermal indoor climate in Meeting room.4206 for Simulation 6 and Simulation 8. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	2 %	54 %	35 %	10 %
Simulation 8	0 %	39 %	38 %	23 %

10.3.2.2 Office.4203

According to Figure 69 in Attachment 9, the most extreme PMV value was measured to -0.6, while the corresponding PPD value was measured to approximately 14 %. A negative PMV value indicated that the operative temperature was too low. In comparison to Simulation 6, the most extreme PMV value changed from 0.9 to -0.6, while the highest measured PPD value decreased from 22.5 % to 14 %. The results show that an increase in the supply air quantities reduced the maximum values for PMV and PPD. However, a PMV value of -0.6 indicated that the operative temperature is too low. Therefore, the supply air quantity in Office.4203 had to be reduced in order to accomplish better results for PMV and PPD.

According to Figure 70 in Attachment 9, 9 of 405 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be good or better in 61.0 % of the residence time, while Simulation 6 had a corresponding value of 62 %. The operative temperature was always kept below 26 °C. The thermal indoor climate in Meeting room.4206 was not improved when the supply air quantities were increased. By reducing the supply air quantity, the PMV- and PPD values and the thermal indoor climate could be improved.

The table below shows an evaluation of the thermal indoor climate in Office.4203 for Simulation 6 and Simulation 8. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	1 %	36 %	34 %	28 %
Simulation 8	2 %	37 %	34 %	27 %

10.3.2.3 Landscape.4241

According to Figure 71 in Attachment 9, the most extreme PMV value was measured to -0.6, while the corresponding PPD value was measured to 12 %. A negative PMV value indicates that the operative temperature was too low. In comparison to Simulation 6, the most extreme value was changed from 0.55 to -0.6, while the highest PPD value increased from 11 % to 12 %. By doubling the supply air quantity in Landscape.4241, the absolute values for PMV and PPD were increased. By reducing the supply air quantity in Landscape.4241, the most extreme PMV- and PPD values can be improved.

According to Figure 72 in Attachment 9, none of 445 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be good or better in 64.7 % of the residence time. This was an improvement in comparison to Simulation 6, which had a corresponding value of 61.0 %. A doubling of the supply air quantity in Landscape.4241 resulted in a small improvement of the thermal indoor climate. However, the improvement would have been larger with a smaller increase in supply air quantity.

The table below shows an evaluation of the thermal indoor climate in Landscape.4241 for Simulation 6 and Simulation 8. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	0 %	39 %	38 %	23 %
Simulation 8	0 %	35 %	34 %	31 %

10.3.3 Indoor air quality

10.3.3.1 Meeting room.4206

According to Figure 73 in Attachment 9, the highest values for CO_2 concentration in Meeting room.4206 were measured to over 1800 ppm. In accordance to Table B.4 in NS-EN 15251:2007, this qualifies for category IV, which can be seen as unacceptable. The ventilation in Meeting room.4206 was set to be temperature controlled. To reduce the high achieved CO_2 concentrations, the ventilation in the meeting rooms would have to be temperature- and CO_2 controlled.

10.3.3.2 Landscape.4241

According to Figure 74 in Attachment 9, the highest values for CO_2 concentration in Landscape.4241 were measured to approximately 650 ppm. In accordance to Table B.4 in NS-EN 15251:2007, this qualifies for category I, which can be seen as best result.

10.3.4 Comments

The decision of increasing the supplied air quantities resulted in a significant reduction of the maximum operative temperatures compared to the results in Simulation 6. The mean operative temperatures in Office.4203 and Lnadscape.4241 were lowered too much, while the mean operative temperature in Meeting room.4206 was considered to be satisfying.

The thermal indoor climate in Meeting room.4206 was improved when the air quantity was doubled. Office.4203 and Landscape.4241 didn't experience an improvement of the thermal indoor climate, because the mean operative temperature was lowered too much.

The results from Simulation 8 showed that increased air quantities were an efficient way for reducing the temperatures in the building.

10.4 Simulation 9

Simulation 9 was carried out with the purpose of finding if increased opening of windows had a significant effect on the maximum operative temperature. The opening control of the windows was handled by a non-user defined PI temperature control and schedule in IDA ICE. The schedule was set from 08.00 to 16.00 with an opening of 100 % and is shown in Figure 24. The opening controls for windows in IDA ICE was set to 100 % open when the indoor air temperature in the zone exceeds 26 °C, and only open between 08.00 and 16.00. The parameters used in Simulation 9 can be found in Table 34 in Attachment 10.

Simulation 7 was carried out with the purpose of lowering maximum operative temperatures. The results showed that the windows wasn't opened enough to have a large enough impact on maximum operative temperatures. Simulation 9 was therefore carried out with the purpose of finding if increased opening of windows had a significant effect on the maximum operative temperature.

The parameters used for Simulation 9, were the same as for Simulation 6, except for the opening of the windows. The opening control of the windows was handled by a non-user defined PI temperature control and schedule in IDA ICE. The schedule was set from 08.00 to 16.00 with an opening of 100 % and is shown in Figure 24. The opening control for windows in IDA ICE was set to; 100 % open when indoor air temperature in zone exceeds 26 °C and only open between 08.00 and 16.00.

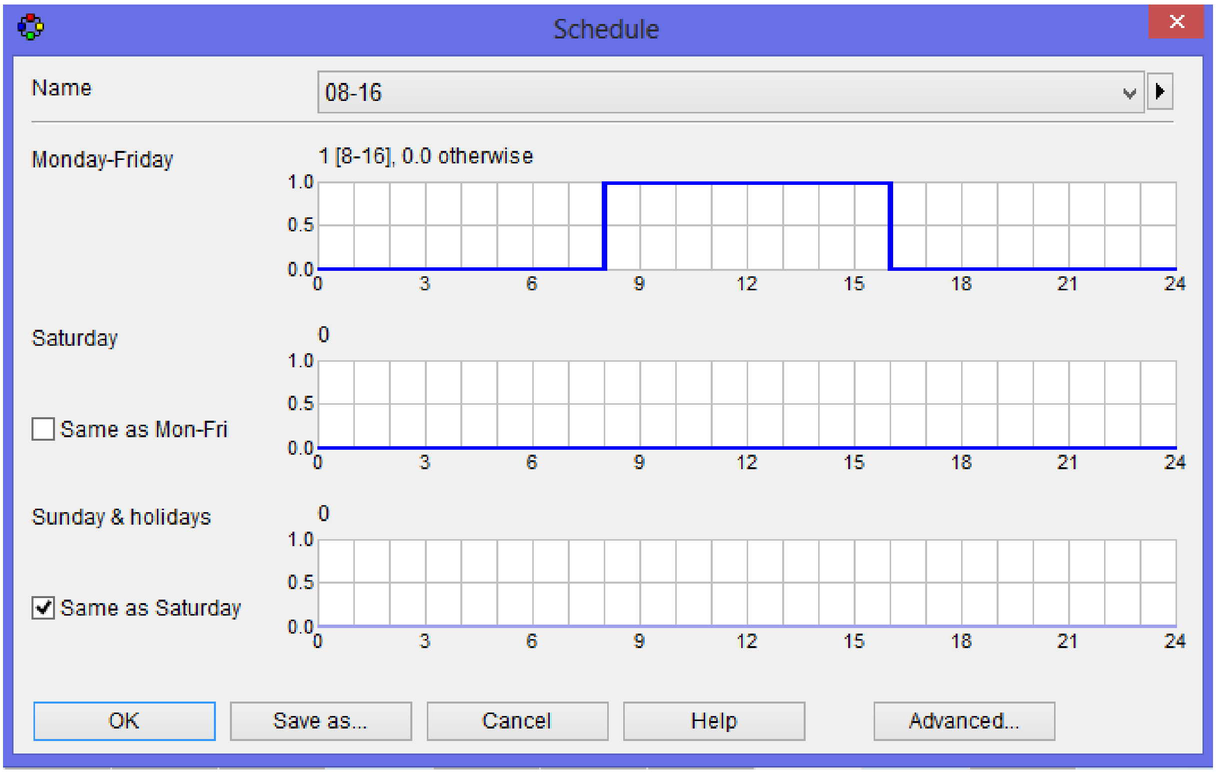


Figure 24: Schedule for opening of windows in Simulation 9

10.4.1 Temperatures

A comparison of the results for main temperatures in the selected zones from Simulation 7 and 9 showed that an increase in the opening and the opening time for the windows had an increased impact on the maximum operative temperature. The maximum operative temperature in Meeting room.4206 was reduced from 27.4 °C to 27.1 °C. For Office.4203, the reduction was from 26.7 °C to 26.6 °C, while the reduction for Landscape.4241 was from 27.7 °C to 26.0 °C.

The results for achieved temperatures in Simulation 9 can be found in Attachment 10.

10.4.2 Thermal indoor climate

10.4.2.1 Meeting room.4206

According to Figure 76 in Attachment 10, the most extreme PMV value was measured to 0.8, while corresponding PPD value was measured to 18 % in Meeting room.4206. The average PMV value was measured to approximately 0.4, while the average PPD value was measured to approximately 8 %. In comparison to simulation 7, the most extreme PMV value decreased from 1.0 to 0.8, while the highest PPD value decreased from 24.5 % to 18 %. The PMV- and PPD values in Simulation 9 were improved in comparison to Simulation 7.

According to Figure 77 in Attachment 10, none of 348 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be good or better in 54.9 % of the residence time, while the corresponding value in Simulation 7 was 53.3 %. Figure 77 in Attachment 10 shows that the operative temperature was above 28 °C on several occasions. The results from Simulation 9 show that the possibilities of increased opening of windows have a small impact on the thermal indoor climate.

The table below shows an evaluation of the thermal indoor climate in Meeting room.4206 for Simulation 6, Simulation 7 and Simulation 9. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	2 %	54 %	35 %	10 %
Simulation 7	1 %	46 %	43 %	11 %
Simulation 9	0 %	45 %	44 %	11 %

10.4.2.2 Office.4203

According to Figure 78 in Attachment 10, the most extreme PMV value was measured to 0.6, while the corresponding PPD value was measured to 14 % in Office.4203. For Simulation 7, these values were measured to 0.75 and 16.5 %. The most extreme PMV- and PPD values were improved compared to the results in Simulation 7.

According to Figure 79 in Attachment 10, 3 of 446 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be good or better in 64.6 % of the residence time. The corresponding value for Simulation 7 was 64.3 %. The operative temperature was kept below 28 °C during the whole simulation period. The results, from Simulation 7 and 9, show that an increased opening of the windows had an insignificant effect on the thermal indoor climate in Office.4203.

The table below presents an evaluation of the thermal indoor climate in Office.4203 for Simulation 6, Simulation 7 and Simulation 9. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	1 %	36 %	34 %	28 %
Simulation 7	1 %	35 %	33 %	31 %
Simulation 9	1 %	35 %	33 %	31 %

10.4.2.3 Landscape.4241

According to Figure 80 in Attachment 10, the maximum PMV value was measured to 0.35, while the minimum PMV value was measured to -0.45. The corresponding PPD values were measured to 7.5 % and 9 %. The results, from Simulation 7 and 9, show that an increase in the possibility of keeping the windows open, don't have an effect on the most extreme PMV- and PPD values.

According to Figure 81 in Attachment 10, none of 437 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be good or better in 63.8 % of the residence time. The corresponding value for Simulation 7 was 63.5 %. The operative temperature was kept below 27 °C during the whole simulation period. An increased possibility for opening windows had an insignificant impact on the thermal indoor climate in Landscape.4241.

The table below shows an evaluation of the thermal indoor climate in Landscape.4241 for Simulation 6, Simulation 7 and Simulation 9. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	0 %	39 %	38 %	23 %
Simulation 7	0 %	36 %	36 %	28 %
Simulation 9	0 %	36 %	35 %	28 %

10.4.3 Indoor air quality

10.4.3.1 Meeting room.4206

According to Figure 82 in Attachment 10, the CO_2 concentration on the first of August was measured to over 3000 ppm, which wasn't considered to be valid for the simulation. The CO_2 concentration in Meeting room.4206 exceeded 1000 ppm every residence day during the simulation. Values over 1000 ppm qualify for category III in Table B.4 in NS-EN 15251:2007. The indoor air quality in Meeting room.4206 was considered to not be satisfying. The VAV ventilation must therefore be controlled by temperature and CO_2, while the supply air quantity may have to be increased.

10.4.3.2 Office.4203

According to Figure 83 in Attachment 10, the CO_2 concentration in Office.4203 was kept below 850 ppm during the whole simulation period, which was considered to qualify for category II or better according to Table B.4 in NS-EN 15251:2007. The indoor air quality in Office.4203 was considered to be satisfying in Simulation 9.

10.4.3.3 Landscape.4241

According to Figure 84, the CO_2 concentration in Landscape.4241 was kept below 850 ppm during the whole simulation period. The indoor air quality in Landscape.4241 qualified for category II or better according to Table B.4 in NS-EN 15251:2007. The indoor air quality in Landscape.4241 was considered to be satisfying in Simulation 9.

10.4.4 Comments

An increased possibility for opening of the windows, when the indoor temperature exceeded 26 °C, resulted in an insignificant reduction for the maximum operative temperatures in the chosen zones. The results from Simulation 9 showed that the thermal indoor climates remained unchanged in comparison to Simulation 7.

10.5 Simulation 10

Simulation 10 was carried out with the purpose of finding the effect external window shading has on the maximum operative temperatures. External window shading would cause a reduction in solar radiation, which would reduce the maximum operative temperature.

The external window shading was set to always drawn. This schedule isn't used in reality, but was added to the simulation model to show the maximum effect external window shading has on the indoor temperatures. The disadvantage of using external window shading is the reduction of letting sunlight into the building, which will reduce the daylight factor. The parameters used in Simulation 10 can be found in Table 37 in Attachment 11.

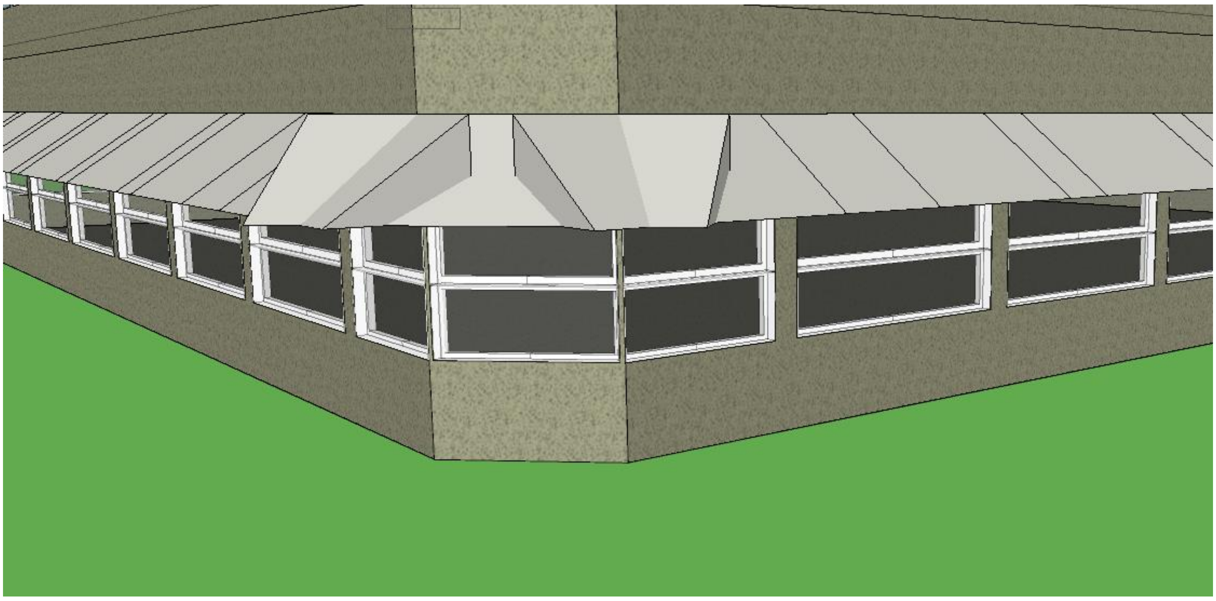


Figure 25: External window shading in Simulation 10

As mentioned in Simulation 7, the windows aren't supposed to be opened to influence the local thermal climate. The windows were therefore closed throughout the simulation period in Simulation 10.

The indoor air quality in Meeting room.4206 was considered to be bad in the previous simulations. It was therefore decided that the VAV ventilation in Meeting room.4206 should be controlled with temperature and CO_2. The maximum value for CO_2 concentration was set to 900 ppm.

10.5.1 Temperatures

In comparison to Simulation 6, the maximum operative temperature in Meeting room.4206 was reduced from 27.7 °C to 24.9 °C. The mean operative temperature was reduced from 26.1 °C to 23.5 °C.

For Office.4203 and Landscape.4241, both mean- and maximum operative temperature were heavily reduced in comparison to Simulation 6.

The results for achieved temperatures in Simulation 10 can be found in Attachment 11.

The decision of using full-time external window shading resulted in huge reduction in mean-, minimum- and maximum operative temperature for the selected zones. However, the temperatures in Office.4203 and Landscape.4241 were considered to be too low.

To avoid too low temperatures in Office.4203 and Landscape.4241, the external window shading would have to be undrawn for a period during the day.

10.5.2 Thermal indoor climate

10.5.2.1 Meeting room.4206

According to Figure 85 in Attachment 11, the most extreme PMV value was measured to -0.6, while the corresponding PPD value was measured to 13 % in Meeting room.4206. These high values only occurred at the beginning of the residence time. After some time, the PMV values approached 0. The PMV values lay above and below 0, which imply that the thermal indoor climate is quite good. In comparison to Simulation 6, the most extreme PMV value was heavily reduced.

According to Figure 86 in Attachment 11, none of 455 occupancy hours were defined as unacceptable in Meeting room.4206 in Simulation 10. The thermal indoor climate was considered to be good or better in 65.5 % of the residence time, while the corresponding value in Simulation 6 was 44.7 %. The thermal indoor climate in Meeting room.4206 was improved by using external window shading. In addition to this, the operative temperature was kept below 26 °C during the whole simulation period.

The table below shows an evaluation of the thermal indoor climate in Meeting room.4206 in Simulation 6 and Simulation 10. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	0 %	39 %	38 %	23 %
Simulation 10	0 %	35 %	34 %	32 %

10.5.2.2 Office.4203

According to Figure 87, the most extreme PMV value was measured to -0.8, while the corresponding PPD value was measured to 16 % in Office.4203. The PMV values were always below 0, which imply that the thermal indoor climate was too cold. The general operative temperature would have to be increased in order to achieve better values for PMV and PPD. Therefore, the external window shading has to be undrawn for some time during the day.

According to Figure 88 in Attachment 11, 15 of 336 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be acceptable or better in 95.5 % of the residence time, and good or better in 52.4 % of the residence time. This was a reduction in comparison to Simulation 6, where the thermal indoor climate was considered to be good or better in 62.6 % of the residence time. The thermal indoor climate was worsened when the external window shading was drawn throughout the simulation period. To improve the thermal indoor climate, the external window shading would have to be used just for some time during the day. The operative temperature in Office .4203 was kept below 24 °C for most of the time during the simulation period.

The table below shows an evaluation of the thermal indoor climate in Office.4203 in Simulation 6 and Simulation 10. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	1 %	36 %	34 %	28 %
Simulation 10	4 %	43 %	38 %	15 %

10.5.2.3 Landscape.4241

According to Figure 89 in Attachment 11, the most extreme PMV value was measured to -0.7, while the corresponding PPD value was measured to 14.5 % in Landscape.4241. The PMV values were always below 0, which imply that the thermal indoor climate was too cold. The general operative temperature would have to be increased in order to achieve better values for PMV and PPD. Therefore, the external window must be used just for some time during the day.

According to Figure 90 in Attachment 11, none of 434 occupancy hours were defined as unacceptable. The thermal indoor climate was considered to be good or better in 63.8 % of the residence time. This was a slightly improvement in comparison to the corresponding value in Simulation 6, which was 61.0 %. In order to achieve an even better thermal indoor climate, the external window shading can't be drawn throughout the simulation period. The operative temperature in Office .4203 was kept below 24 °C for most of the time during the simulation period.

The table below shows an evaluation of the thermal indoor climate in Landscape.4241 in Simulation 6 and Simulation 10. The table is based on the tables in Attachment 14.

Percent of occupancy hours in each comfort category				
Comfort category	**Unacceptable (IV)**	**Acceptable (III)**	**Good (II)**	**Best (I)**
Simulation 6	0 %	39 %	38 %	23 %
Simulation 10	0 %	36 %	34 %	30 %

10.5.3 Indoor air quality

According to Figure 91, the CO_2 concentration in Meeting room.4206 was kept equal or below 900 ppm throughout the simulation period. This value qualifies for category II in Table B.4 in NS-EN 15251:2007.

The decision of letting the VAV ventilation in Meeting room.4206 be controlled by temperature and CO_2, resulted in a big improvement for the indoor air quality. This result shows that the VAV ventilation in the meeting rooms at Powerhouse Kjørbo must be controlled by temperature and CO_2.

10.5.4 Comments

The decision of using full-time external window shading resulted in huge reduction in mean-, minimum- and maximum operative temperature for the selected zones. However, the temperatures in Office.4203 and Landscape.4241 were considered to be too low.

To avoid too low temperatures in Office.4203 and Landscape.4241, the external window shading would have to be undrawn for a period during the day.

The thermal indoor climate for Meeting room.4206 remained unchanged in comparison to Simulation 6, while the thermal indoor climate in Office.4203 was worsened. Landscape.4241 experienced an improvement of the thermal indoor climate in comparison to Simulation 6.

The results from Simulation 10 showed that external window shading was effective in order to reduce the maximum operative temperatures in the selected zones.

11 Discussion

The purpose for this thesis has been to create a simulation model in the simulation program IDA ICE. The simulation model was created with the evaluation of the thermal indoor climate in mind. The technical systems, such as the heat pump system, weren't given any particular attention. Various simulations were carried out with the purpose of showing what influence different actions have on the thermal indoor climate. A challenge is whether the model was detailed enough. A very detailed simulation model is more likely to give correct results in comparison to the actual building. The second floor in Building 4 was created with a high level of detailing. In order to create an even better simulation model, the technical systems should be paid more attention and the other floors should have been more detailed.

Bjørn Jensen has concluded that the operating temperature may be somewhat low in most areas if the heating set point in the landscape is kept constant at 22 °C during winter conditions. He further concludes that the heating set point should be increased to 24 °C in the landscape during extreme winter conditions, in order to maintain acceptable operative temperatures in all zones. He finally concludes that for meeting rooms facing west (such as Meeting room.4206) and office cells facing north (similar to Office.4203), it should be considered to get installed a small heating device, in order to secure acceptable comfort. If a heating device is installed, these zones are less dependent on the heat distribution from the landscape, whether the office doors are open or closed. (Jensen, 2013)

The results from Simulation 5, where the heating set point was 22 °C, showed that the operative temperatures in both Meeting room.4206 and Office.4203 were too low. Instead of increasing the set point for heating from 22 °C to 24 °C, the supply air temperature was heavily increased during the night in order to heat the building. The results from Simulation 11, where the supply air temperature was 40 °C, showed that acceptable operative temperatures were achieved in both Meeting room.4206 and Office.4203 throughout the simulation period.

The increased supply air temperature secures a direct heat distribution to each zone, while when increasing the heating set point from 22 °C to 24 °C in landscape, the heat distribution to other zones is dependent on air flow through open doors. If the office doors are kept open during the day, the increased set point for heating might be a better solution for maintaining acceptable operative temperatures, than supplying hot ventilation air during the night. Nevertheless, it is uncertain if the occupants are willing to keep the doors open throughout the residence time.

The results from the winter simulations performed in this thesis, corresponds well with the results in the report written by Bjørn Jensen.

Bjørn Jensen's report showed that the thermal indoor climate was good during summer conditions. The report doesn't mention which actions are being used to prevent high operative temperatures. (Jensen, 2013)

The summer simulations in this thesis showed that good operative temperatures and a good thermal indoor climate could be achieved with use of different actions. External window shading and increased ventilation quantities were considered to be an effective way for preventing high operative temperatures in the zones.

The decision of using external window shading resulted in a massive reduction in the maximum operative temperature, which also was the intension. However, in order to create a good COP efficiency for the heat pump system during the winter, the energy wells would have to be charged during the summer. By cooling the ventilation air, the energy wells can be charged. In the simulations carried out in this thesis, the solution of using cooled ventilation air hasn't been used. Instead, heavily use of external window shading was used in one of the simulations.

The same number of occupants, residence time, presence and simulation period were used for both Simulation 2 and Simulation 5. Despite this, the numbers of occupancy hours in Office.4203 were unequal for the two simulations. Simulation 2 had 181 occupancy hours, while Simulation 5 had 228 occupancy hours. It is unknown why the two simulations had different numbers for occupancy hours. However, this wasn't considered to be an issue when evaluating the thermal indoor climate.

In Simulation 5, the heating set point was increased from 20 °C to 22 °C, while the supply air temperature was kept at 19 °C. If the temperatures in the zones, without radiator heating, exceeded 19 °C, the ventilation air would cool the room. To prevent this, the supply air temperature should have been increased. Nevertheless, this change wasn't performed in Simulation 5 and Simulation11.

12 Conclusion

The results from the winter simulations showed that a thermal indoor climate considered to be good or better, was difficult to obtain without radiator heating in Meeting room.4206 and Office.4203. The results showed that the operative temperature was very low at the beginning of the residence time, which was set to be 08.00.

The results from the simulations showed that the temperatures in the meeting rooms and offices were way too low when the internal doors always were kept closed. The temperature distribution increased when the internal doors were kept open outside the residence time. Despite this, the experienced temperatures were still below the desired temperatures, which resulted in mediocre results for the thermal indoor climate.

The temperatures were increased and the thermal indoor climate was improved in the meeting rooms and office cells, when the set point for heating was increased from 20 °C to 22 °C. Nevertheless, this action wasn't enough to secure a sufficient temperature distribution to the meeting rooms and office cells.

The temperatures and thermal indoor climate in the meeting rooms and office cells were considered to be good, when the supply air temperature was increased to 40 °C during the night. The increased supply air temperature secured an appropriate temperature at the beginning of the residence time.

The decision of increasing the supply air temperature during the night was considered to be absolutely necessary to secure a good thermal indoor climate in the meeting rooms and office cells during the coldest periods of the year.

The results from the summer simulations showed that the zones in the simulation model would experience operative temperatures above 26.0 °C during the warmest periods of the year. Increased supply air quantities or/and extensive use of external window shading showed a significant capability of reducing the maximum operative temperatures.

The overall temperatures and thermal indoor climate in the summer simulations were considered to be good, when actions for preventing high operative temperatures were made.

The indoor air quality was considered to be good in the open landscapes when normal air quantities were used. The supply air quantities in the open landscapes were controlled by temperature. The results from the simulations showed that air quantities should have been higher than normal and controlled by temperature and CO_2, in order to achieve a good indoor air quality in meeting rooms.

13 Further work

A proposal for hurter work is to perform actual measurements for the thermal indoor climate in Powerhouse Kjørbo during summer- and winter conditions. The results from these measurements can be evaluated against the results for thermal indoor climate in this thesis.

The measurements can also be used to verify that the thermal indoor climate in Powerhouse Kjørbo is acceptable during extreme conditions. The measurements can be carried out using a device for measuring operative temperature.

The results from this thesis showed that Meeting room.4206 experienced the lowest temperatures during winter conditions. If actual measurements for the thermal indoor climate are performed, it should at least be carried out measurements in this room.

14 References

AVSTAND.ORG. Available: http://no.avstand.org/fornebu/sandvika [Accessed 13.08.2014.

DIREKTORATET FOR BYGGKVALITET 2010. Veiledning om tekniske krav til byggverk. Direktoratet for byggkvalitet.

DJURIC, N., FEILBERG, N., BAKKEN, B., ANDRESEN, I., HAASE, M. & MURPHY, M. 2010. Overview of available simulation tools in our environment. The Research Centre on Zero Emission Buildings.

EQUA SIMULATION AB. 2010. *Validation in accordance with NS-EN 15265:2007* [Online]. Available: http://www.equaonline.com/iceuser/validation/CEN_VALIDATION_EN_15255_AND_15265.pdf [Accessed 31.08.2014 2014].

EQUA SIMULATION AB. 2014. *IDA Indoor Climate and Energy* [Online]. Available: http://www.equa.se/index.php/en/ida-ice [Accessed 11.09.2014 2014].

INTERNATIONAL ENERGY AGENCY 1992. Annex 20 Air Flow Patterns within Buildings, Airflow through large openings in buildings. International Energy Agency.

JENSEN, B. 2013. Powerhouse Kjørbo - Romklimatiske simuleringer. Skanska Norge AS.

MATHISEN, H. M. 26.08.2014 2014. *RE: Personal communication.*

METEREOLOGISK INSTITUTT. 2013. *Årsmiddeltemperaturer i Norge, sortert alfabetisk* [Online]. Forbrukerrådet. Available: http://www.forbrukerradet.no/_attachment/1130013/binary/7701 [Accessed 25.08.2014.

MIDTBUST, H. M. 2014. *IDA ICE.*

NEXANS. 2013. Varmehåndboka 2013/2014. Available: http://www.nexans.no/eservice/Norway-no_NO/fileLibrary/Download_540156630/Norway/files/2013_Varmehandboka_LAV_1.pdf.

NTNU SINTEF 2007. *ENØK i bygninger: effektiv energibruk,* Oslo, Gyldendal undervisning.

POWERHOUSE ALLIANSEN 2012. Sluttrapport forprosjekt Powerhouse Kjørbo.

PROGRAMBYGGERNE ANS. *Validation in accordance with NS-EN 15265:2007* [Online]. Available: http://www.programbyggerne.no/SIMIEN/doku.php/validering [Accessed 31.08.2014 2014].

SNØHETTA. 2013. *Powerhouse Kjørbo plan 2 bygg 4* [Online]. Available: https://service.projectplace.com/pp/pp.cgi/0/696359333#folder/865388008.

SNØHETTA. 2014. *Powerhouse Kjørbo* [Online]. Available: http://snohetta.com/project/40-powerhouse-kjorbo.

STANDARD NORGE 2007a. NS-EN 15251:2007. Standard Norge.

STANDARD NORGE 2007b. NS 3031:2007. Standard Norge.

THE ENERGY SYSTEMS RESEARCH UNIT. *ESP-r* [Online]. Available: http://www.esru.strath.ac.uk/Programs/ESP-r.htm.

TRNFLOW 2009. A module of an air flow network for coupled simulation with TYPE 56 (multi-zone building of TRNSYS), Version 1.4.

TRNSYS. 2014. *What is TRNSYS?* [Online]. Available: http://www.trnsys.com/ [Accessed 31.08.2014 2014].

U.S. DEPARTMENT OF ENERGY. 2013. *EnergyPlus Energy Simulation Software* [Online]. Available: http://apps1.eere.energy.gov/buildings/energyplus/ [Accessed 07.09.2014 2014].

15 Attachments

Attachment 1 - Setup for the simulation model

Partitioning of zones

The second floor in building 4 was the main focus in the simulations, and every room at this floor was defined as a separate zone. For the rest of the building, neighboring rooms with the same usage patterns was gathered into common zones. This was done to simplify the simulation model and minimize the simulation time in IDA ICE.

The basements for the two buildings weren't considered to be a part of the simulations.

IDA ICE utilizes equal temperature for a zone, meaning that a zone has no vertical variation in temperature. In reality, there will be a temperature difference between the lower and the upper level of a zone (room). Regarding the staircases, the intention was to divide the stairs into zones for each floor and then connect these with horizontal openings. This would prevent the effect of equal zone temperature, which a staircase that is constructed over several floors has. Unfortunately, the horizontal openings can't be constructed in IDA ICE, and the staircases were therefore constructed over several floors.

Global data

The location for the simulation model was chosen to be Oslo (Fornebu), which is located 6 kilometers in linear distance from Powerhouse Kjørbo in Sandvika. (avstand.org)

Oslo/Fornebu_ASHRAE was chosen as climate for the simulation model. Default urban was considered to fit the wind profile for the simulation model. The only selectable option for holidays in IDA ICE, were "public holiday in Sweden". Due to this, there was not chosen any holidays for the simulation model in IDA ICE.

External wall

Several different external walls are being used in Powerhouse Kjørbo. To simplify the simulation model, there was made a standard wall for the external walls.

According to the feasibility study for Powerhouse Kjørbo, the U-value for external walls has been calculated to be 0.13 W/(m^2*K). The calculations are carried out by Byggforsk. (Powerhouse Alliansen, 2012)

The chosen external wall (yv01) consists of:

- 22 mm burned wood panels
- 68 mm aeration
- 15 mm asphalt plate (extruded polystyrene)
- 100 mm studs/insulation (heavy insulation)
- 100 mm insulation (heavy insulation)

- Diffusion barrier (extruded polystyrene)
- 100 mm studs/insulation (heavy insulation)
- 15 mm internal lining

When adding this information to the defaults in IDA ICE, the U-value for the external wall became 0.145 W/(m^2*K). This U-value was used in the simulations, even though the U-value has been calculated to be 0.13 W/(m^2*K) in the feasibility study for Powerhouse Kjørbo. The thickness of the external wall was 0.425 m.

Internal wall

Several different internal walls are being used in Powerhouse Kjørbo. According to the plan drawings, the two most common internal walls are iv02 (internal wall 02) and iv04 (internal wall 04). (Snøhetta, 2013)

Iv02 consists of:

- 12.5 mm gypsum
- 100 mm insulation
- 12.5 mm gypsum

Iv04 consists of:

- 2 x 12.5 mm gypsum
- 100 mm insulation
- 2 x 12.5 mm gypsum

Instead of having two different internal walls, the chosen internal wall was an average between iv02 and iv04. This was done to simplify the simulation model. The chosen internal wall used in IDA ICE consisted of:

- 23 mm gypsum
- 100 mm studs/insulation
- 23 mm gypsum

This give a thickness of 0.146 m and a U-value of 0.3168 W/(m^2*K).

The internal walls for the toilets and shafts are made in the existing concrete walls. However, these internal walls were drawn in IDA ICE with the same U-value and thickness as the rest of the internal walls in the simulation model. This was done to simplify the simulation model.

Internal floor

The slabs were made in 200 mm concrete. (Powerhouse Alliansen, 2012)

Roof

According to the feasibility study for Powerhouse Kjørbo, the Roof consists of:

- 200 mm concrete floor
- 0.2 mm plastic film (extruded polystyrene)
- 450 mm insulation (heavy insulation)
- 2 mm roofing (extruded polystyrene)

When adding this information to the defaults in IDA ICE, the U-value for the roof became 0.07783 W/(m^2*K). This gives the roof a total thickness of 0.6522 m. According to the calculations, which have been carried out in the feasibility study for Powerhouse Kjørbo, the U-value for the roof has been calculated to be 0.082 W/(m^2*K). Nevertheless, the U-value of 0.07783 W/(m^2*K) was used in the simulations in IDA ICE.

External floor

Because of the decision of excluding the basements for both building 4 and building 5, the first floor is considered to face the ground.

According to the feasibility study for Powerhouse Kjørbo, the U-value for the external floors facing the ground, has been calculated to be 0.117 W/(m^2*K). The external floor consists of two layers of concrete with a layer of insulation between. The U-value was improved by adding at least 100 mm of insulation. (Powerhouse Alliansen, 2012)

In IDA ICE, the external floor was constructed with these materials:

- 5 mm floor coating
- 37 mm concrete
- 425 mm insulation (heavy insulation)
- 0.5 mm diffusion barrier (extruded polystyrene)
- 200 mm concrete

According to IDA ICE, this resulted in a U-value of 0.1173 W/(m^2*K) and a thickness of 0.6675 m for the external floor.

Glazing and windows

The window area at Powerhouse Kjørbo stands for 40 % of the total façade area. In the simulation model, the windows were designed with a total U-value of 0.80 W/(m^2*K), which corresponds with the U-value that actually are being used. The transmittance was set to 68 % and the emissivity was set to 3.7 %. The widows consist of triple glazing, where two of the layers are equipped with low emitting coatings. The glazing area stands for 82 % of the total window area. (Powerhouse Alliansen, 2012)

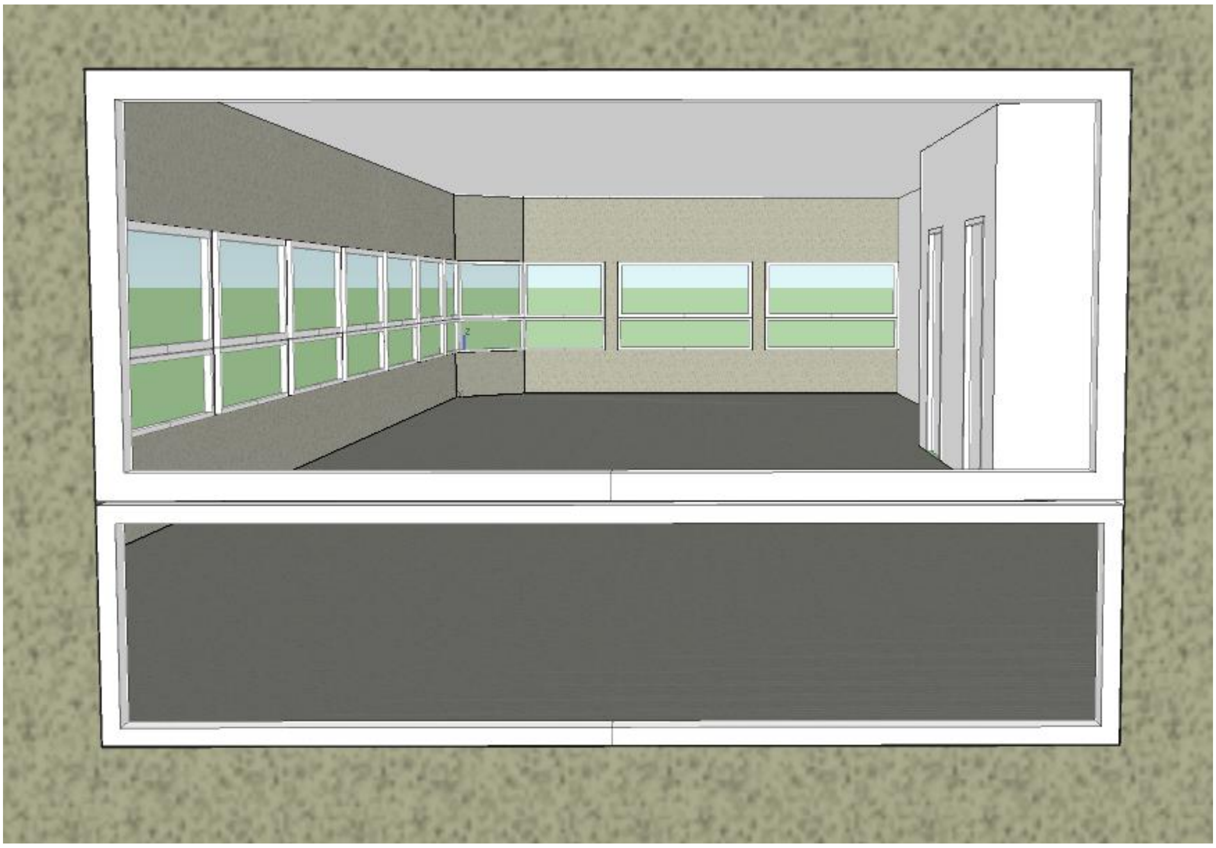


Figure 26: Upper and lower window. (Midtbust, 2014)

Figure 26 shows the design of the windows that was used in the simulation model. The upper window is a fixed window, while the lower window is able to open for window aeration in office cells, meeting rooms and open landscapes.

Various opening schedules were used for the windows during the simulations.

Doors

The internal doors, which were used in the making of the simulation model, were designed with the same U-value as the internal walls.

A discharge coefficient (C_d) of 0.65 was used for the internal doors in the simulation model in IDA ICE. The leak area for closed internal doors was set to 0.01 m^2.

External window shading

According to the feasibility study for Powerhouse Kjørbo, the windows are equipped with external window shading. The users of the buildings are able to control their local indoor environment by using the window shading. (Powerhouse Alliansen, 2012)

External window shading was implemented in Simulation 11.

Thermal bridges

According to the feasibility study for Powerhouse Kjørbo, the normalized thermal bridge value is calculated to U = 0.02. (Powerhouse Alliansen, 2012)

IDA ICE allows one to set the thermal bridge value for several types of joint. A thermal bridge value of 0.02 was added for all types of thermal bridges in IDA ICE.

Ground properties

Default ground with insulation was chosen for both ground layers under basement slab and outside basement walls. These ground layers consists of:

- 0.1 m insulation
- 1.0 m soil

This resulted in a U-value of 0.29 W/(m^2*K) and a thickness of 1.1 m.

Ventilation strategy

The ventilation strategy in Powerhouse Kjørbo is based on both CAV and VAV. The office cells are designed with CAV, while larger meeting rooms and open landscapes are designed with VAV. The VAV was set to be controlled by temperature.

Displacement ventilation was chosen as ventilation principle. The stratification value was set to 1 in IDA ICE, which stands for displacement ventilation. This was done for all zones in the simulation model. Unfortunately, only rectangular zones, such as the office cells, could be implemented with displacement ventilation in IDA ICE. Mixed ventilation was therefore applied to the non-rectangular zones.

The return air flow was designed to use the stairs, as extract ducts. At the top floor in each building, the return air from all floors below were gathered and brought into the ventilation unit. The zones, except for copy rooms and toilets, were only designed with air supply.

Ventilation units

Name	Served zones	Area, m2	Zone required min supply, L/s	Zone required max supply, L/s	Zone required min return, L/s	Zone required max return, L/s
AHU 5	5	1905.1	2060.6	2060.6	2060.6	2060.6
AHU 4	16	1603.1	1508.4	2894.9	1809.2	3146.1
Supply air only (no return side)	20	443.77	632.4	632.4	0.0	0.0
Return air only (no supply side)	8	123.05	0.0	0.0	369.15	369.15

Figure 27: Air quantities for the ventilation units.

Figure 27 shows the air quantities for the different ventilation units. "AHU 5" was designed to ventilate Building 5. "AHU 4" was designed to ventilate the VAV zones in Building 4. "Supply air only" was designed to supply the CAV zones in Building 4 with ventilation air, while "Return air only" was designed to extract ventilation air from toilets and copyrooms.

Supply air temperatures

The supply air temperature was set to 19 °C. The reason for choosing a high supply air temperature was due to the displacement ventilation. By choosing a low supply air temperature when using displacement ventilation, there's a risk of causing draught. To prevent draught, the supply air temperature was set to 19 °C in the simulation model in IDA

ICE. Because of choosing a high supply air temperature, the cooling potential for the ventilation was reduced.

Air flows

In reality, there is a physical connection between the air flows in Building 4 and 5, since they are both using the main stairs as an extract duct. Despite this, the physical connection between these air flows was eliminated by using closed doors. This was done to simplify the simulation model, and was considered to not have any effect on the air flows in Building 4. The location of the closed doors is shown in Figure 28.

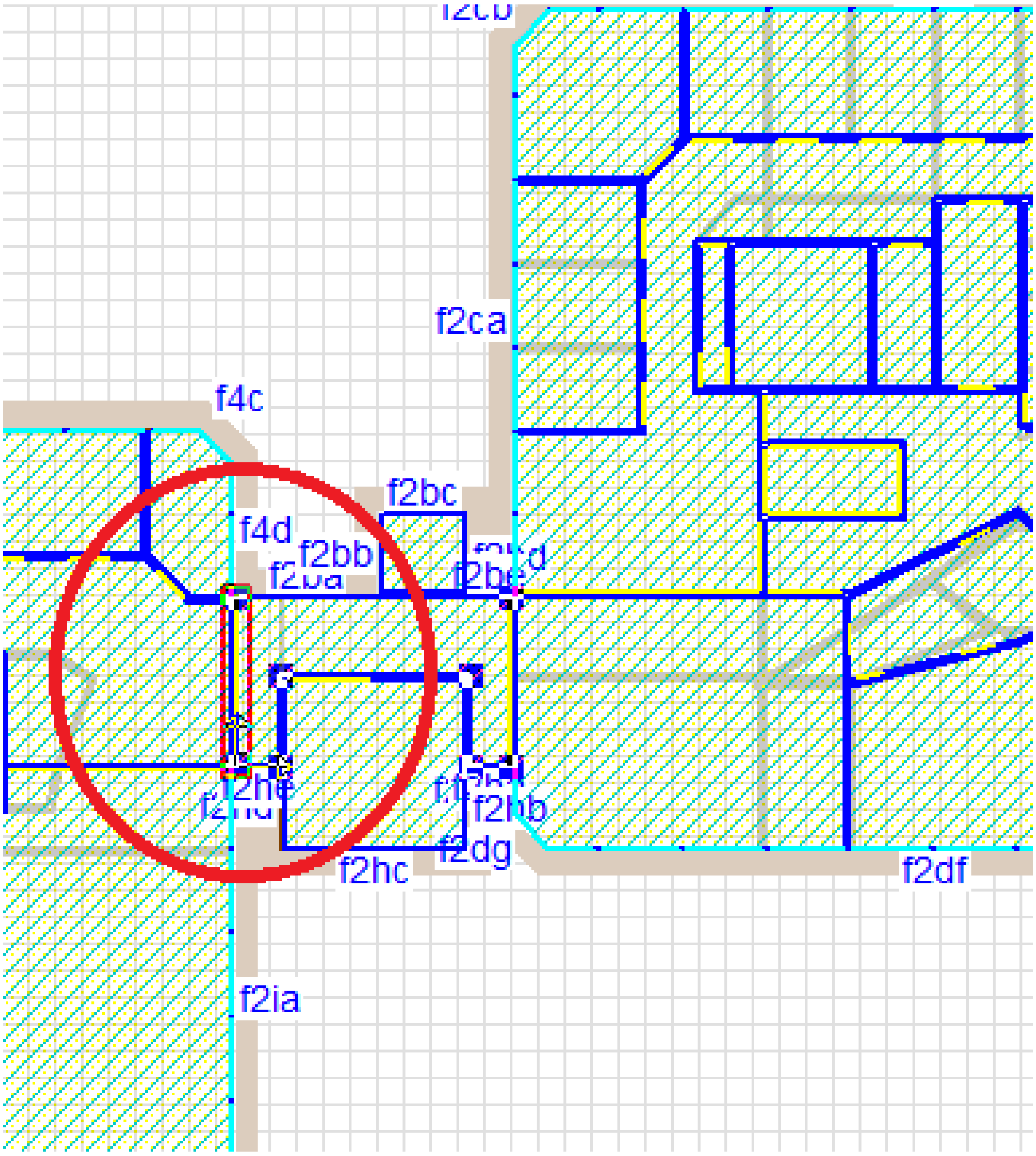


Figure 28: Closed doors between Building 4 and Building 5. (Midtbust, 2014)

Ventilation of Building 5

The zones, located in Building 5, were designed with CAV (Constant Air Volume). The amount of supplied air and extracted air were set to be equal.

As mentioned in earlier, the recommended air quantity for a category II building is 0.7 $l/(s*m^2)$ for the building itself and 7 l/(s*person) for occupants. (Standard Norge, 2007a)

According to the feasibility study for Powerhouse Kjørbo, the area per person was calculated to 19 m^2/ person. (Powerhouse Alliansen, 2012)

According to the Norwegian technical regulations (Teknisk forskrift), an area of 15 m^2/person is recommended for office buildings. (Direktoratet for byggkvalitet, 2010)

Despite this, an area of 19 m^2/ person was used for calculating the air quantities for Building 5 in the simulation model in IDA ICE.

$$\frac{7\ l/(s \cdot person)}{19\, m^2/person} = 0.368\ l/(s\ \cdot\ m^2) \approx 0.37\ l/(s\ \cdot\ m^2)$$

This resulted in an average air volume of:

$$Average\ air\ volume = 0.7\ l/(s\ \cdot\ m^2) + 0.37\ l/(s\ \cdot\ m^2) = 1.07\ l/(s\ \cdot\ m^2)$$

$$1.07\ l/(s\ \cdot\ m^2) = 3.852\ m^3/(h\ \cdot\ m^2)$$

This average value was added for the supply air and the return air for all zones in Building 5.

The average air volume of 3.852 $m^3/(h\ \cdot\ m^2)$ is higher than the minimum air quantity given in Norwegian technical regulation, which is 2.5 $m^3/(h\ \cdot\ m^2)$ during residence time.

Ventilation of Building 4

As mentioned previously in this thesis, the main focus is the second floor in Building 4. The occupancy and area for each zone in Building 4 were calculated. Further, the air quantity for each zone was calculated and added into the simulation model in IDA ICE. The reason for calculating the air quantity for all zones in Building 4 was for getting the air flows right, which was considered to be important.

According to the Norwegian technical regulations, a minimum extract air quantity of 3.6 m^3 per hour per m^2 floor area is required for rooms with high emitting equipment. This air quantity is equal to 1.0 l per second per m^2 floor area. (Direktoratet for byggkvalitet, 2010)

The required value in the Norwegian technical regulations is a minimum value. For the copy rooms in Building 4, the extracted air quantity was set to 3.0 l per second per m^2 floor area.

According to the Norwegian technical regulations, a minimum extract air quantity of 36 m^3 per hour per toilet is required. This air quantity is equal to 10 l/s per toilet. (Direktoratet for byggkvalitet, 2010)

The bathrooms at Powerhouse Kjørbo are each equipped with three toilets. This resulted in a total extract air quantity of 30 l/s for the bathrooms. The total floor area for each bathroom was calculated to be 17.55 m^2.

$$\frac{30\ l/s}{17.55\,m^2} = 1.71\ l/(s\ \cdot\ m^2)$$

An extract air quantity of 3 $l/s\ \cdot\ m^2$ was set for the bathrooms in Building 4 in the simulation model in IDA ICE.

For the rest of the zones in Building 4, the supply air quantity was calculated in accordance to equation B.1 in Annex B in NS-EN 15251:2007. The zones with CAV were designed with a constant air supply based on 100 % presence of the occupants. The zones with VAV were designed with a maximum air supply and a minimum air supply. The maximum air supply was calculated based on a presence of 100 % from the occupants, while the minimum air supply was calculated based on a presence of 0 % from the occupants. Examples of air quantity calculations are shown below.

Office cell.4203 (CAV) has a floor area of 8.828 m^2 and was designed for one person.

$$q_{tot} = 1\,person \cdot\ 7\ l/(s \cdot person) + 8.828\,m^2 \cdot 0.7\ l/(s\ \cdot\ m^2) = 13.18\ l/s$$

$$\dot{q} = \frac{13.18\ l/s}{8.828\,m^2} = 1.49\ l/(s\ \cdot\ m^2)$$

The total supplied air quantity for Office.4203 was calculated to 1.49 $l/(s\ \cdot\ m^2)$.

Meeting room.4206 (VAV) has a floor area of 23.7 m^2 and was designed for ten persons.

$$q_{tot,max} = 10\,person \cdot\ 7\ l/(s \cdot person) + 23.7\,m^2 \cdot 0.7\ l/(s\ \cdot\ m^2) = 86.59\ l/s$$

$$\dot{q} = \frac{86.59\ l/s}{23.7\,m^2} = 3.65\ l/(s\ \cdot\ m^2)$$

$$q_{tot,min} = 0\,person \cdot\ 7\ l/(s \cdot person) + 23.7\,m^2 \cdot 0.7\ l/(s\ \cdot\ m^2) = 16.59\ l/s$$

$$\dot{q} = \frac{16.59\ l/s}{23.7\,m^2} = 0.7\ l/(s\ \cdot\ m^2)$$

The maximal supplied air quantity for Meeting room.4206 was calculated to 3.65 $l/(s\ \cdot\ m^2)$, while the minimum supplied air quantity was calculated to 0.7 $l/(s\ \cdot\ m^2)$.

An equal calculation was performed for each zone in Building 4 and can be found in Table 45 in the Attachment 13.

Landscape.4416.4440, located in the fourth floor in Building 4, was equipped with the main extract air valve. The maximum extract air quantity was calculated to 3146 l/s, while the minimum extract air quantity was calculated to 1809 l/s.

The ventilation air volumes and strategies for Building 4 were designed with a high level of detailing in the simulation model in IDA ICE. As for Building 5, an average air volume was calculated in accordance with Annex B.1 in NS-EN 15251:2007.

Heating and cooling

The heating set point was set to 20°C and the cooling set point was set to 26°C in the simulation model in IDA ICE.

The office cells and meeting rooms on the second floor in Building 4 were not equipped with radiators in the simulation model in IDA ICE. The radiators were mounted in the open landscapes. This resulted in that the heating power was set to zero in all zones, except for the open landscapes and toilets (floor heating). For Building 5, each floor was installed with a heating power of 12 kW.

According to Bjørn Jensen`s report, the installed heating power in the open landscapes are set to 12 kW. (Jensen, 2013)

This value was used in the open landscapes, both at the second floor in Building 4 and for the other floors.

According to the floor plan for the second floor in Building 4 at Powerhouse Kjørbo, six radiators are installed. It was assumed that the radiators had the same power, which meant that each radiator had a power of 2 kW.

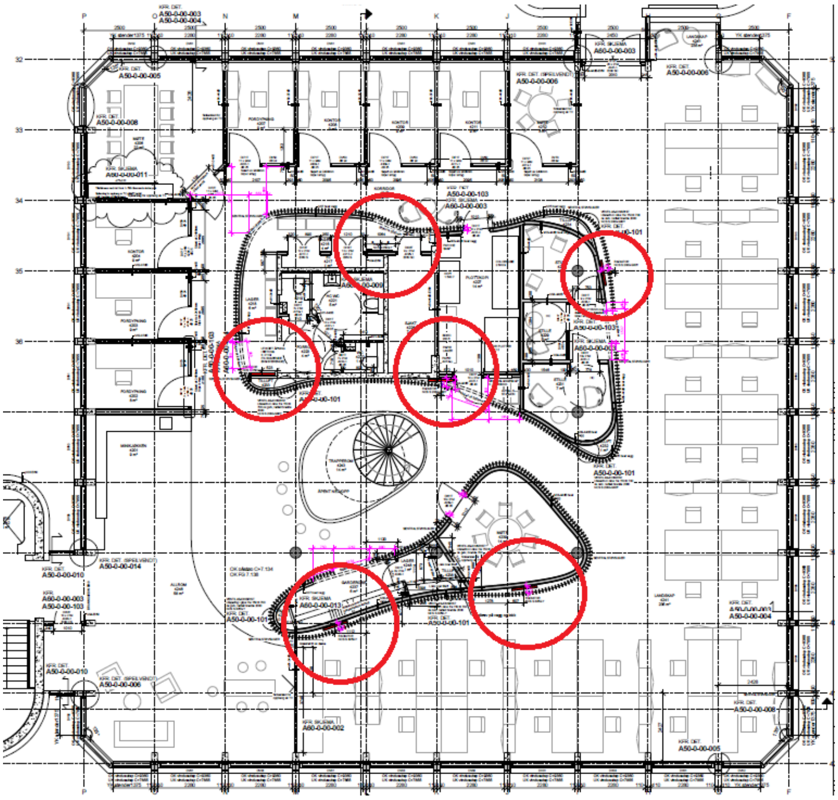


Figure 29: Radiator placing at the second floor in Building 4. (Snøhetta, 2013)

Figure 29 shows the radiator placing at the second floor in Building 4. Four of the radiators are placed in the open landscapes, while the two remaining radiators are placed by the toilets. The radiators in the simulation model in IDA ICE were placed in accordance with the floor plan. A heating power of 8 kW was installed in Landscape.4241, while the remaining 4 kW was installed in the zone storage unit.4216.4218. The location of these zones is shown in Figure 30.

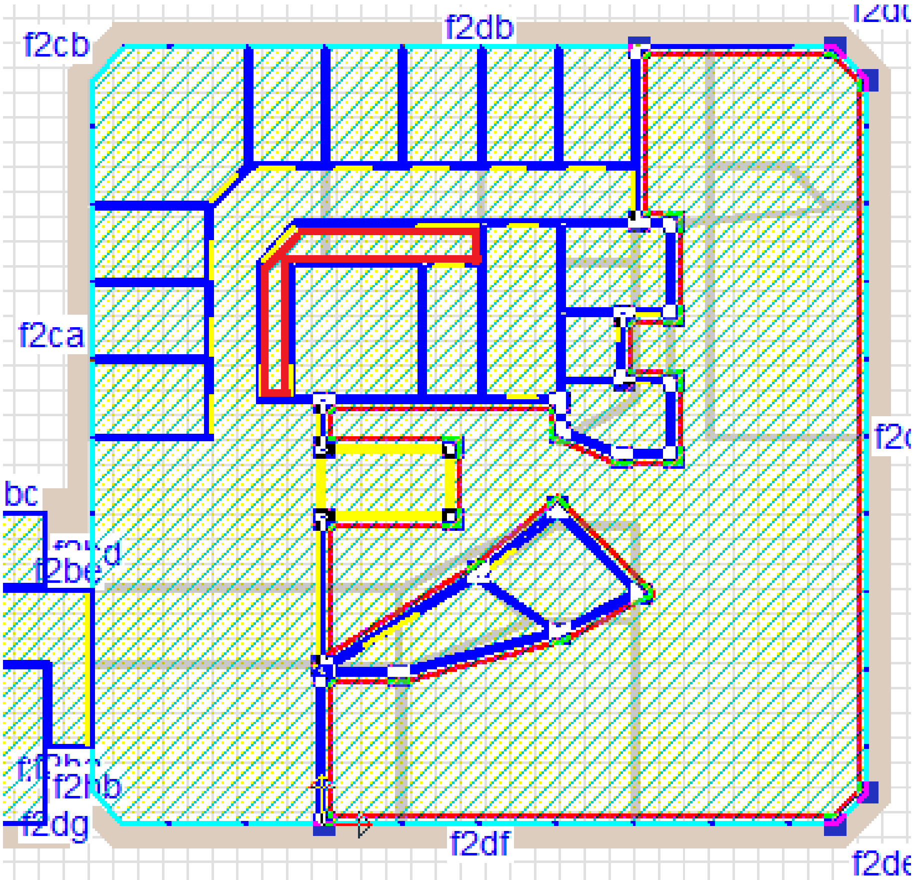


Figure 30: Location of the zones Landscape.4241 and Storage unit.4216.4218. (Midtbust, 2014)

According to Nexan's heat handbook (Varmehåndboka) for 2013/2014, a power of 120 to 150 W/m^2 floor, is recommended as surface power for toilets. (Nexans, 2013)

The toilets at the second floor in Building 4, was installed with a surface power of 120 W/m^2. The total floor area for the toilets at the second floor was calculated to be 17.5 m^2, which resulted in a total surface power of 2.1 kW.

None of the rooms at Powerhouse Kjørbo are equipped with cooling coils. The buildings are designed to avoid high indoor temperatures by using the ventilation systems, window aeration, external window shading and heavy constructions. (Powerhouse Alliansen, 2012)

Therefore, the cooling power was set to zero for all zones in the simulation model.

Internal gains

For the second floor in Building 4, various values for the occupancies and schedules were set for different simulations performed in IDA ICE. As for the rest of the building, these values were set as standard. This means that the occupants always were present.

According to the feasibility study for Powerhouse Kjørbo, the residence time is set to last between 06.00 and 18.00. (Powerhouse Alliansen, 2012)

Recommended values

Standardized values for average heat gain during operating time are given in Table A.2 in NS 3031:2007. The standard gives recommended values for lighting, equipment and occupancy in office buildings. The recommended values are 8 W/m^2 for lighting, 11 W/m^2 for equipment and 4 W/m^2 for occupants. (Standard Norge, 2007b)

Values for internal gains in the feasibility study for Powerhouse Kjørbo

According to the results from passive house evaluation performed in Simien (energy calculation program) in the feasibility study for Powerhouse Kjørbo, the average heat gain from equipment was set to be 6.0 W/m^2 during operating time. (Powerhouse Alliansen, 2012)

This value is significantly smaller than the recommended value in NS 3031:2007.

According to the feasibility study for Powerhouse Kjørbo, the energy demand for lighting was set to 3 W/m^2. (Powerhouse Alliansen, 2012)

According to the feasibility study for Powerhouse Kjørbo, the area per person was calculated to 19 m^2/ person. (Powerhouse Alliansen, 2012)

19 m^2 per person is equivalent to 0.052 occupants per m^2. An activity level of 1.2 met, results in a heat gain of 3.68 W/m^2 from the occupants. This value corresponds quite well with the recommended value in NS 3031:2007.

Chosen average values for internal gains in the simulation model in IDA ICE

The values for internal gains in the simulation model in IDA ICE were chosen based on the values given in the feasibility study for Powerhouse Kjørbo. This was done with the intention of making the simulation model as similar as possible to the actual building.

The internal gains from lighting were designed to be 3 W/m^2, and had an operating time between 06.00 and 18.00.

The internal gains from equipment were designed to be 6.0 W/m^2, and had an operating time between 06.00 and 18.00.

The internal gains from occupants were designed with occupancy of 0.052 occupants per m^2, and had a residence time between 06.00 and 18.00.

Chosen values for internal gains at the second floor in Building 4

The internal gains from lighting were designed to be 3 W/m^2, and had an operating time between 06.00 and 18.00. The lighting in offices and meeting rooms were designed with an operating time equal to the residence time.

Internal gains from occupants and equipment were implemented to the second floor by adding a reasonable number of occupants and units to each zone.

Each office cell was designed to have occupancy of one person per office. For the open landscapes, the number of workstations was counted in order to find the total number of occupants. For example Landscape.4241, which is the area for the workstations at the second floor, resulted in a number of 30 occupants. The residence time and presence for the occupants varied between the different rooms.

Rooms, with different usage patterns than office cells and open landscapes, were designed individually. For example, the storage unit and toilets were only designed with the internal gain from lighting.

The internal gains from equipment in the office cells and landscapes were set to 75 W per occupant. This value is a standard value from IDA ICE, and was considered to match the heat emission from a computer. The operating time for the equipment was mainly linked to the residence time in the actual room. Exceptions from this were for example made in the copy rooms, where the operating time for the equipment was set to last between 06.00 and 18.00.

The occupants were designed with a clothing level of clo = 1 for the whole year, except for July, which was set to a clothing level of clo = 0.5. The metabolic rate was set to 1.2 met, for both the users of the office cells and the open landscapes.

Attachment 2 - Simulation 1

Simulation period 01.01-31.01		
Parameter	**Set point / state**	**Comment**
Heating set point	20°C	
Doors	closed	Always closed
Windows	closed	Always closed
Occupancy Office 4204	1 Person	Occupancy from 08.00-16.00 with a presence of 75 % (30 min lunch break)
Occupancy Meeting room.4206	10 Persons	Occupancy between 09.00-11.00 and 13.00-16.00 with a presence of 50 %.
Occupancy open landscapes	30 Persons	Occupancy from 08.00-16.00 with a presence of 50 % (30 min lunch break)
Air supply temperature	19 °C	For the whole day
Run time per day for the air handling units	24 hours	
Installed heating power at the second floor	12 kW	
Clothing	1 Clo	
Air quantities	Normal	Building: 0.7 l/(s*m^2) Person: 7 l/(s*person)

Table 2: Parameters used in Simulation 1

Main temperatures

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	15.0	15.2
Minimum temperature	12.8	12.9
Maximum temperature	18.7	19.0

Table 3: Main temperatures for Meeting room.4206 in Simulation 1

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	17.8	17.7
Minimum temperature	16.3	16.2
Maximum temperature	20.8	20.5

Table 4: Main temperatures for Office.4203 in Simulation 1

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	20.1	20.3
Minimum temperature	20.0	20.1
Maximum temperature	20.6	20.7

Table 5: Main temperatures for Landscape.4241 in Simulation 1

Thermal indoor climate

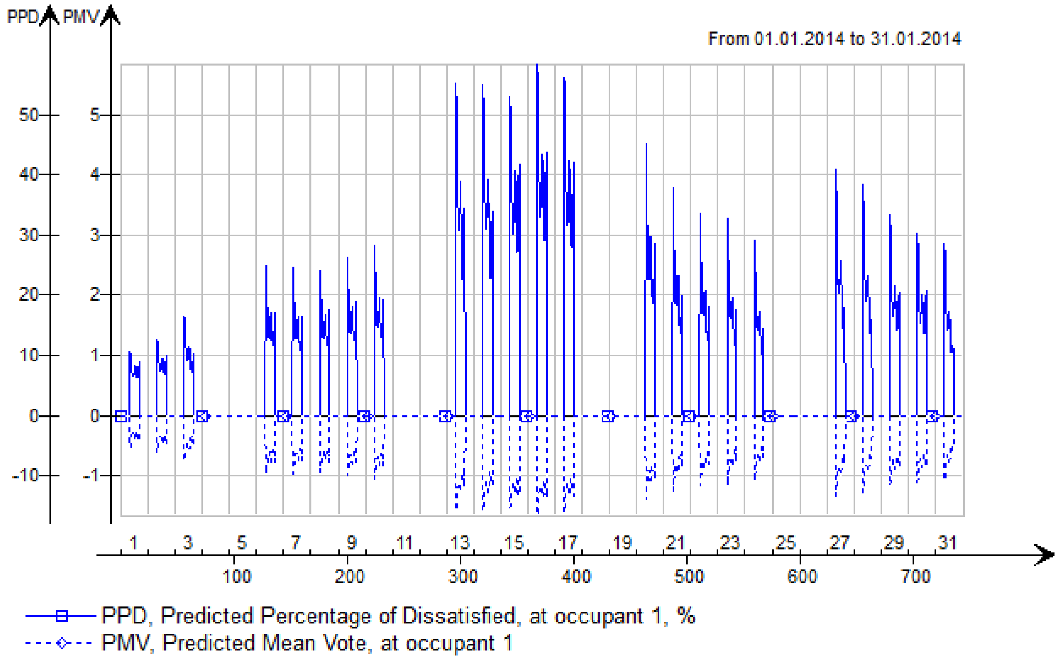


Figure 31: PPD and PMV for Meeting room.4206 in Simulation 1

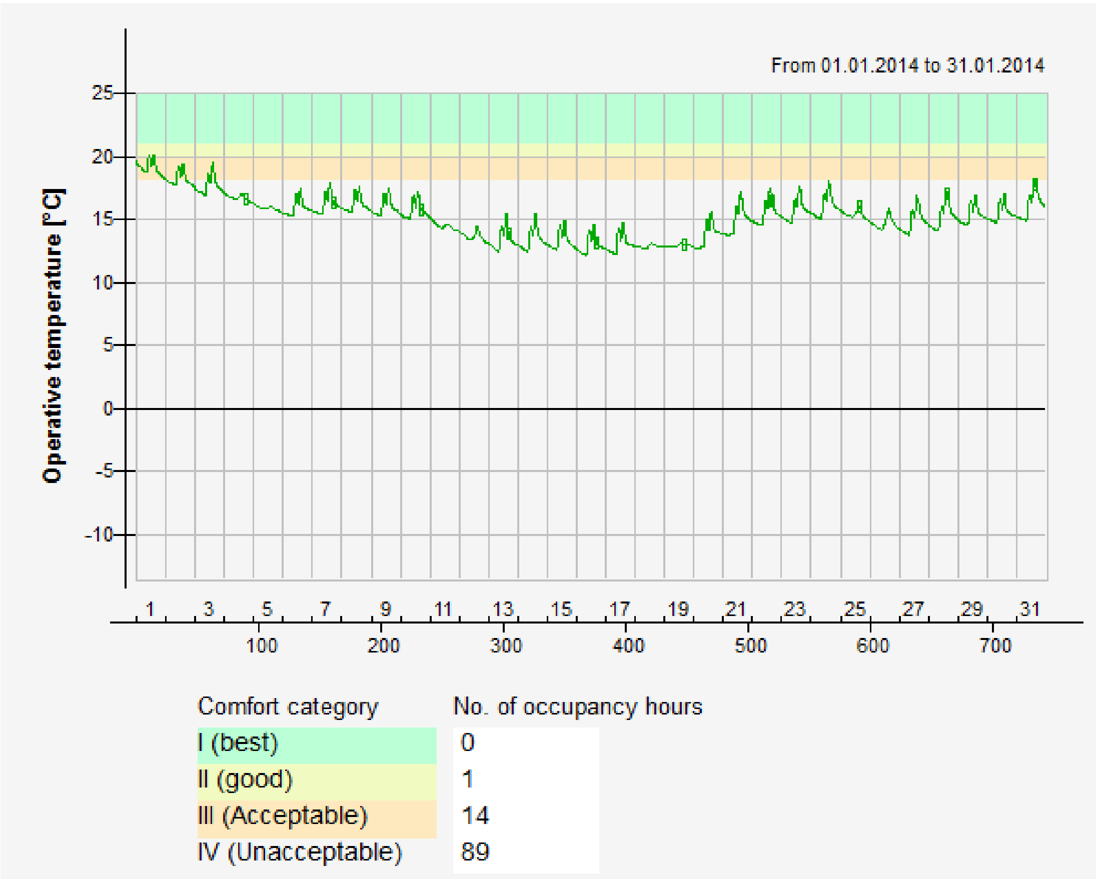


Figure 32: Thermal comfort for Meeting room.4206 according to EN 15251 in Simulation 1

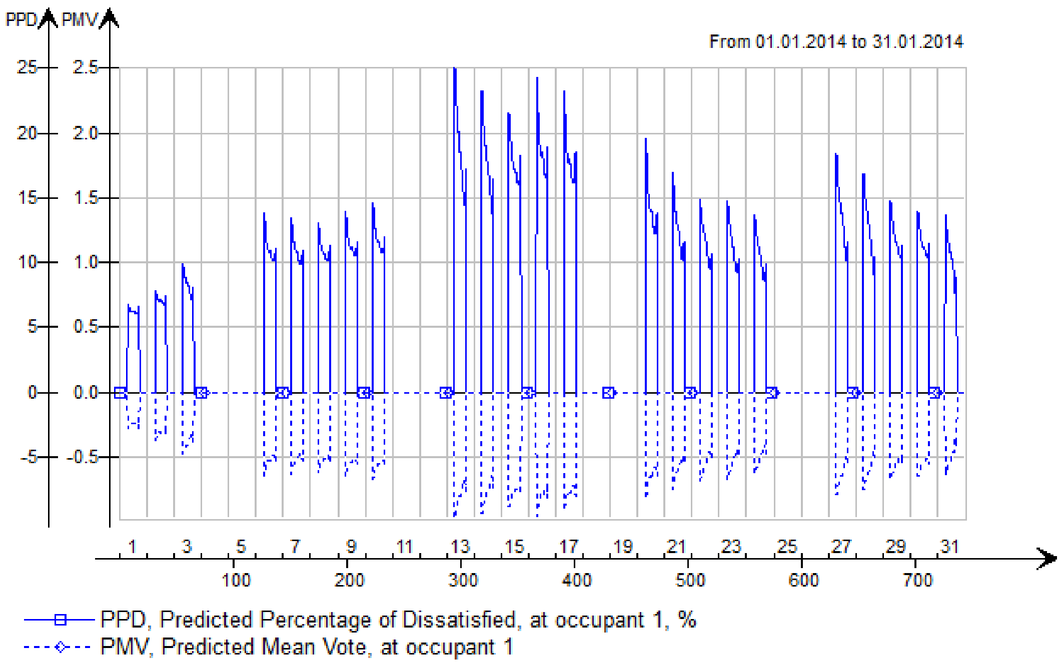


Figure 33: PPD and PMV for Office.4203 in Simulation 1

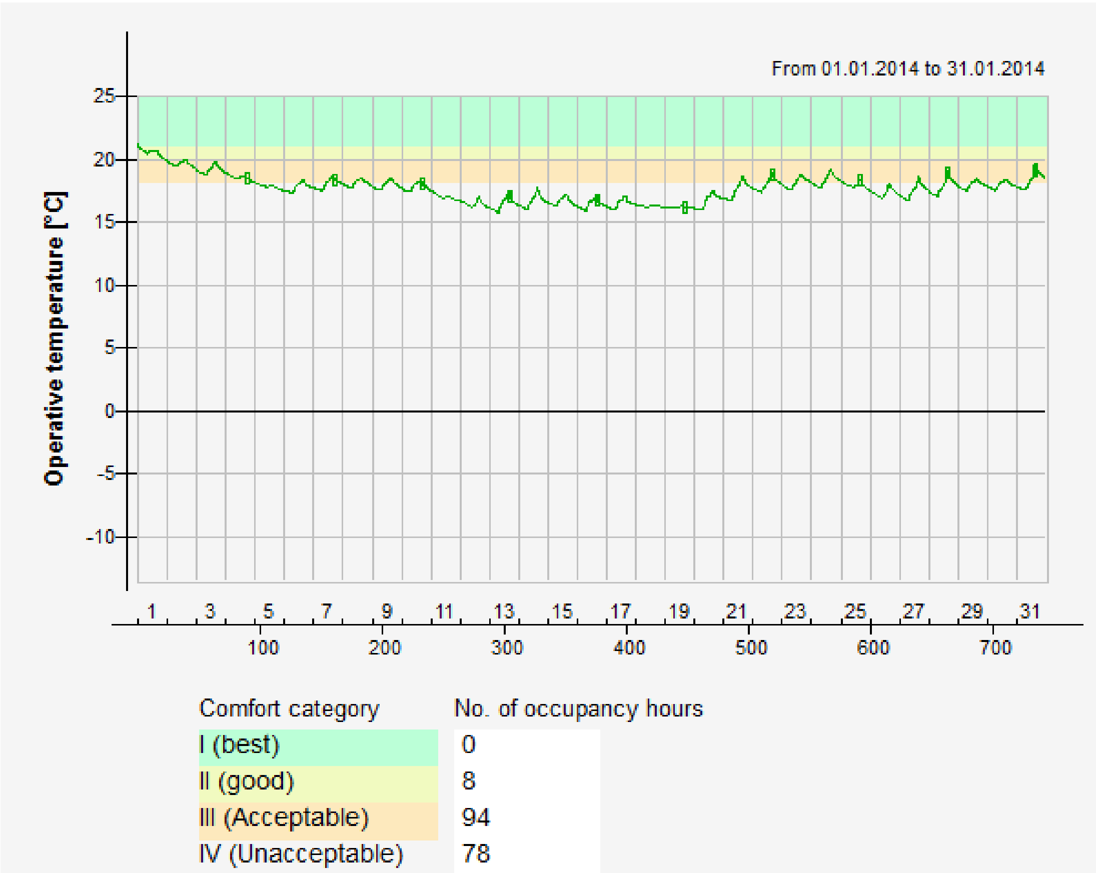


Figure 34: Thermal comfort for Office.4203 according to EN 15251 in Simulation 1

Attachment 3 - Simulation 2

Simulation period 01.01-31.01		
Parameter	**Set point / state**	**Comment**
Heating set point	20°C	
Doors	Closed/Open	Closed during residence time and open outside the residence time.
Windows	Closed	Always closed
Occupancy Office 4204	1 Person	Occupancy from 08.00-16.00 with a presence of 75 % (30 min lunch break)
Occupancy Meeting room.4206	10 Persons	Occupancy between 09.00-11.00 and 13.00-16.00 with a presence of 50 %.
Occupancy open landscapes	30 Persons	Occupancy from 08.00-16.00 with a presence of 50 % (30 min lunch break)
Air supply temperature	19 °C	For the whole day
Run time per day for the air handling units	24 hours	
Installed heating power at the second floor	12 kW	
Clothing	1 Clo	
Air quantities	Normal	Building: 0.7 $l/(s*m^2)$ Person: 7 l/(s*person)

Table 6: Parameters used in Simulation 2

Main temperatures

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	17.9	17.9
Minimum temperature	16.8	16.7
Maximum temperature	19.7	19.8

Table 7: Main temperatures for Meeting room.4206 in Simulation 2

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	19.0	18.9
Minimum temperature	18.4	18.2
Maximum temperature	20.8	20.5

Table 8: Main temperatures for Office.4203 in Simulation 2

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	20.1	20.3
Minimum temperature	20.0	20.1
Maximum temperature	20.6	20.8

Table 9: Main temperatures for Landscape.4241 in Simulation 2

Thermal indoor climate

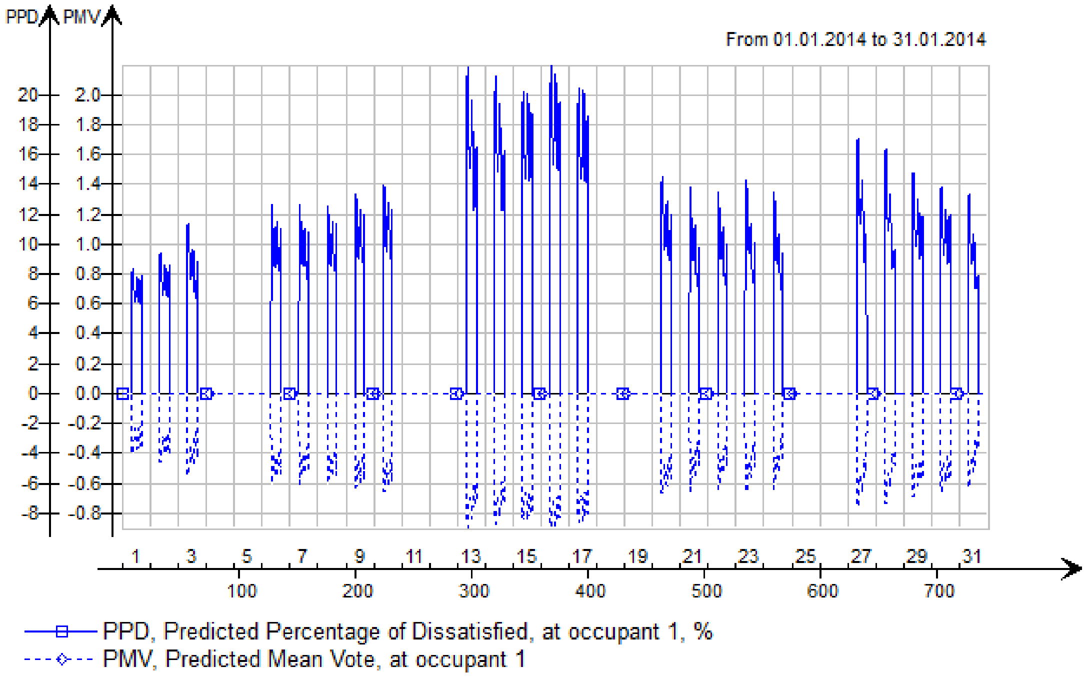


Figure 35: PPD and PMV for Meeting room.4206 in Simulation 2

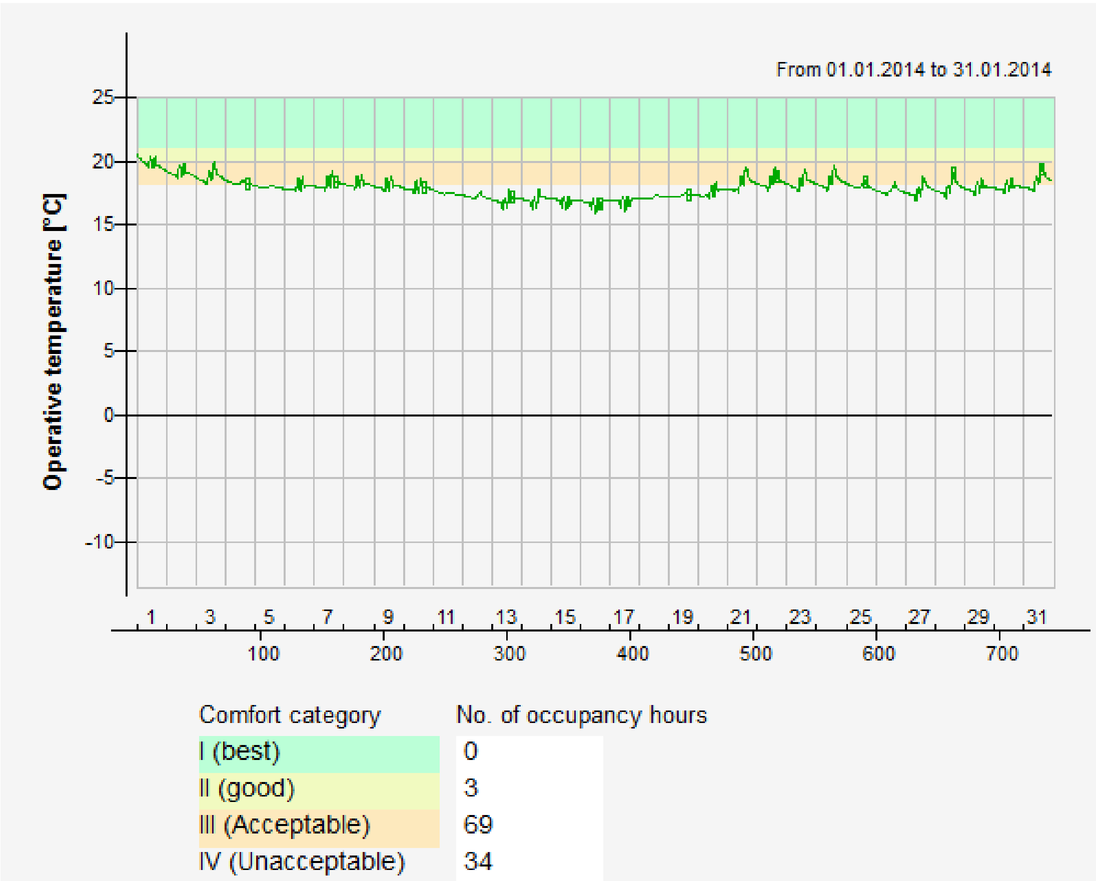


Figure 36: Thermal comfort for Meeting room.4206 according to EN 15251 in Simulation 2

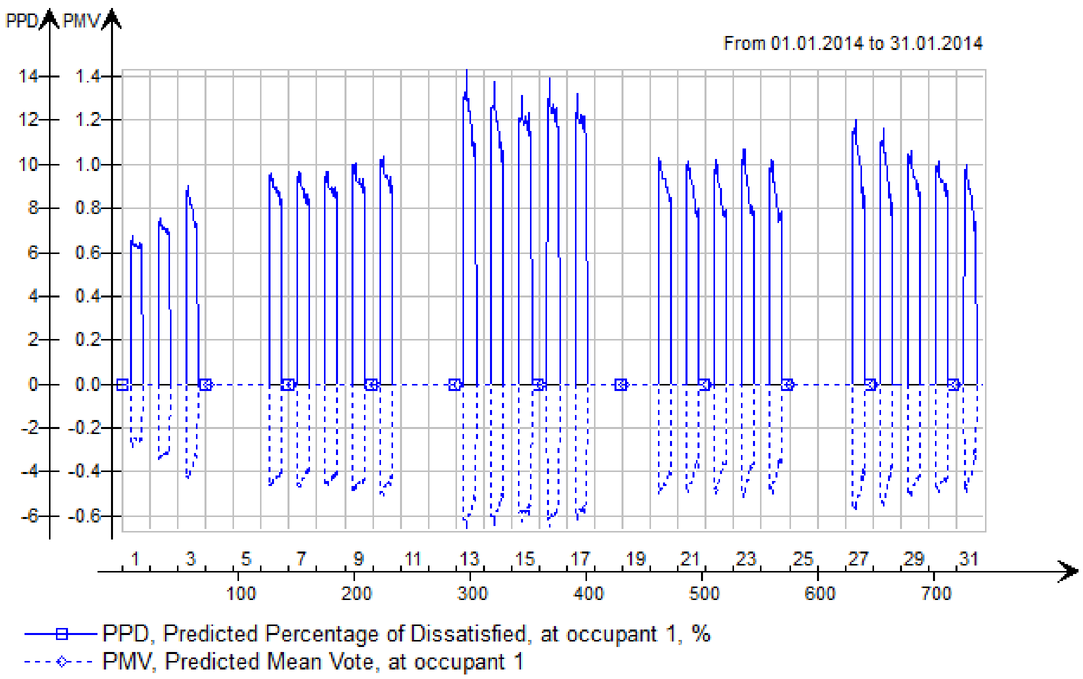


Figure 37: PPD and PMV for Office.4203 in Simulation 2

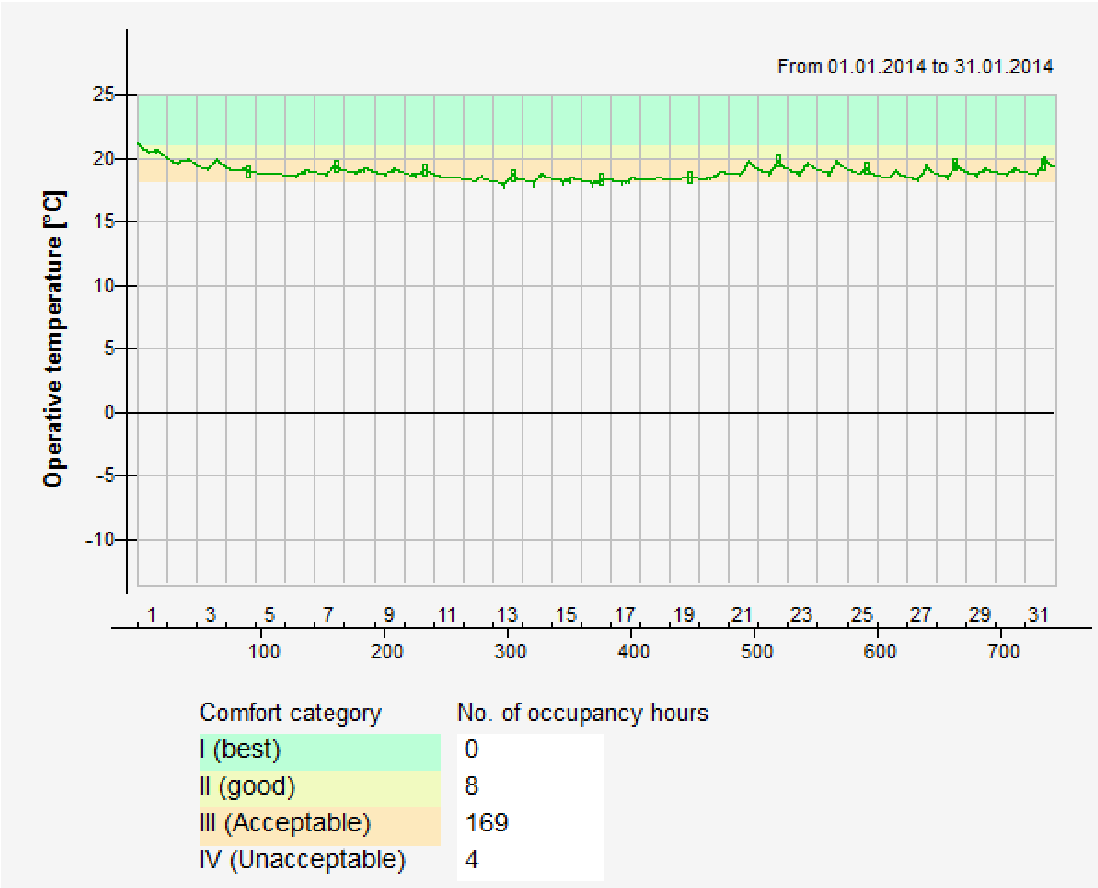


Figure 38: Thermal comfort for Office.4203 according to EN 15251 in Simulation 2

Attachment 4 - Simulation 3

Simulation period 01.01-31.01		
Parameter	**Set point / state**	**Comment**
Heating set point	20°C	
Doors	Open	Always open
Windows	Closed	Always closed
Occupancy Office 4204	1 Person	Occupancy from 08.00-16.00 with a presence of 75 % (30 min lunch break)
Occupancy Meeting room.4206	10 Persons	Occupancy between 09.00-11.00 and 13.00-16.00 with a presence of 50 %.
Occupancy open landscapes	30 Persons	Occupancy from 08.00-16.00 with a presence of 50 % (30 min lunch break)
Air supply temperature	19 °C	For the whole day
Run time per day for the air handling units	24 hours	
Installed heating power at the second floor	12 kW	
Clothing	1 Clo	
Air quantities	Normal	Building: 0.7 l/(s*m^2) Person: 7 l/(s*person)

Table 10: Parameters used in Simulation 3

Main Temperatures

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	18.2	18.1
Minimum temperature	17.4	17.2
Maximum temperature	19.8	19.9

Table 11: Main temperatures for Meeting room.4206 in Simulation 3

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	19.1	19.0
Minimum temperature	18.5	18.4
Maximum temperature	20.7	20.6

Table 12: Main temperatures for Office.4203 in Simulation 3

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	20.1	20.3
Minimum temperature	20.0	20.1
Maximum temperature	20.9	21.1

Table 13: Main temperatures for Landscape.4241 in Simulation 3

Thermal indoor climate

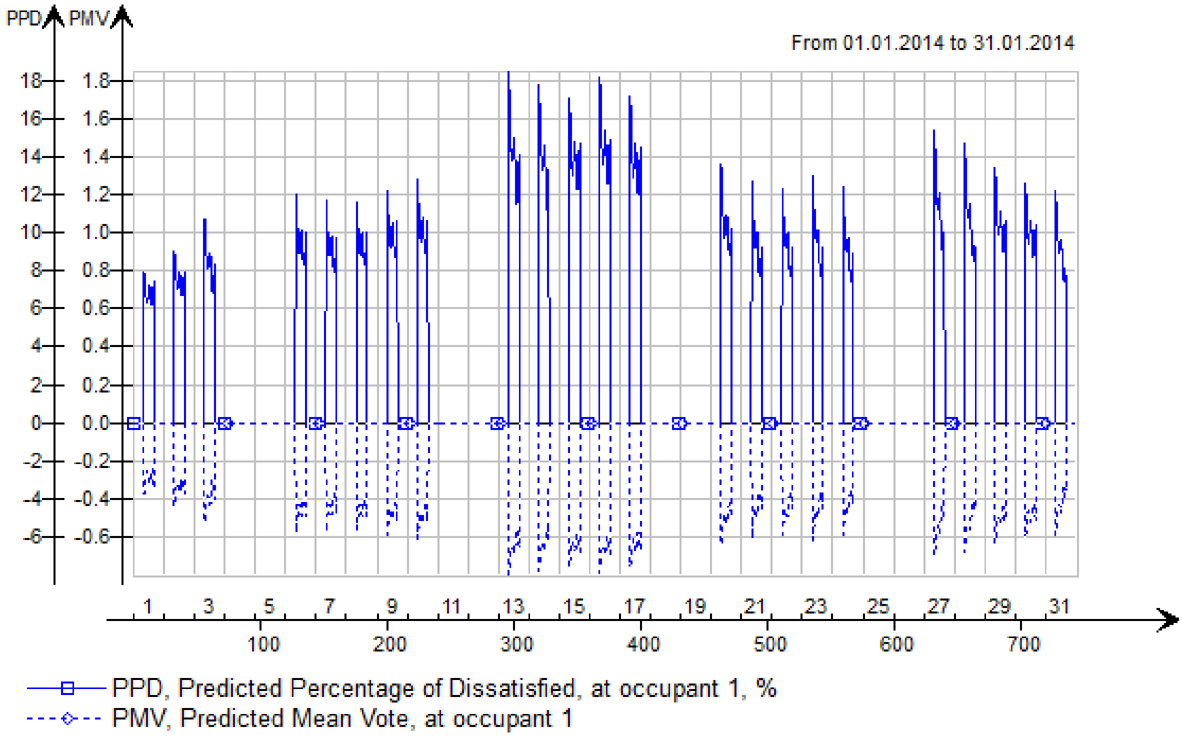


Figure 39: PPD and PMV for Meeting room.4206 in Simulation 3

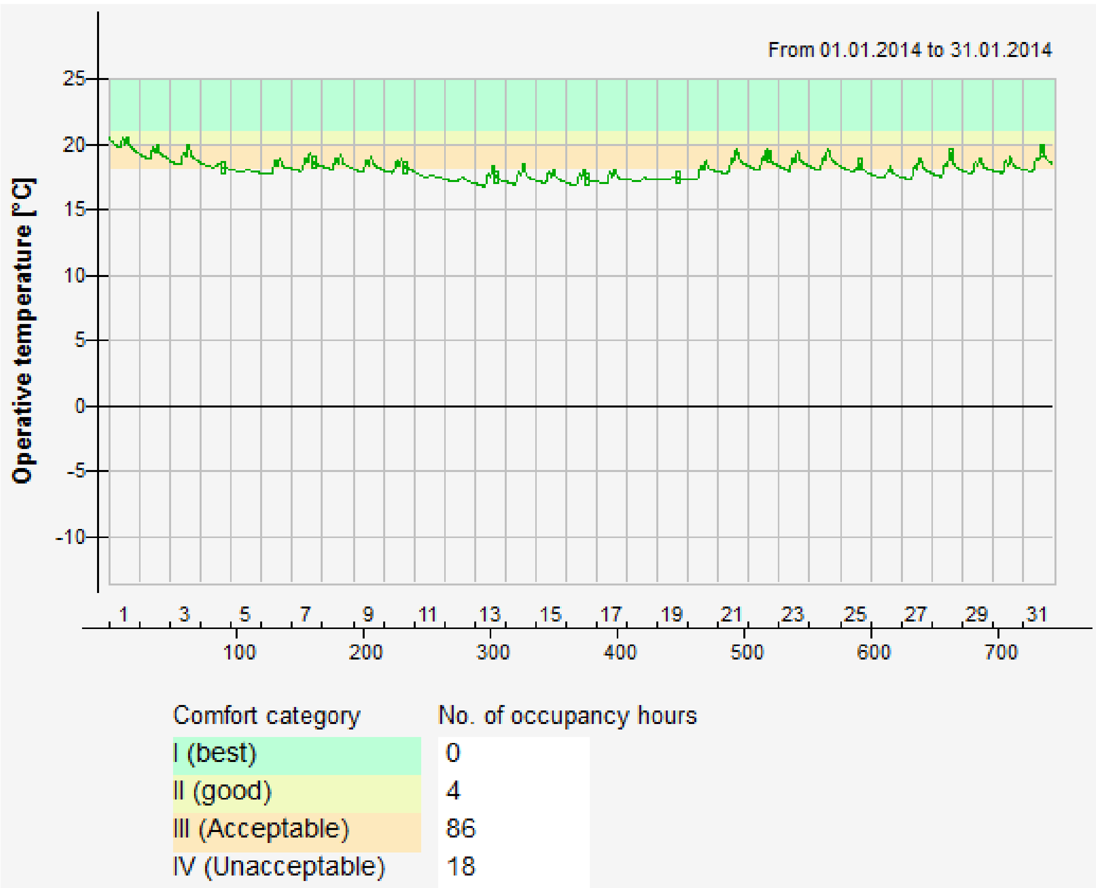


Figure 40: Thermal comfort for Meeting room.4206 according to EN 15251 in Simulation 3

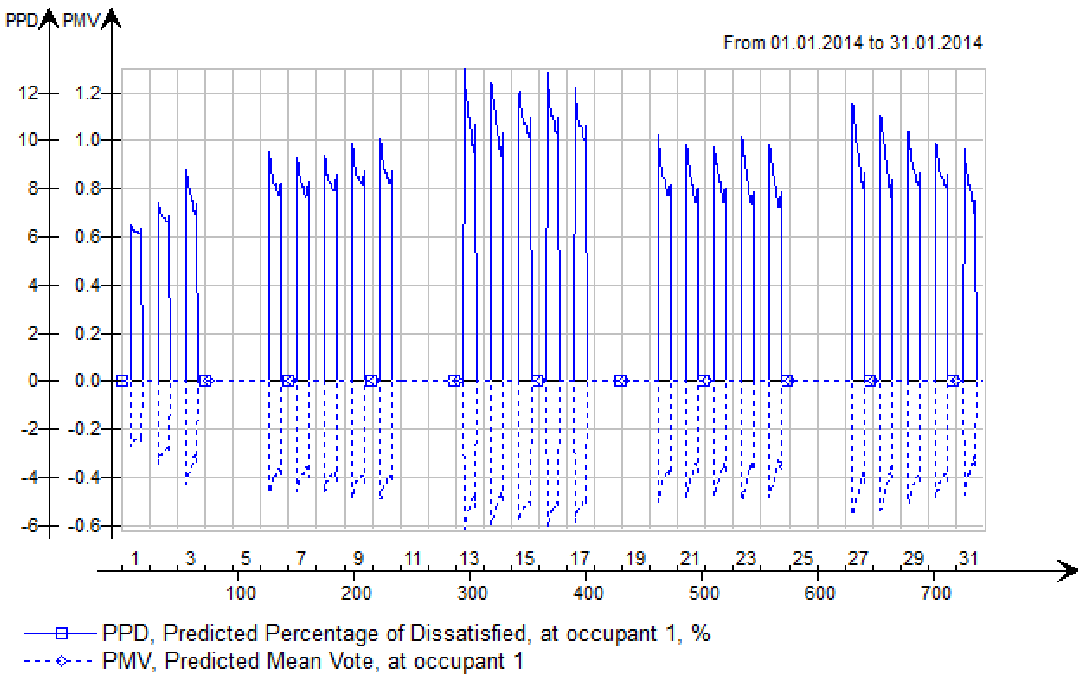


Figure 41: PPD and PMV for Office.4203 in Simulation 3

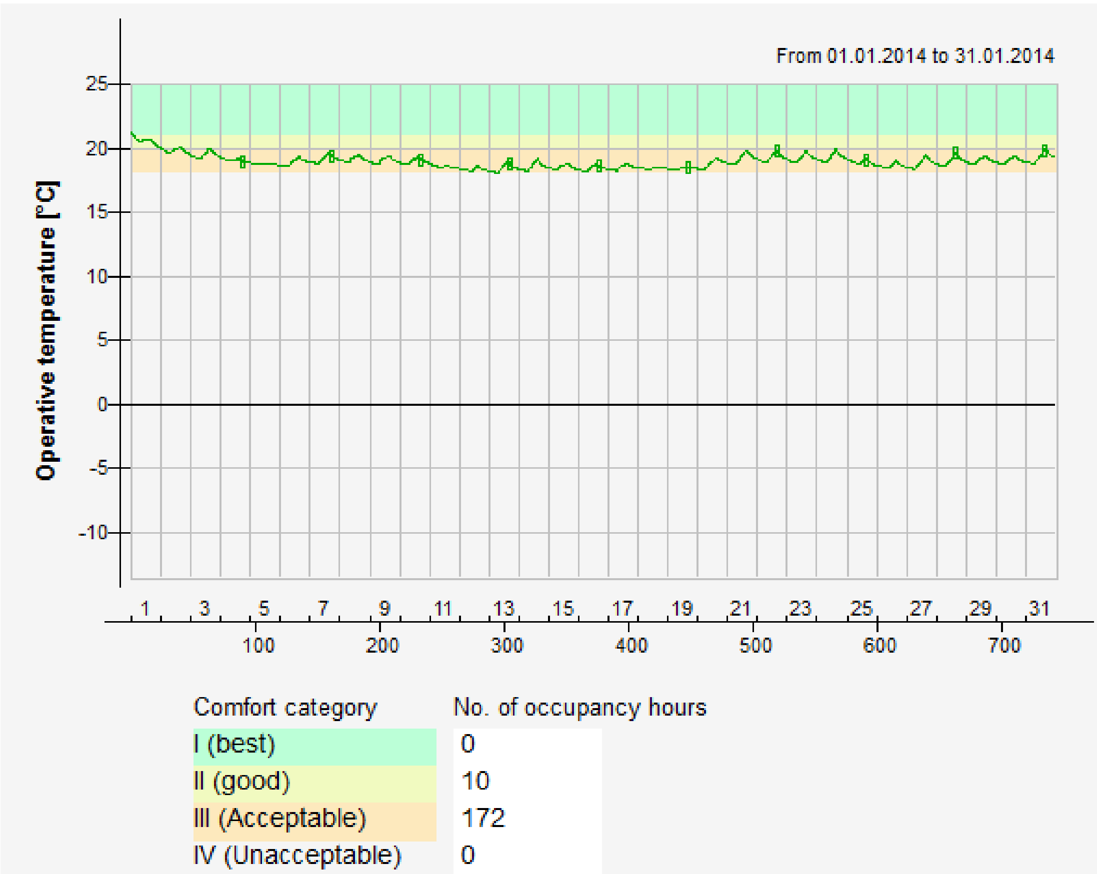


Figure 42: Thermal comfort for Office.4203 according to EN 15251 in Simulation 3. (Midtbust, 2014)(Midtbust, 2014)(Midtbust, 2014)(Midtbust, 2014)(Midtbust, 2014)(Midtbust, 2014)(Midtbust, 2014)(Midtbust, 2014)(Midtbust, 2014)(Midtbust, 2014)(Midtbust, 2014)(Midtbust, 2014)(Midtbust, 2014)

Attachment 5 - Simulation 4

Simulation period 01.01-31.01		
Parameter	**Set point / state**	**Comment**
Heating set point	20°C	
Doors	Closed/open	Closed during residence time and open outside the residence time.
Windows	Closed	Always closed
Occupancy Office 4204	1 Person	Occupancy from 08.00-16.00 with a presence of 100 % (30 min lunch break)
Occupancy Meeting room.4206	10 Persons	Occupancy between 09.00-11.00 and 13.00-16.00 with a presence of 100 %.
Occupancy open landscapes	30 Persons	Occupancy from 08.00-16.00 with a presence of 100 % (30 min lunch break)
Air supply temperature	19 °C	For the whole day
Run time per day for the air handling units	24 hours	
Installed heating power at the second floor	12 kW	
Clothing	1 Clo	
Air quantities	Normal	Building: 0.7 l/(s*m^2) Person: 7 l/(s*person)

Table 14: Parameters used in Simulation 4

Main temperatures

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	18.2	18.1
Minimum temperature	17.2	17.1
Maximum temperature	20.0	20.1

Table 15: Main temperatures for Meeting room.4206 in Simulation 4

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	19.1	18.9
Minimum temperature	18.5	18.3
Maximum temperature	20.9	20.7

Table 16: Main temperatures for Office.4203 in Simulation 4

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	20.2	20.4
Minimum temperature	20.0	20.1
Maximum temperature	21.2	21.3

Table 17: Main temperatures for Landscape.4241 in Simulation 4

Thermal indoor climate

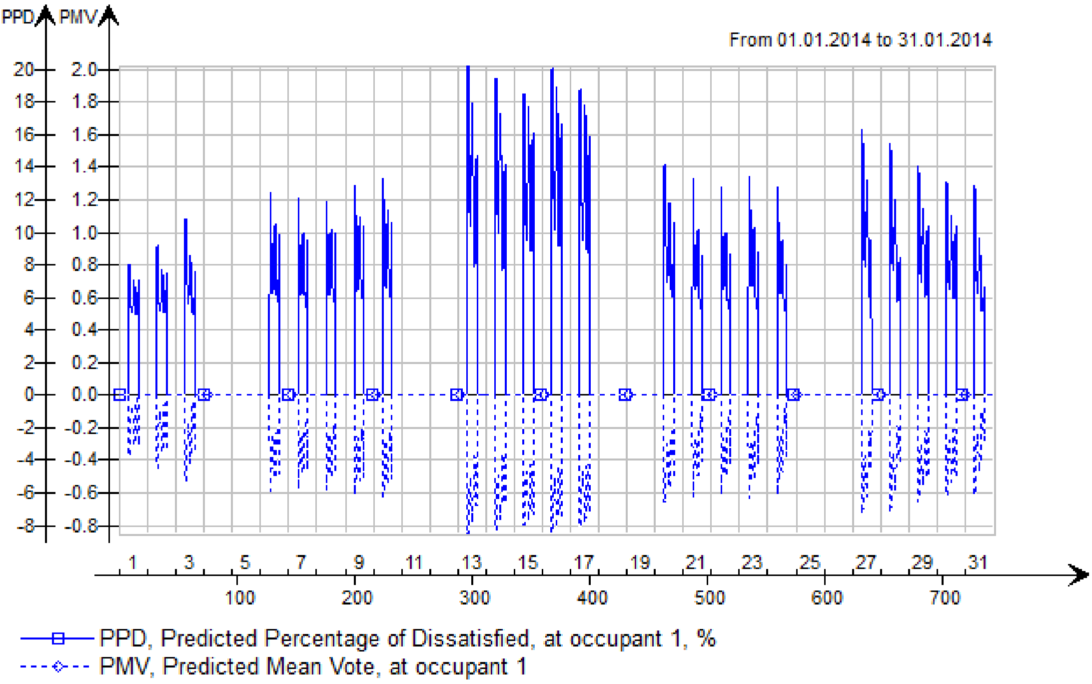


Figure 43: PPD and PMV for Meeting room.4206 in Simulation 4

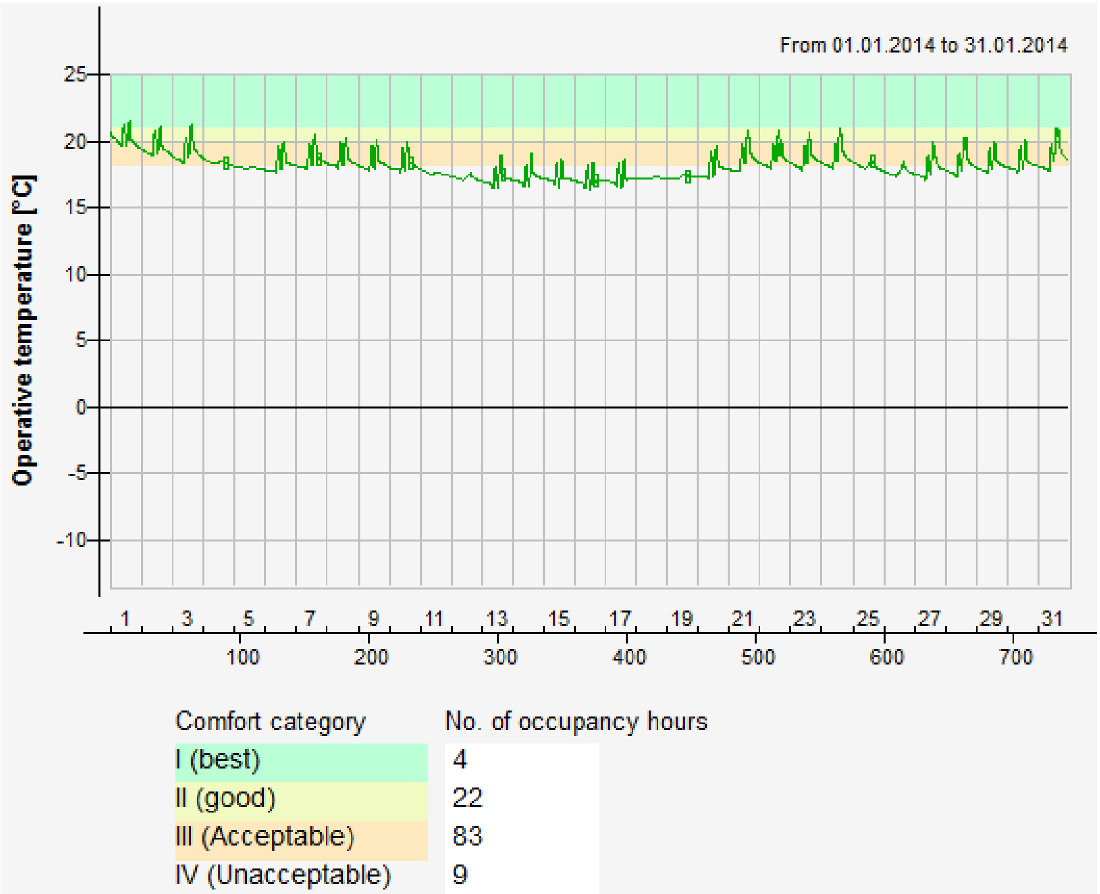


Figure 44: Thermal comfort for Meeting room.4206 according to EN 15251 in Simulation 4.

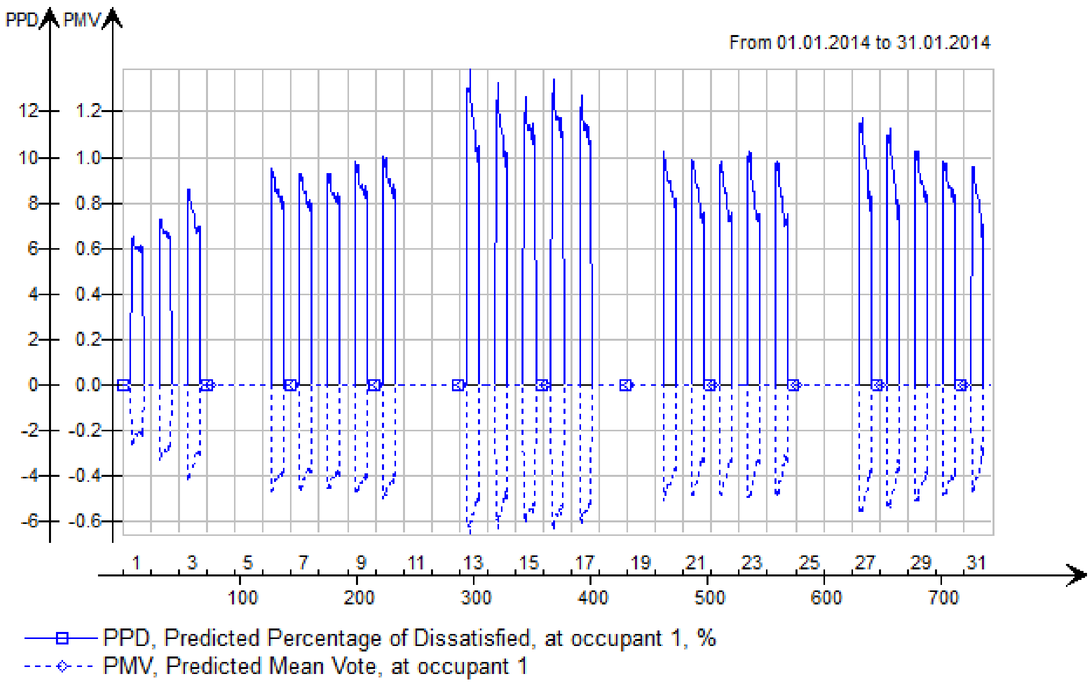


Figure 45: PPD and PMV for Office.4203 in Simulation 4

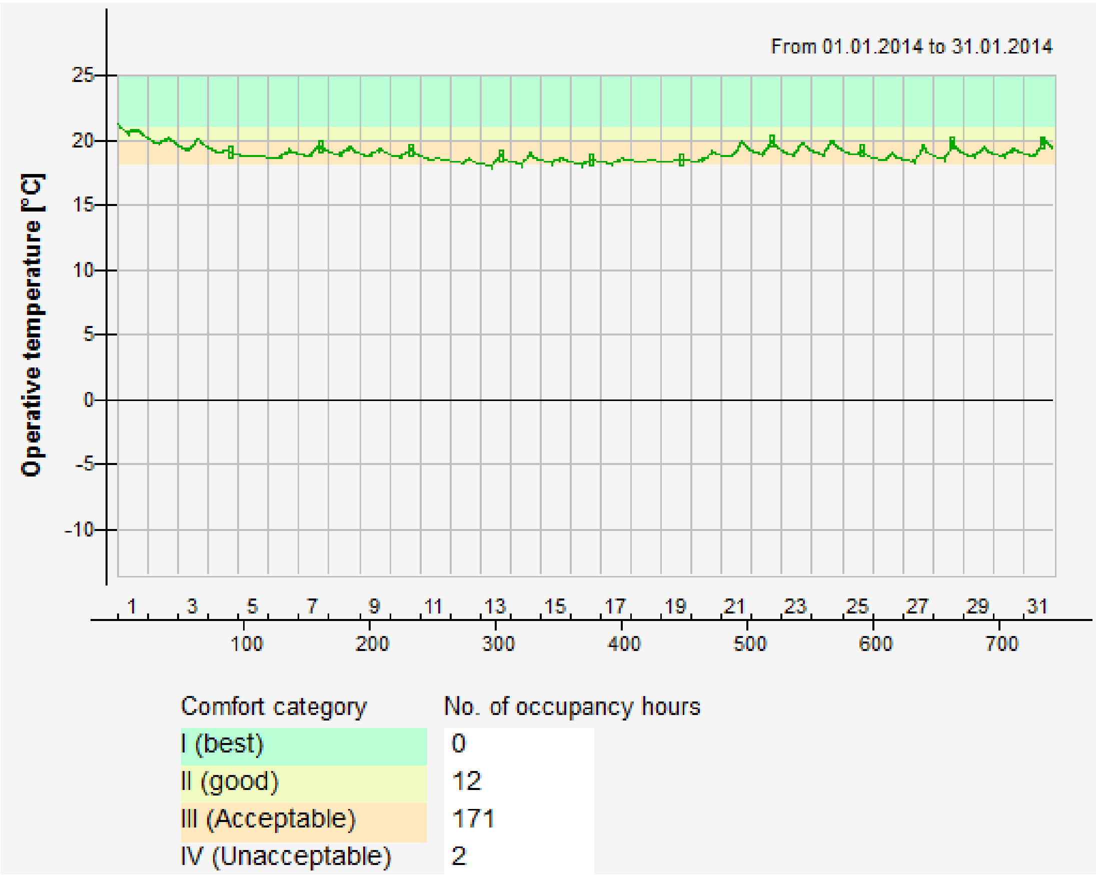


Figure 46: Thermal comfort for Office.4203 according to EN 15251 in Simulation 4.

Attachment 6 - Simulation 5

Simulation period 01.01-31.01		
Parameter	**Set point / state**	**Comment**
Heating set point	22°C	
Doors	Closed/Open	Closed during residence time and open outside the residence time.
Windows	Closed	Always closed
Occupancy Office 4204	1 Person	Occupancy from 08.00-16.00 with a presence of 75 % (30 min lunch break)
Occupancy Meeting room.4206	10 Persons	Occupancy between 09.00-11.00 and 13.00-16.00 with a presence of 50 %.
Occupancy open landscapes	30 Persons	Occupancy from 08.00-16.00 with a presence of 50 % (30 min lunch break)
Air supply temperature	19 °C	For the whole day
Run time per day for the air handling units	24 hours	
Installed heating power at the second floor	12 kW	
Clothing	1 Clo	
Air quantities	Normal	Building: 0.7 $l/(s*m^2)$ Person: 7 l/(s*person)

Table 18: Parameters used in Simulation 5

Main temperatures

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	20.3	20.2
Minimum temperature	19.7	19.5
Maximum temperature	21.0	21.0

Table 19: Main temperatures for Meeting room.4206 in Simulation 5

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	20.3	20.1
Minimum temperature	19.7	19.5
Maximum temperature	21.1	20.9

Table 20: Main temperatures for Office.4203 in Simulation 5

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	22.0	22.3
Minimum temperature	22.0	22.2
Maximum temperature	22.1	22.3

Table 21: Main temperatures for Landscape.4241 in Simulation 5

Thermal indoor climate

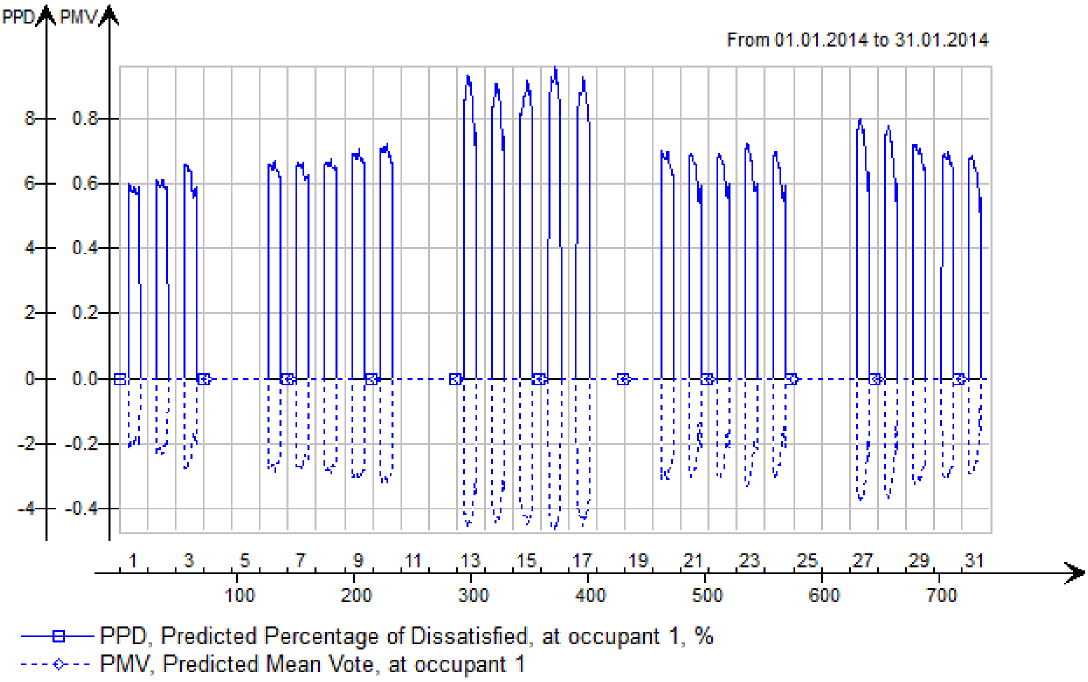


Figure 47: PPD and PMV for Meeting room.4206 in Simulation 5

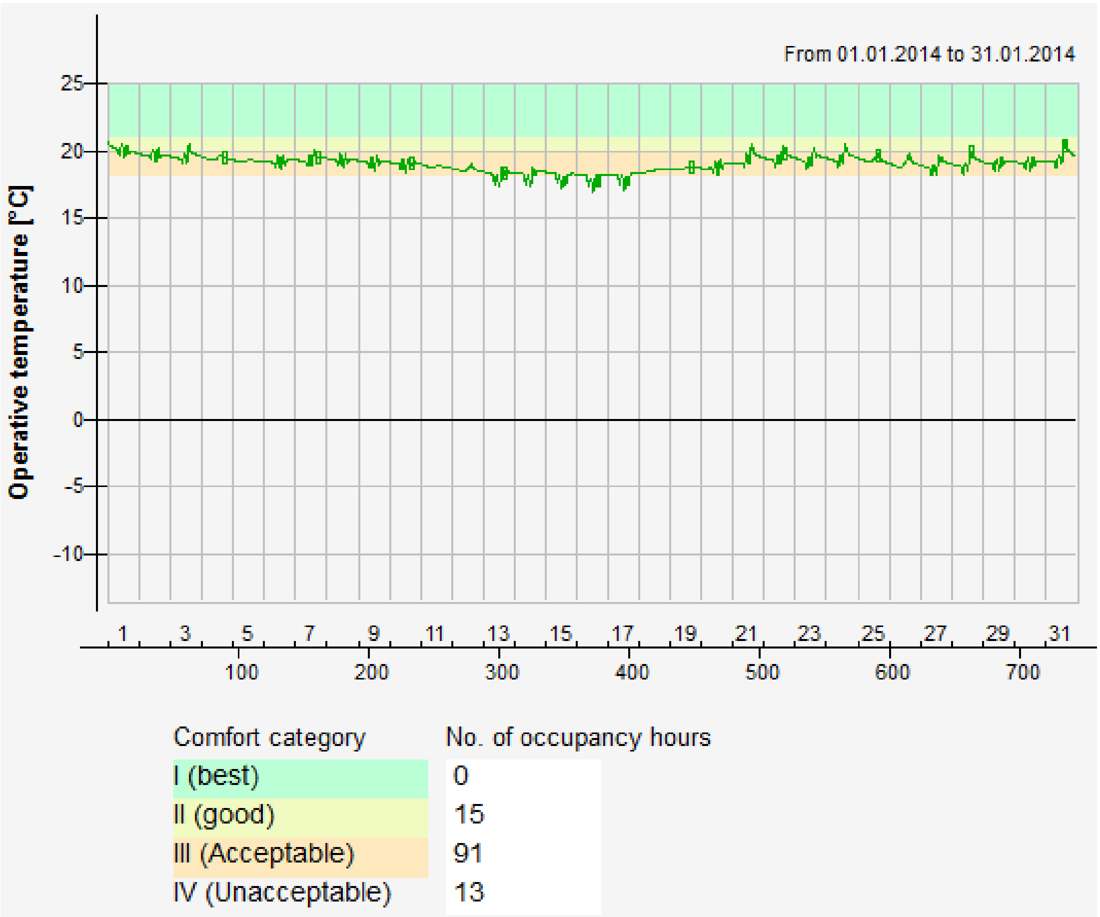


Figure 48: Thermal comfort for Meeting room.4206 according to EN 15251 in Simulation 5

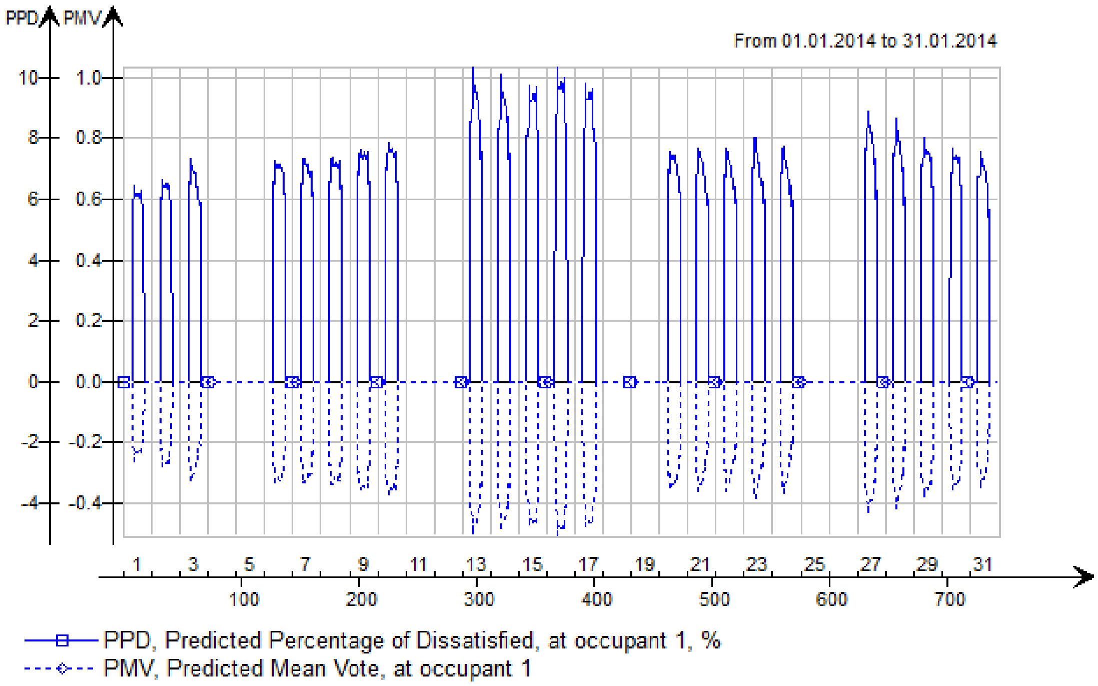


Figure 49: PPD and PMV for Office.4203 in Simulation 5

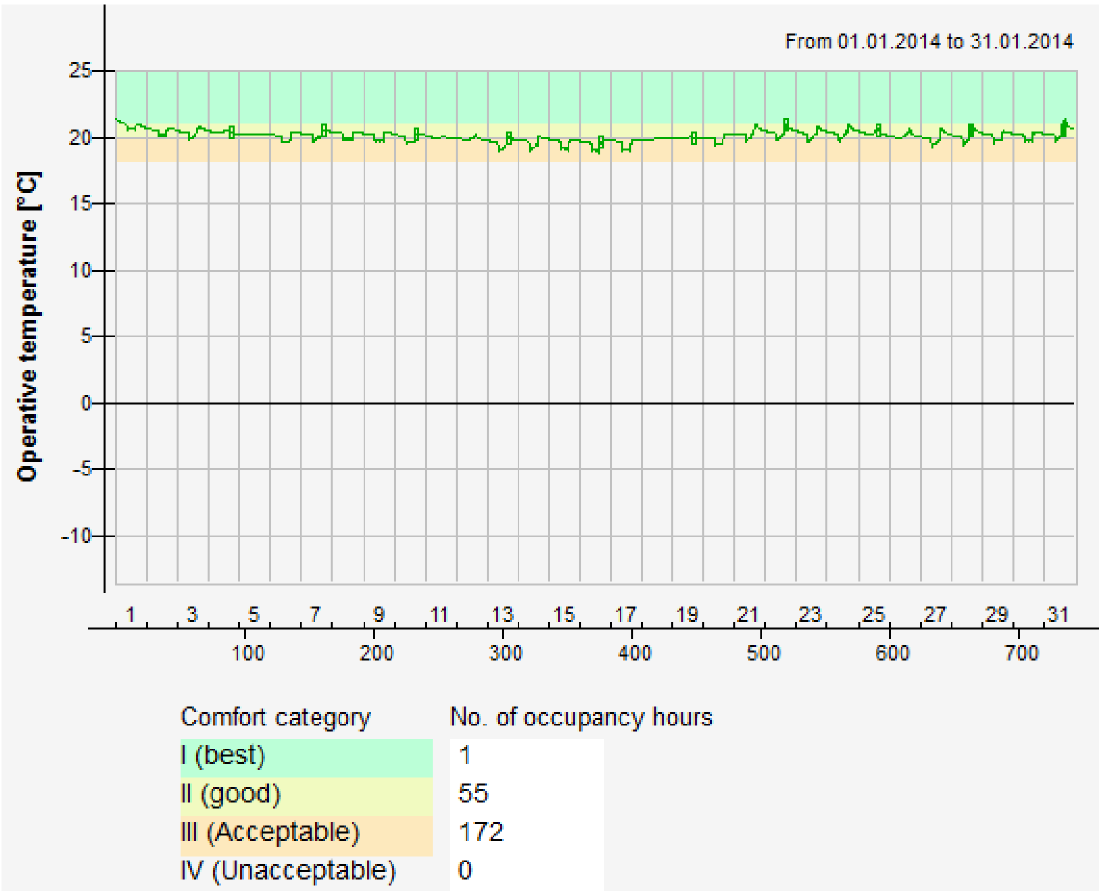


Figure 50: Thermal comfort for Office.4203 according to EN 15251 in Simulation 5

Attachment 7 - Simulation 6

Simulation period 01.08-31.08		
Parameter	**Set point / state**	**Comment**
Cooling set point	26°C	
Doors	Closed/Open	Closed during residence time and open outside the residence time.
Windows	Closed	Always closed
Occupancy Office 4204	1 Person	Occupancy from 08.00-16.00 with a presence of 100 % (30 min lunch break)
Occupancy Meeting room.4206	10 Persons	Occupancy between 09.00-11.00 and 13.00-16.00 with a presence of 100 %.
Occupancy open landscapes	30 Persons	Occupancy from 08.00-16.00 with a presence of 100 % (30 min lunch break)
Air supply temperature	19 °C	For the whole day
Run time per day for the air handling units	24 hours	
Installed cooling power at the second floor	0 kW	
Exterior sun shading		Not equipped
Clothing	0.5 Clo	
Air quantities	Normal	Building: 0.7 l/(s*m^2) Person: 7 l/(s*person)

Table 22: Parameters used in Simulation 6

Main temperatures

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	25.7	26.1
Minimum temperature	22.8	22.9
Maximum temperature	27.0	27.7

Table 23: Main temperatures for Meeting room.4206 in Simulation 6

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	25.5	25.2
Minimum temperature	22.2	21.9
Maximum temperature	27.5	27.1

Table 24: Main temperatures for Office.4203 in Simulation 6

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	24.8	25.0
Minimum temperature	22.3	22.4
Maximum temperature	26.1	26.4

Table 25: Main temperatures for Landscape.4241 in Simulation 6

Thermal indoor climate

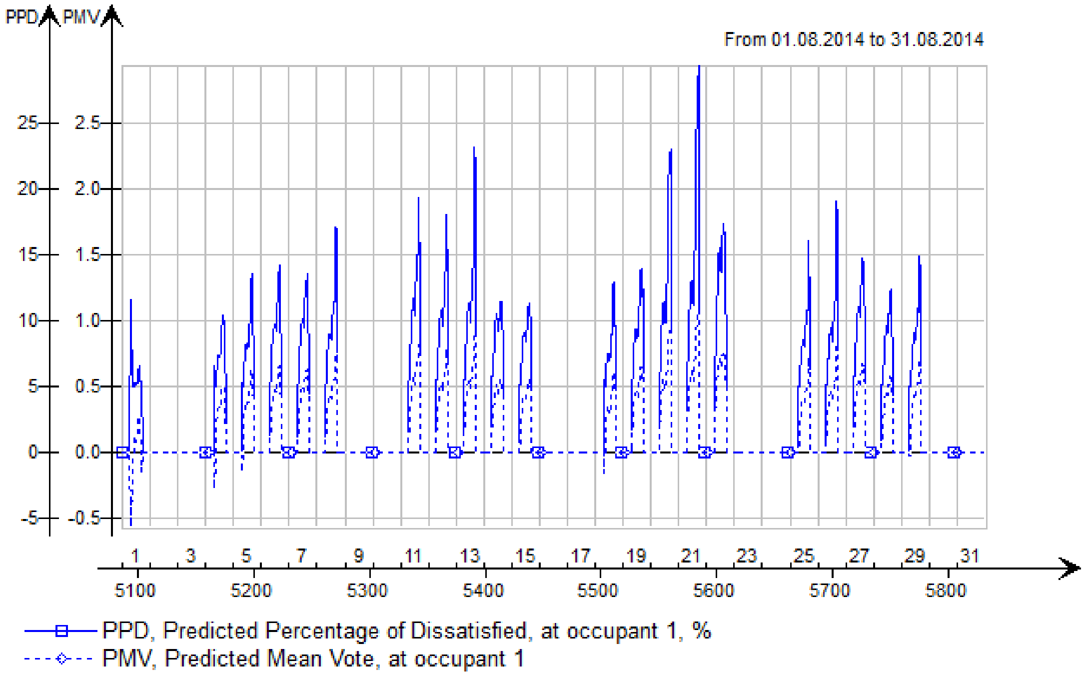
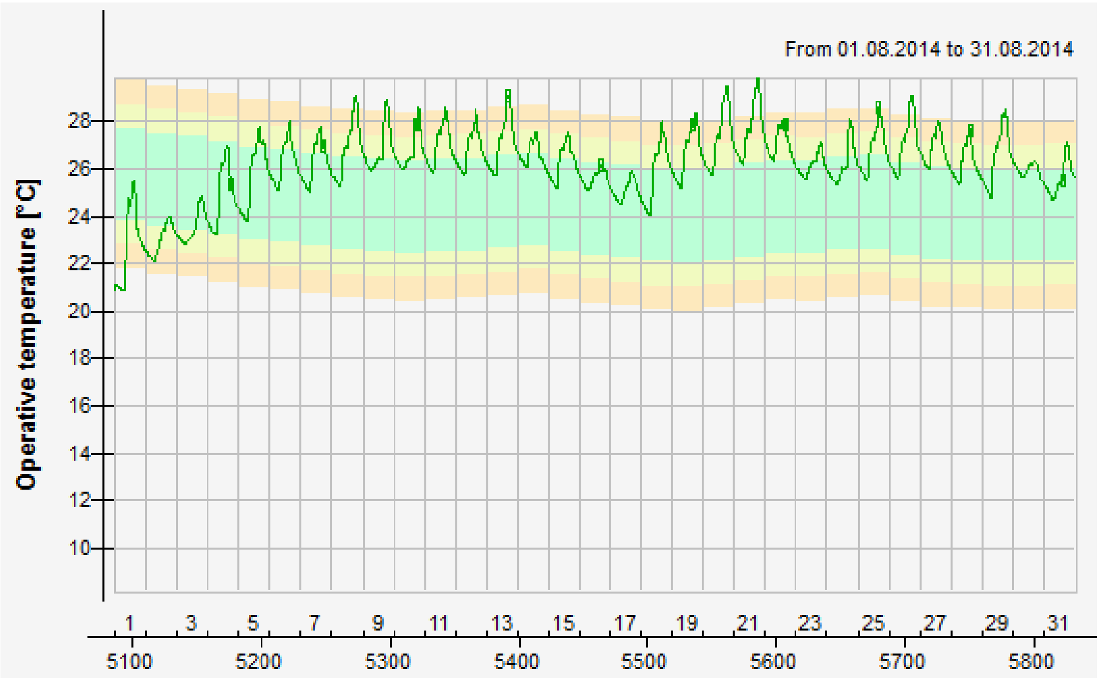


Figure 51: PPD and PMV for Meeting room.4206 in Simulation 6



Comfort category	No. of occupancy hours
I (best)	28
II (good)	99
III (Acceptable)	152
IV (Unacceptable)	5

Figure 52: Thermal comfort for Meeting room.4206 according to EN 15251 in Simulation 6

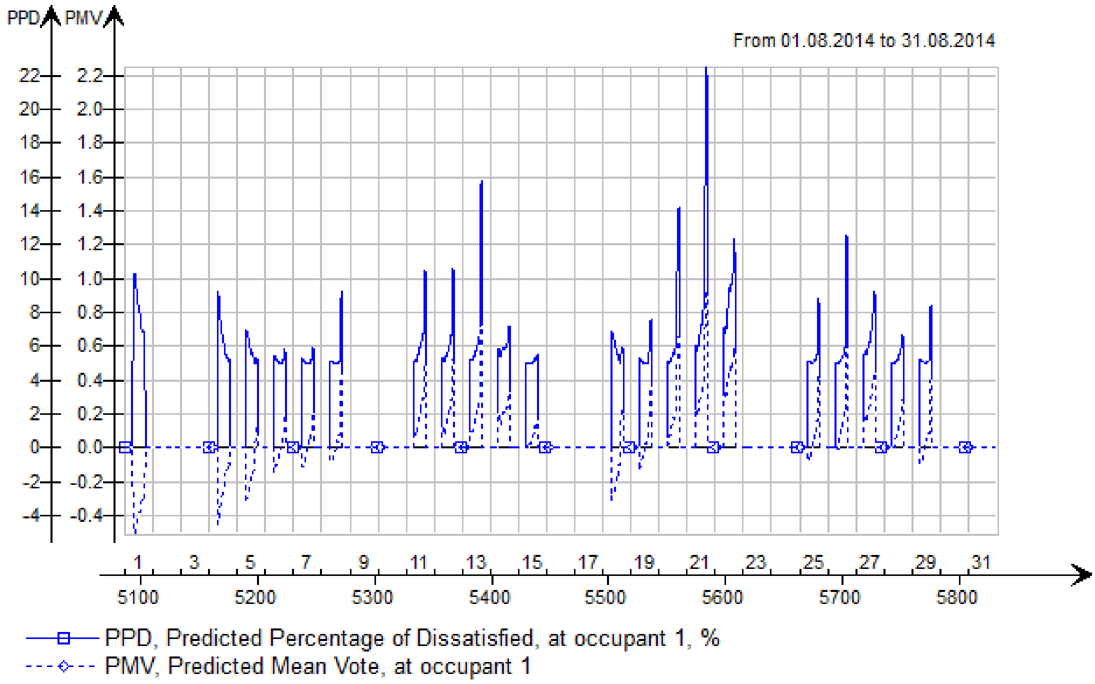


Figure 53: PPD and PMV for Office.4203 in Simulation 6

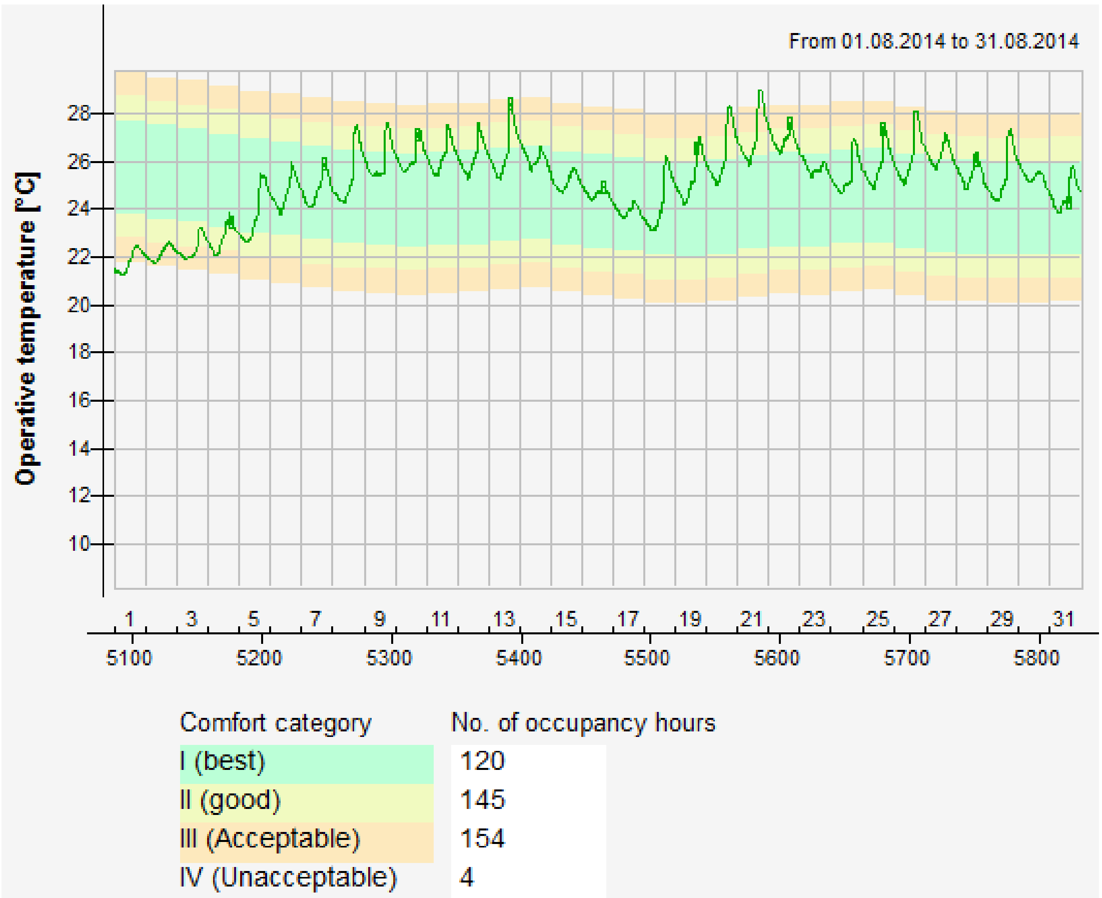


Figure 54: Thermal comfort for Office.4203 according to EN 15251 in Simulation 6

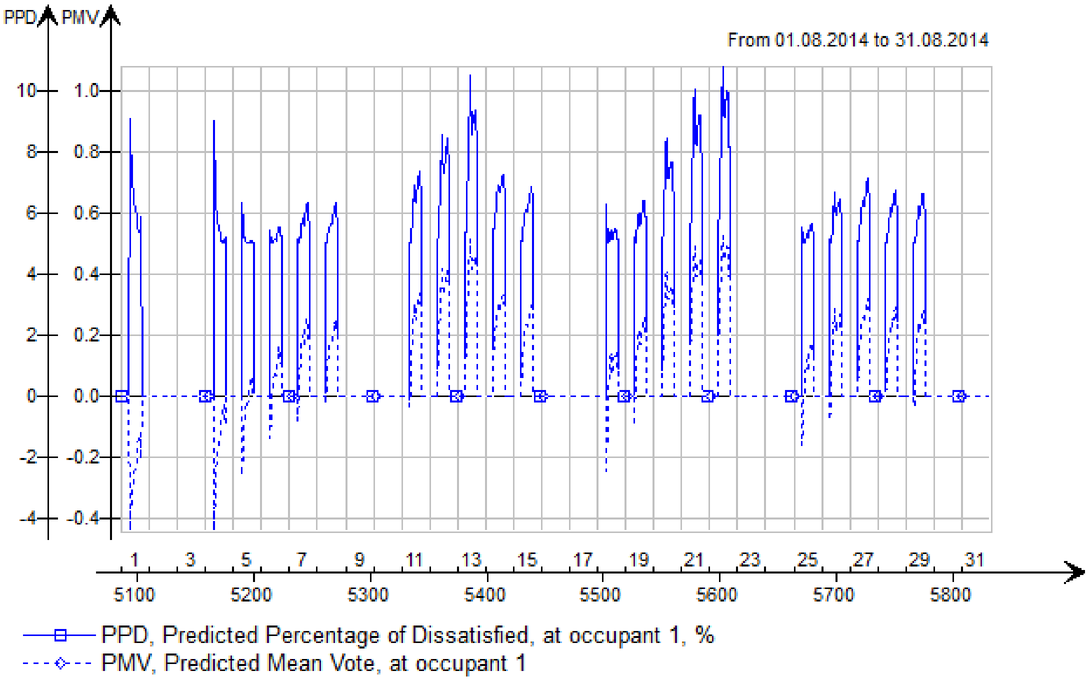


Figure 55: PPD and PMV for Landscape.4241 in Simulation 6

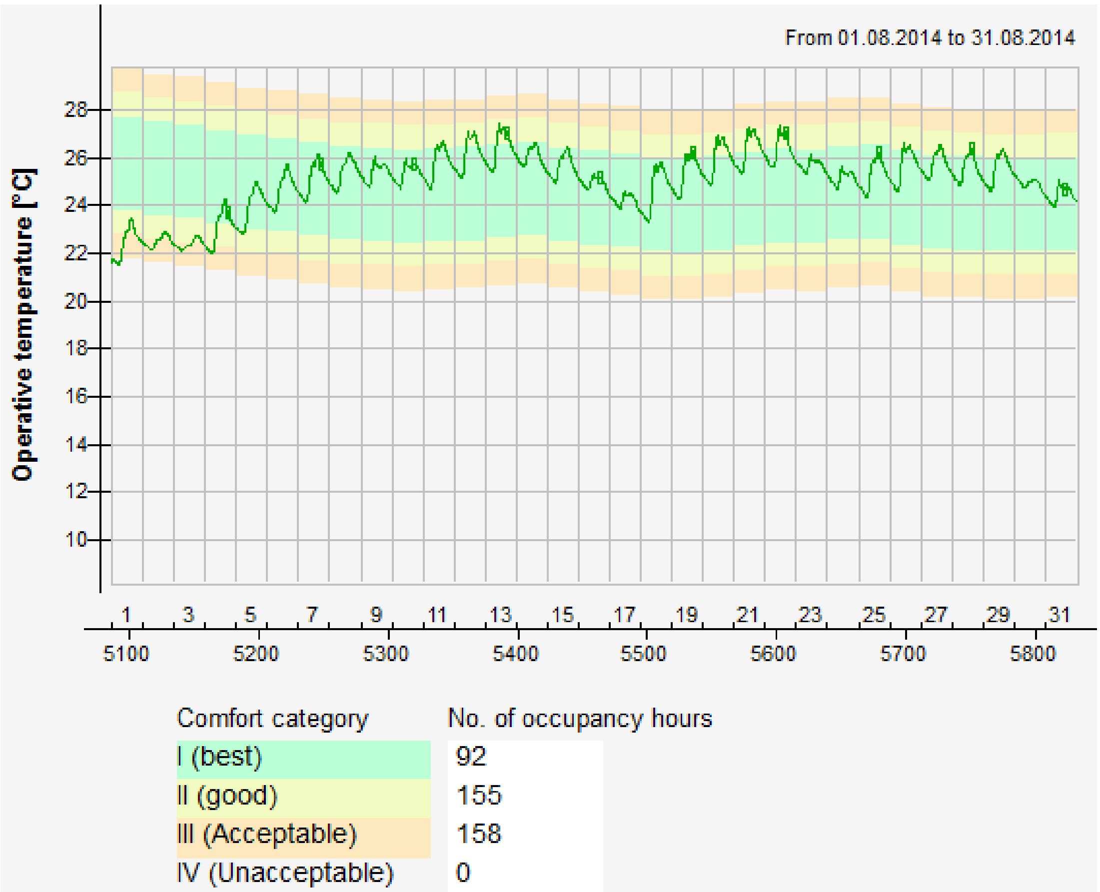


Figure 56: Thermal comfort for Landscape.4241 according to EN 15251 in Simulation 6

Attachment 8 - Simulation 7

Simulation period 01.08-31.08		
Parameter	**Set point / state**	**Comment**
Cooling set point	26°C	
Doors	Closed/Open	Closed during residence time and open outside the residence time.
Windows	Closed/Open	PI temperature control and schedule (9-11 and 13-16 with an opening of 50 %)
Occupancy Office 4204	1 Person	Occupancy from 08.00-16.00 with a presence of 100 % (30 min lunch break)
Occupancy Meeting room.4206	10 Persons	Occupancy between 09.00-11.00 and 13.00-16.00 with a presence of 100 %.
Occupancy open landscapes	30 Persons	Occupancy from 08.00-16.00 with a presence of 100 % (30 min lunch break)
Air supply temperature	19 °C	For the whole day
Run time per day for the air handling units	24 hours	
Installed cooling power at the second floor	0 kW	
Exterior sun shading		Not equipped
Clothing	0.5 Clo	
Air quantities	Normal	Building: 0.7 l/(s*m^2) Person: 7 l/(s*person)

Table 26: Parameters used in Simulation 7

Main temperatures

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	25.5	26.0
Minimum temperature	22.8	22.9
Maximum temperature	26.7	27.4

Table 27: Main temperatures for Meeting room.4206 in Simulation 7

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	25.3	25.0
Minimum temperature	22.2	21.9
Maximum temperature	27.0	26.7

Table 28: Main temperatures for Office.4203 in Simulation 7

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	25.7	26.1
Minimum temperature	22.8	22.9
Maximum temperature	27.0	27.7

Table 29: Main temperatures for Landscape.4241 in Simulation 7

Thermal indoor climate

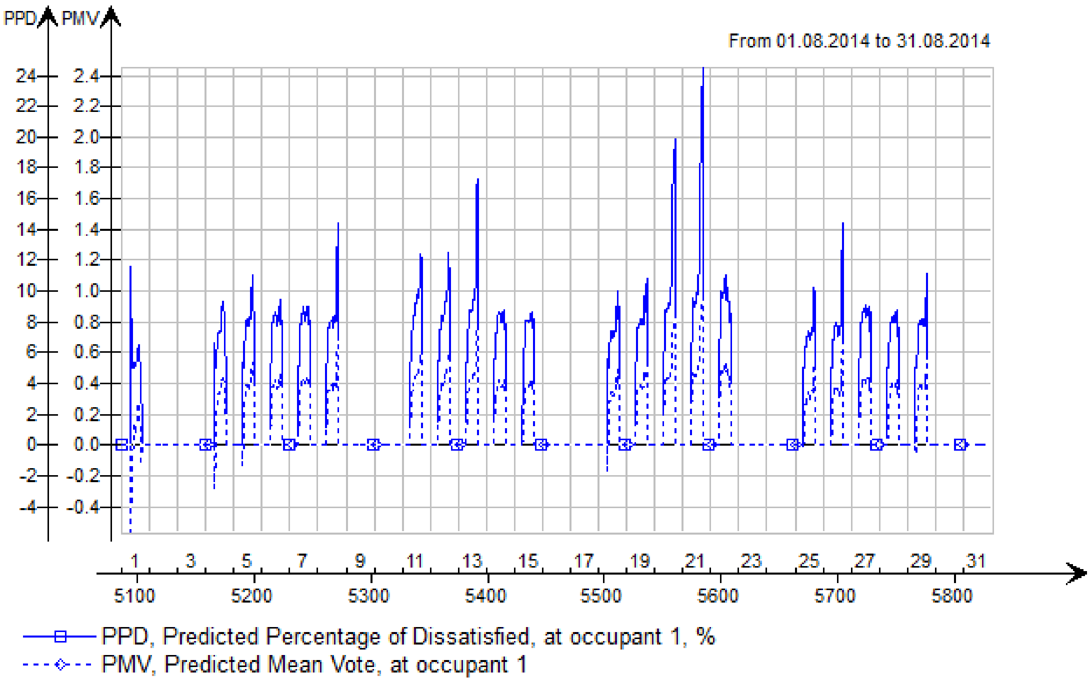


Figure 57: PPD and PMV for Meeting room.4206 in Simulation 7

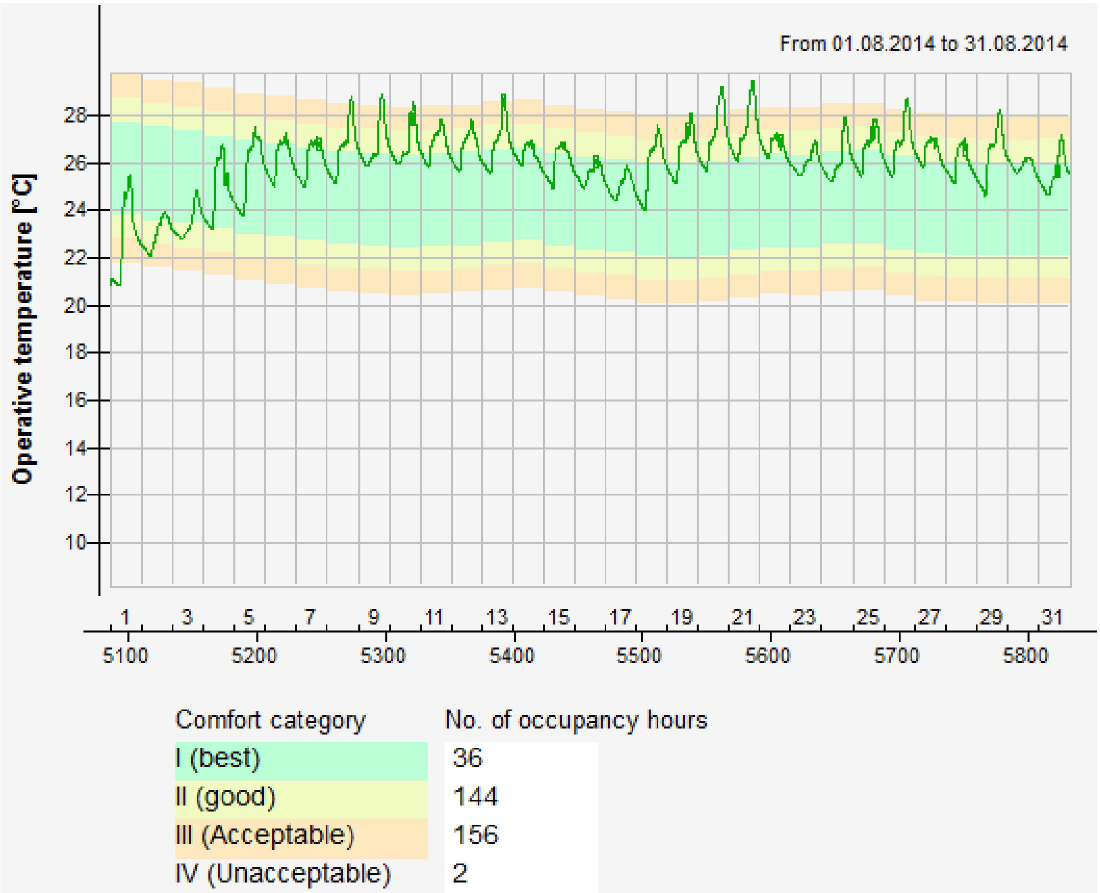


Figure 58: Thermal comfort for Meeting room.4206 according to EN 15251 in Simulation 7

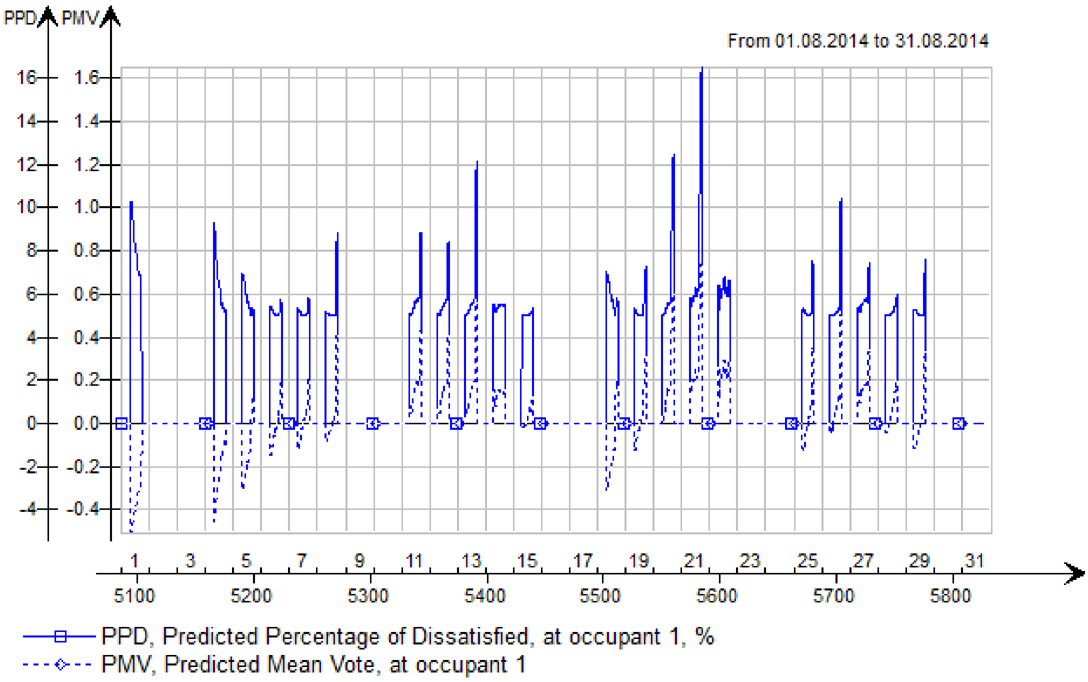


Figure 59: PPD and PMV for Office.4203 in Simulation 7

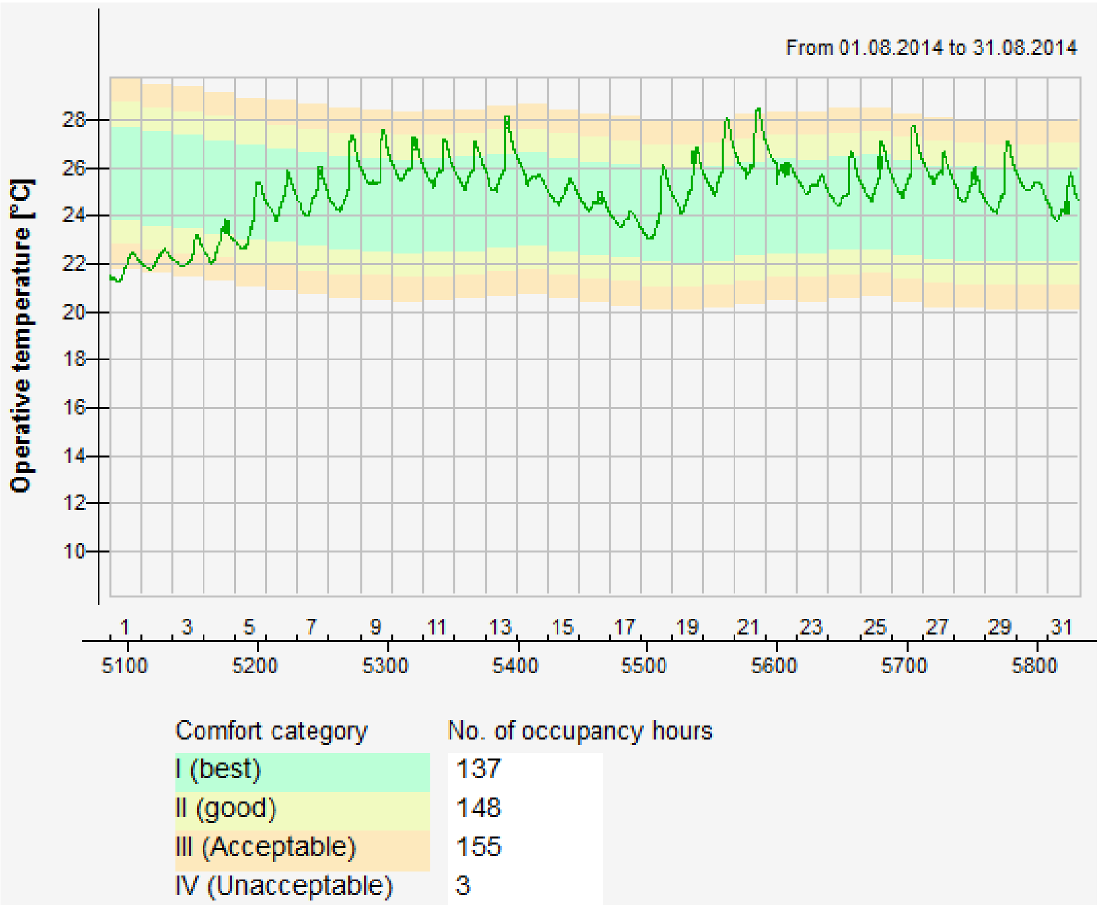


Figure 60: Thermal comfort for Office.4203 according to EN 15251 in Simulation 7

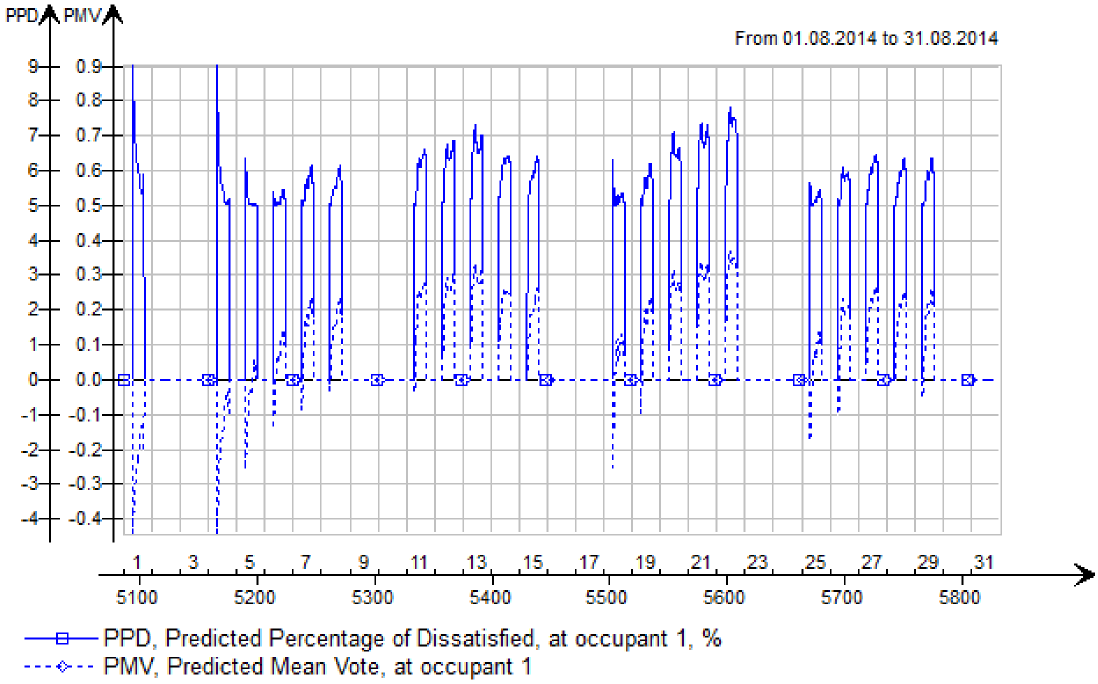


Figure 61: PPD and PMV for Landscape.4241 in Simulation 7

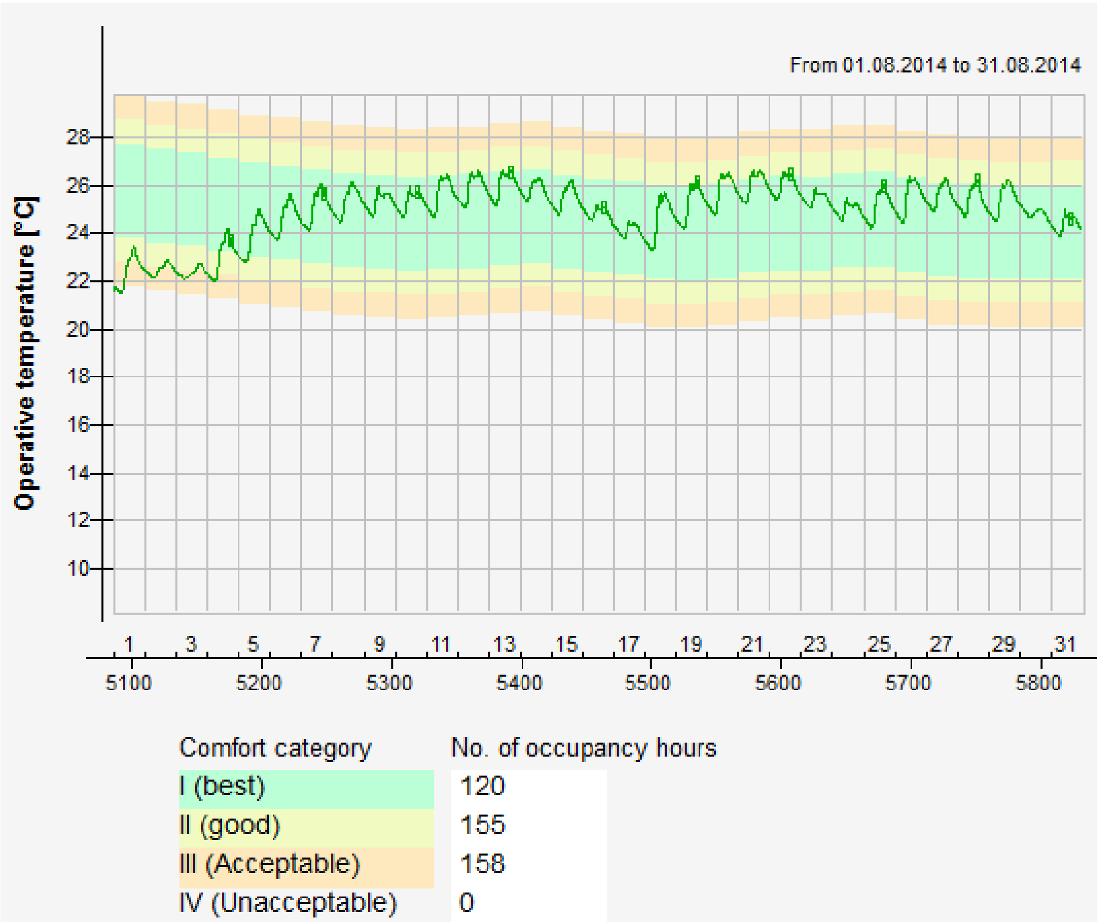


Figure 62: Thermal comfort for Landscape.4241 according to EN 15251 in Simulation 7

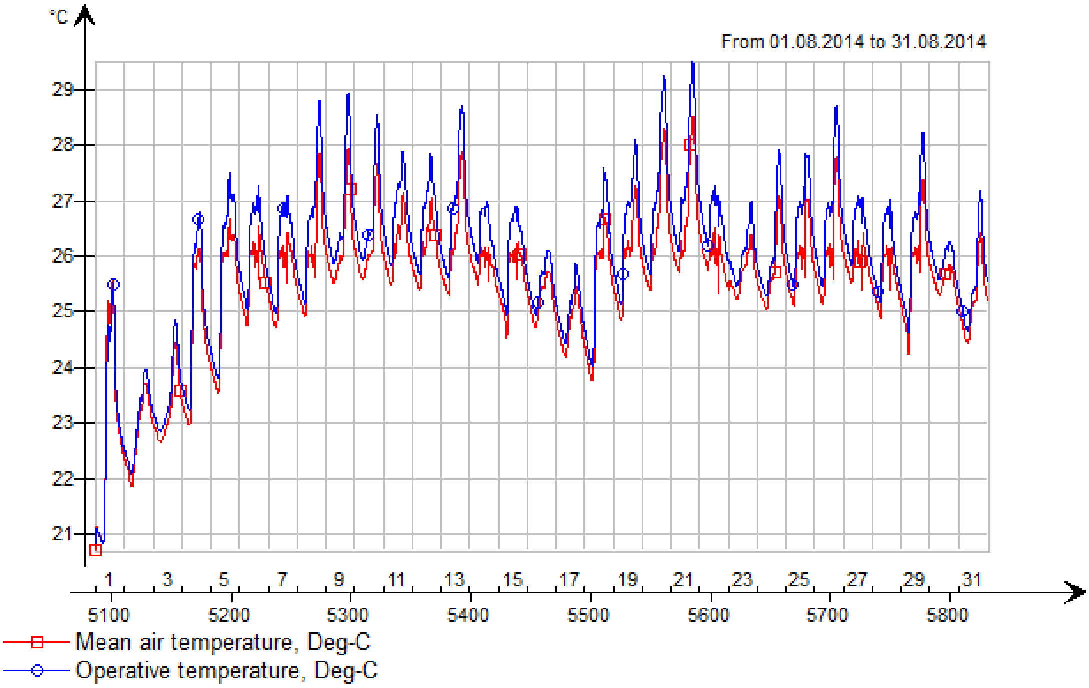


Figure 63: Temperatures in Meeting room.4206 in Simulation 7

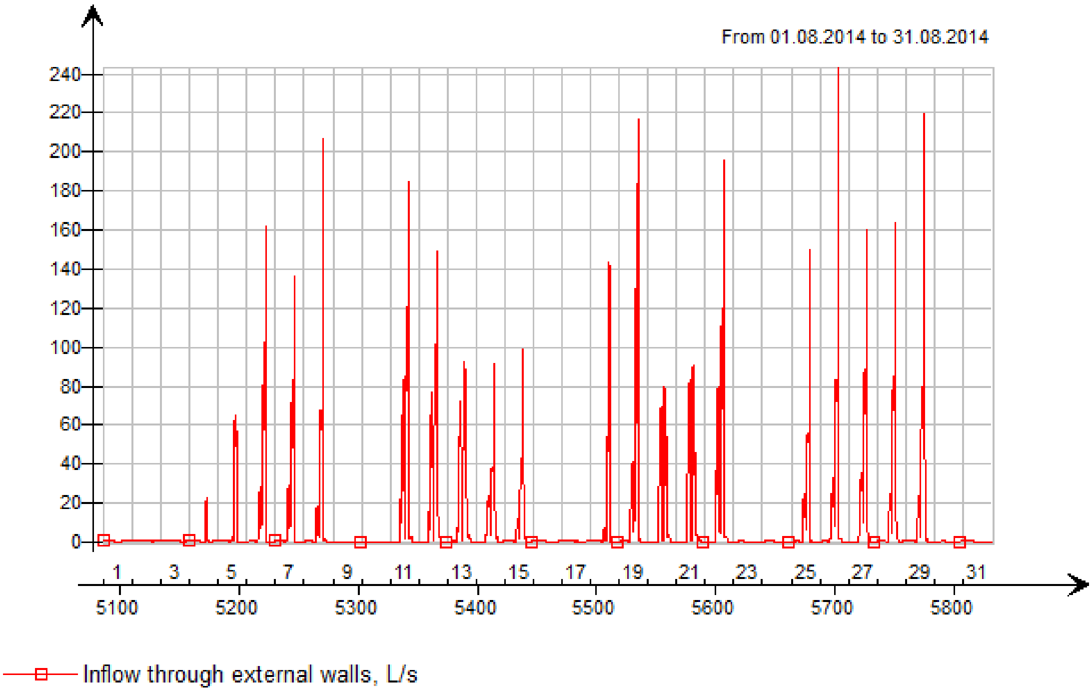


Figure 64: Inflow through windows in Meeting room.4206 in Simulation 7

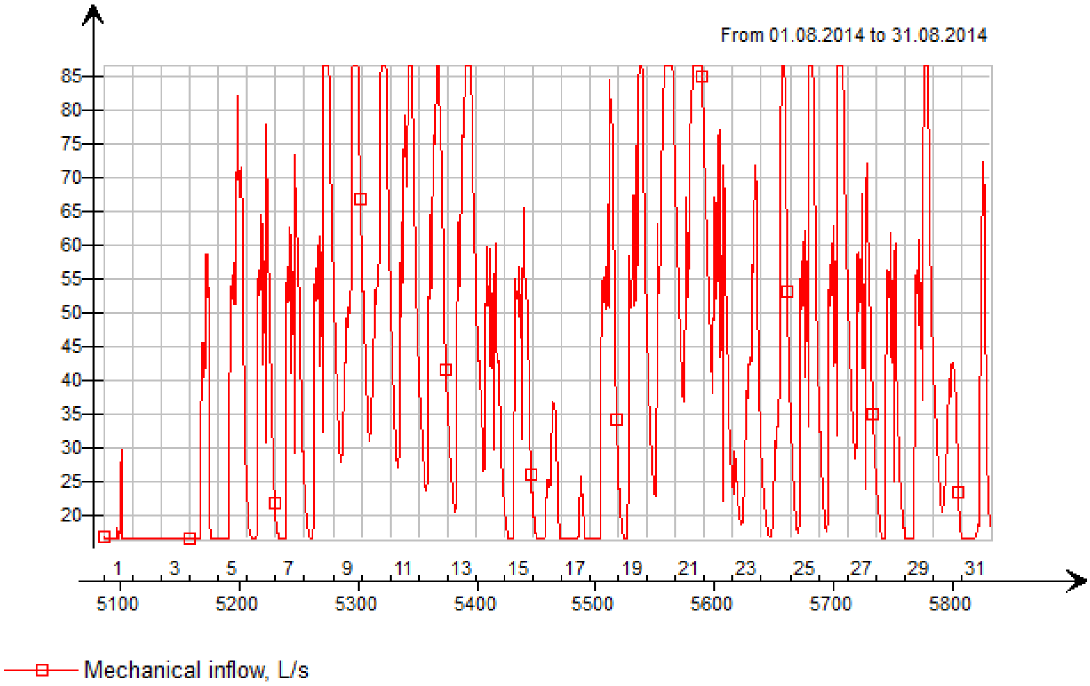


Figure 65: Supply airflow in Meeting room.4206 in Simulation 7

Indoor air quality

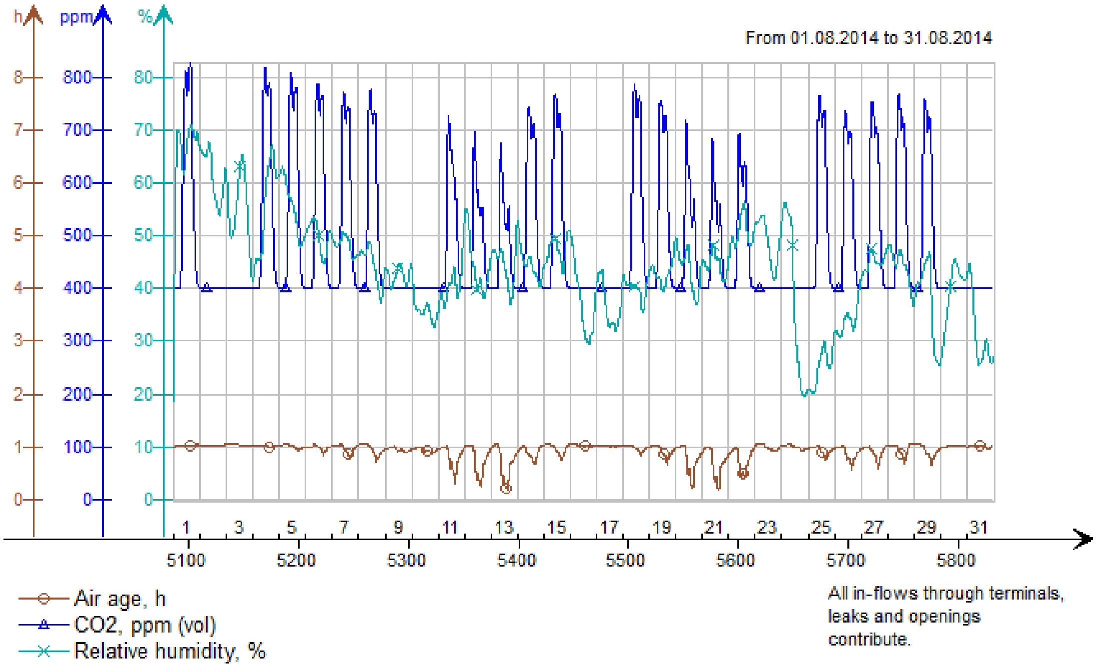


Figure 66: Indoor air quality in landscape.4241 in Simulation 7

Attachment 9 - Simulation 8

Simulation period 01.08-31.08		
Parameter	**Set point / state**	**Comment**
Cooling set point	26°C	
Doors	Closed/Open	Closed during residence time and open outside the residence time.
Windows	Closed	Always closed
Occupancy Office 4204	1 Person	Occupancy from 08.00-16.00 with a presence of 100 % (30 min lunch break)
Occupancy Meeting room.4206	10 Persons	Occupancy between 09.00-11.00 and 13.00-16.00 with a presence of 100 %.
Occupancy open landscapes	30 Persons	Occupancy from 08.00-16.00 with a presence of 100 % (30 min lunch break)
Air supply temperature	19 °C	For the whole day
Run time per day for the air handling units	24 hours	
Installed cooling power at the second floor	0 kW	
Exterior sun shading		Not equipped
Clothing	0.5 Clo	
Air quantities	2 x normal	Building: 1.4 l/(s*m^2) Person: 14 l/(s*person)

Table 30: Parameters used in Simulation 8

Main temperatures

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	24.3	24.8
Minimum temperature	22.1	22.3
Maximum temperature	25.5	26.2

Table 31: Main temperatures for Meeting room.4206 in Simulation 8

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	23.2	22.9
Minimum temperature	21.3	21.2
Maximum temperature	24.9	24.5

Table 32: Main temperatures for Office.4203 in Simulation 8

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	22.8	23.0
Minimum temperature	21.2	21.3
Maximum temperature	24.0	24.3

Table 33: Main temperatures for Landscape.4241 in Simulation 8

Thermal indoor climate

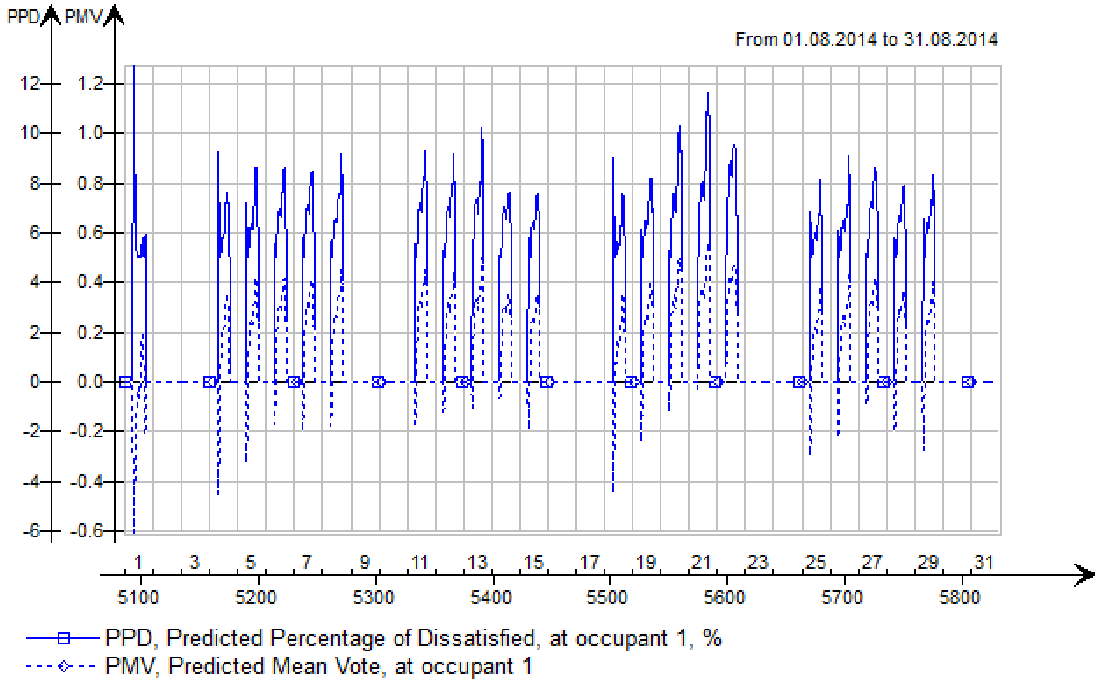


Figure 67: PPD and PMV for Meeting room.4206 in Simulation 8

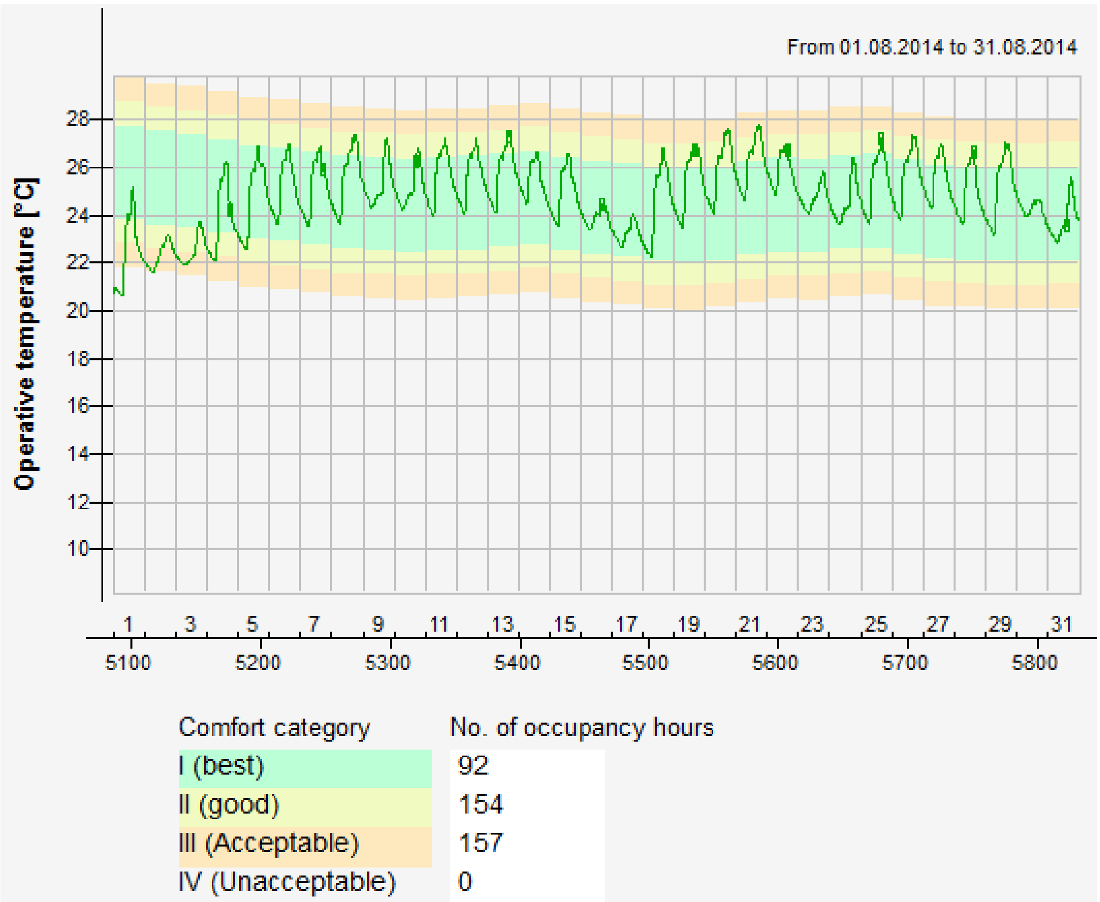


Figure 68: Thermal comfort for Meeting room.4206 according to EN 15251 in Simulation 8

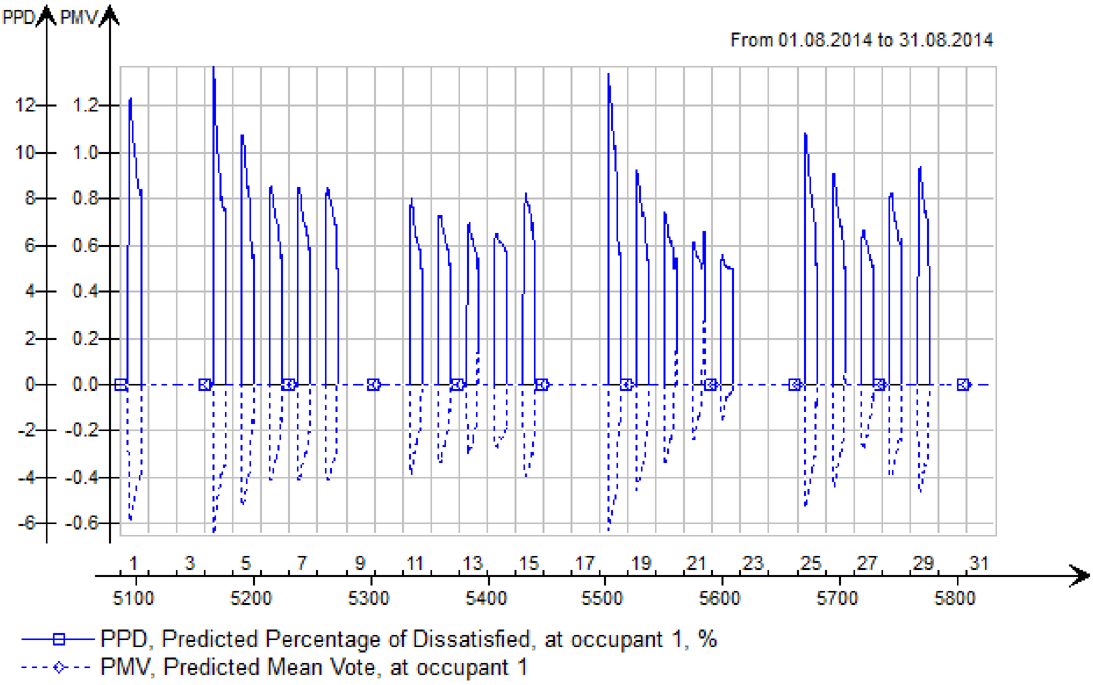


Figure 69: PPD and PMV for Office.4203 in Simulation 8

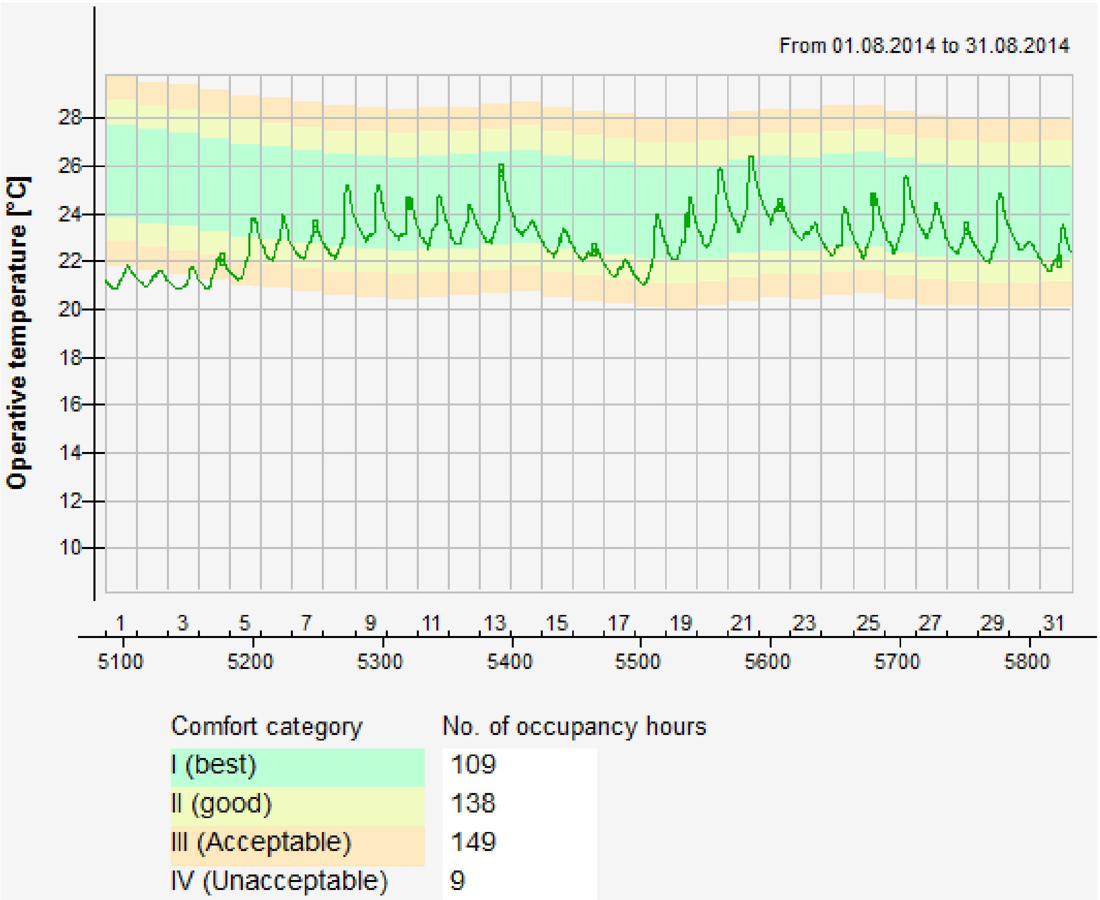


Figure 70: Thermal comfort for Office.4203 according to EN 15251 in Simulation 8

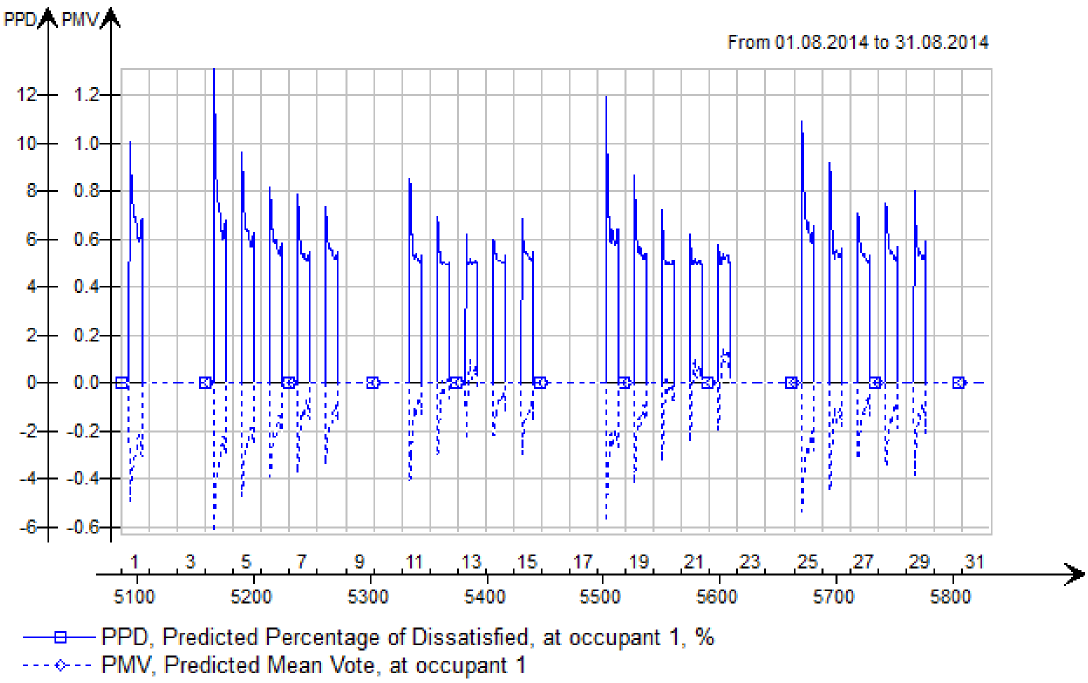


Figure 71: PPD and PMV for Landscape.4241 in Simulation 8

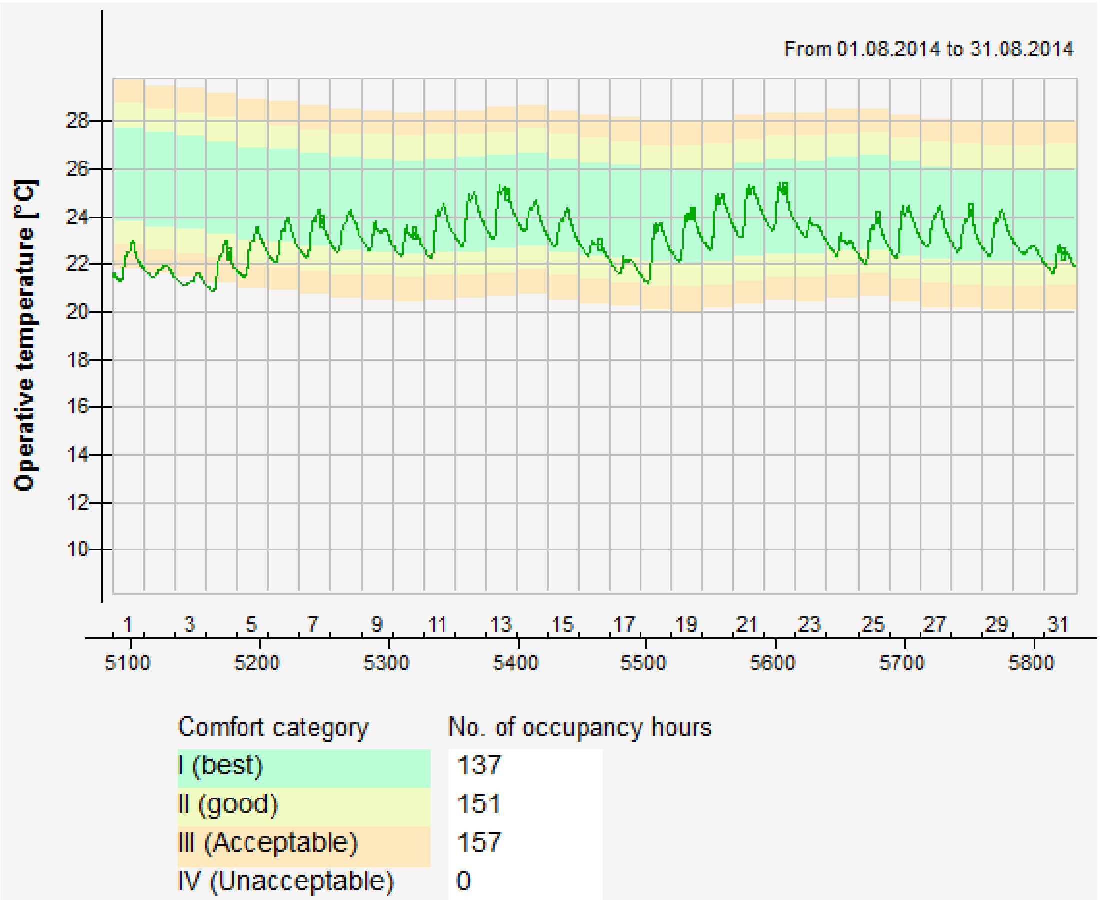


Figure 72: Thermal comfort for Landscape.4241 according to EN 15251 in Simulation 8

Indoor air quality

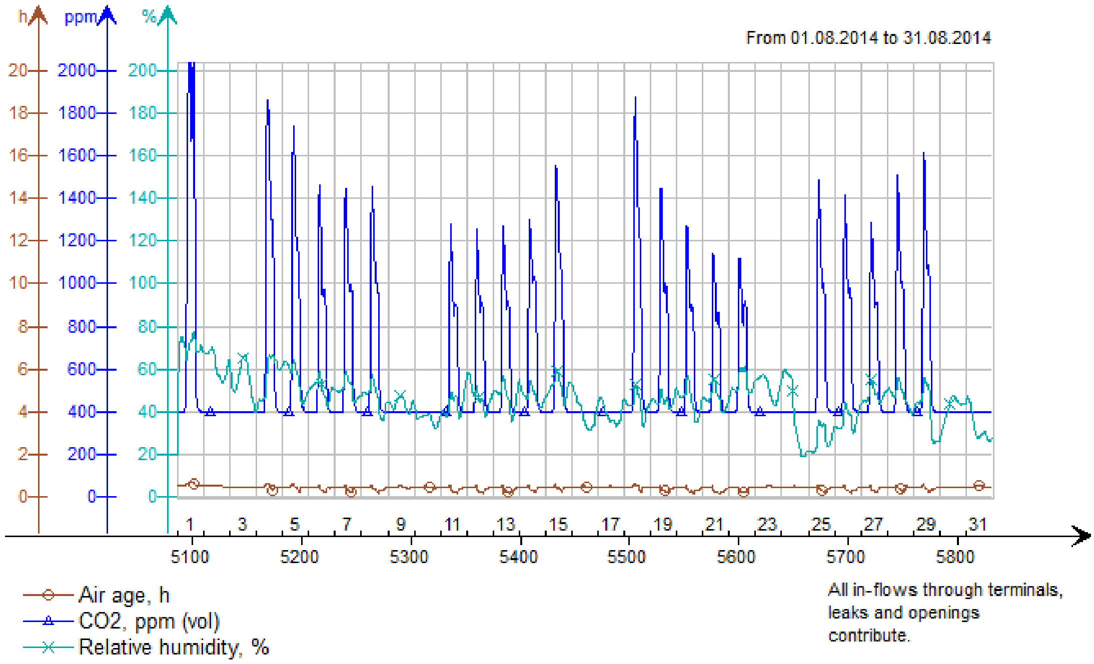


Figure 73: Indoor air quality in Meeting room.4206 in Simulation 8

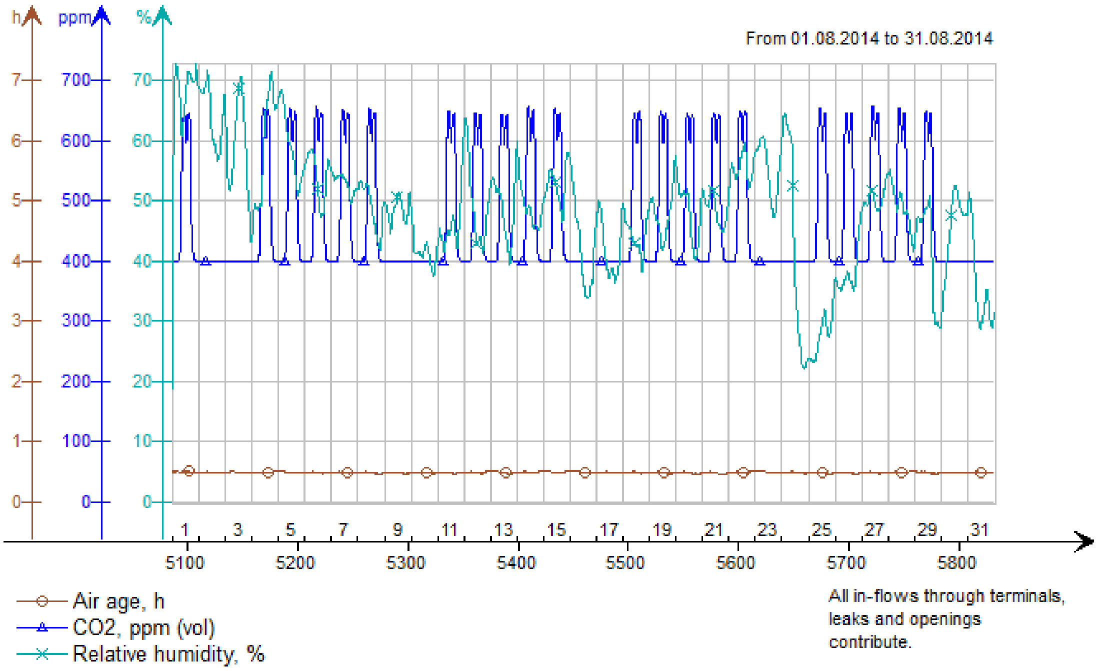


Figure 74: Indoor air quality in Landscape.4241 in Simulation 8

Attachment 10 - Simulation 9

Simulation period 01.08-31.08		
Parameter	**Set point / state**	**Comment**
Cooling set point	26°C	
Doors	Closed/Open	Closed during residence time and open outside the residence time.
Windows	Closed/Open	PI temperature control and schedule (8-16 with an opening of 100 %)
Occupancy Office 4204	1 Person	Occupancy from 08.00-16.00 with a presence of 100 % (30 min lunch break)
Occupancy Meeting room.4206	10 Persons	Occupancy between 09.00-11.00 and 13.00-16.00 with a presence of 100 %.
Occupancy open landscapes	30 Persons	Occupancy from 08.00-16.00 with a presence of 100 % (30 min lunch break)
Air supply temperature	19 °C	For the whole day
Run time per day for the air handling units	24 hours	
Installed cooling power at the second floor	0 kW	
Exterior sun shading		Not equipped
Clothing	0.5 Clo	
Air quantities	Normal	Building: 0.7 l/(s*m^2) Person: 7 l/(s*person)

Table 34: Parameters used in Simulation 9

Main temperatures

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	25.4	25.9
Minimum temperature	22.8	22.9
Maximum temperature	26.4	27.1

Table 35: Main temperatures for Meeting room.4206 in Simulation 9

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	25.2	24.9
Minimum temperature	22.2	21.9
Maximum temperature	26.8	26.6

Table 36: Main temperatures for Office.4203 in Simulation 9

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	24.7	24.9
Minimum temperature	22.3	22.4
Maximum temperature	25.7	26.0

Figure 75: Main temperatures for Landscape.4241 in Simulation 9

Thermal indoor climate

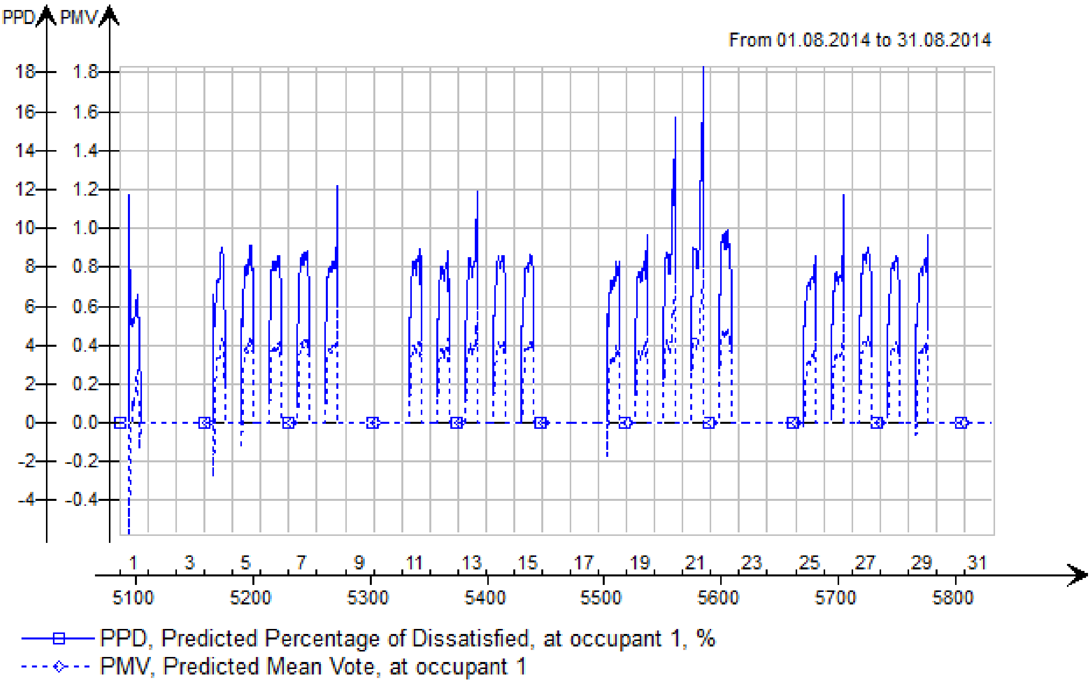


Figure 76: PPD and PMV for Meeting room.4206 in Simulation 9

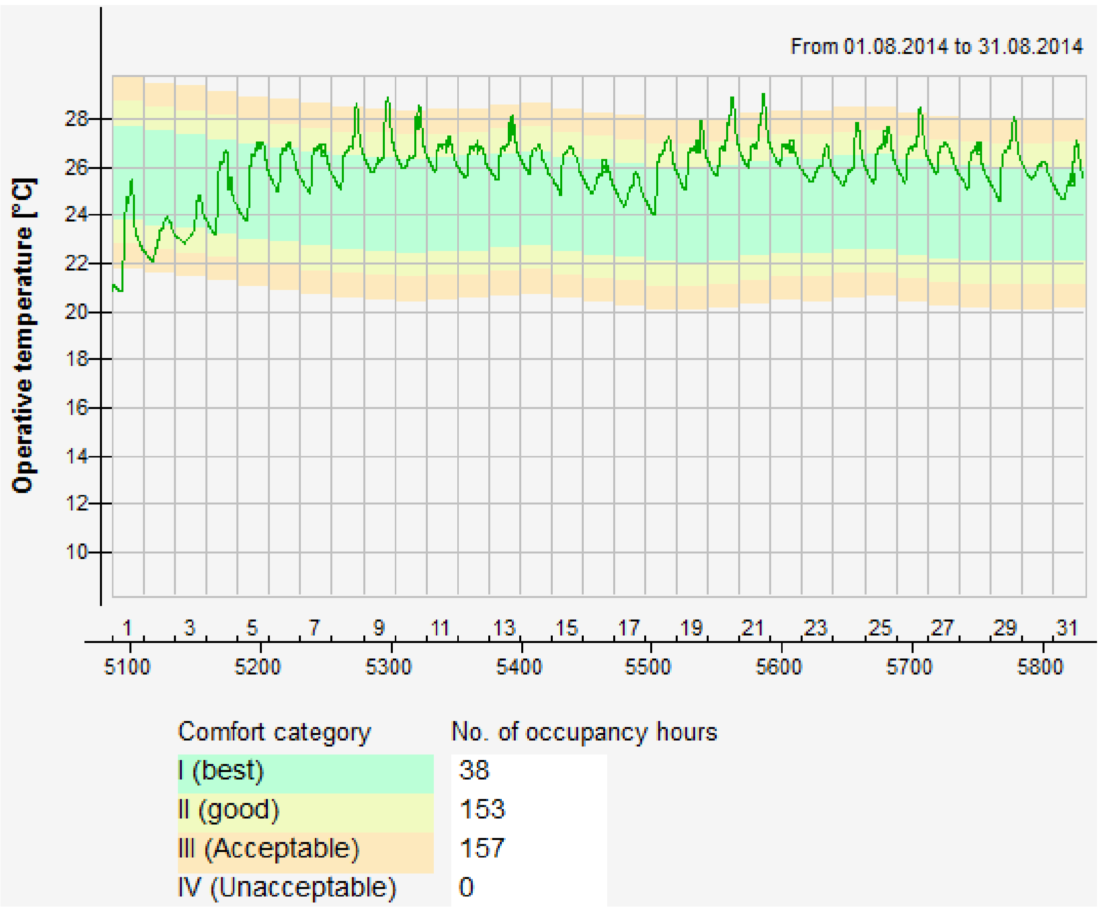


Figure 77: Thermal comfort for Meeting room.4206 according to EN 15251 in Simulation 9

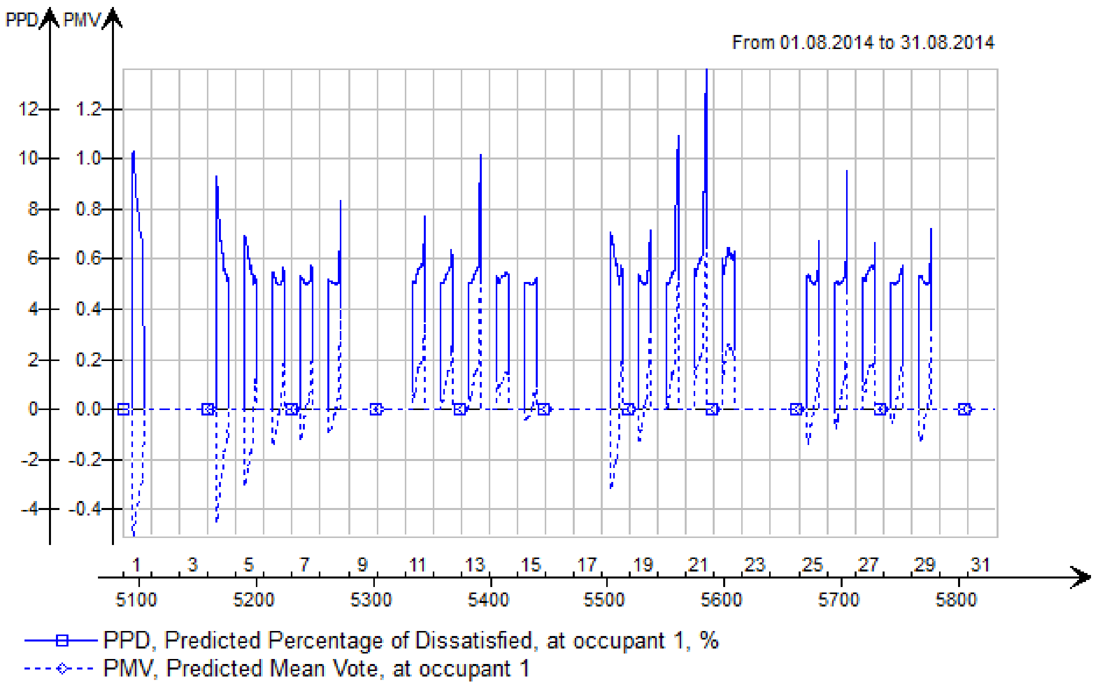
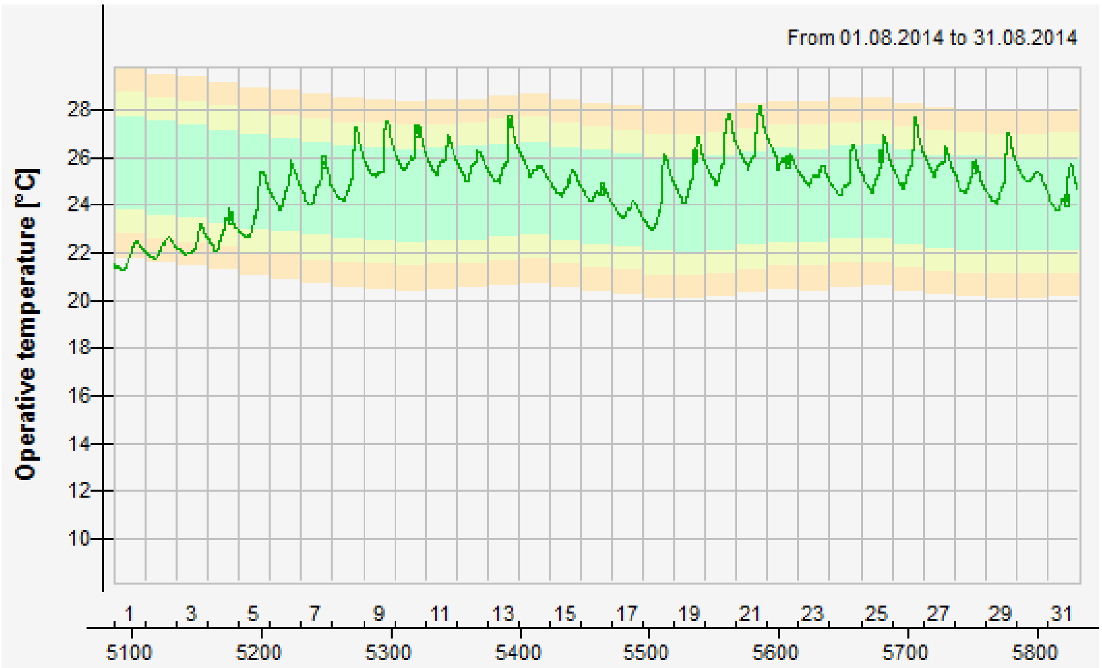


Figure 78: PPD and PMV for Office.4203 in Simulation 9



Comfort category	No. of occupancy hours
I (best)	140
II (good)	148
III (Acceptable)	155
IV (Unacceptable)	3

Figure 79: Thermal comfort for Office.4203 according to EN 15251 in Simulation 9

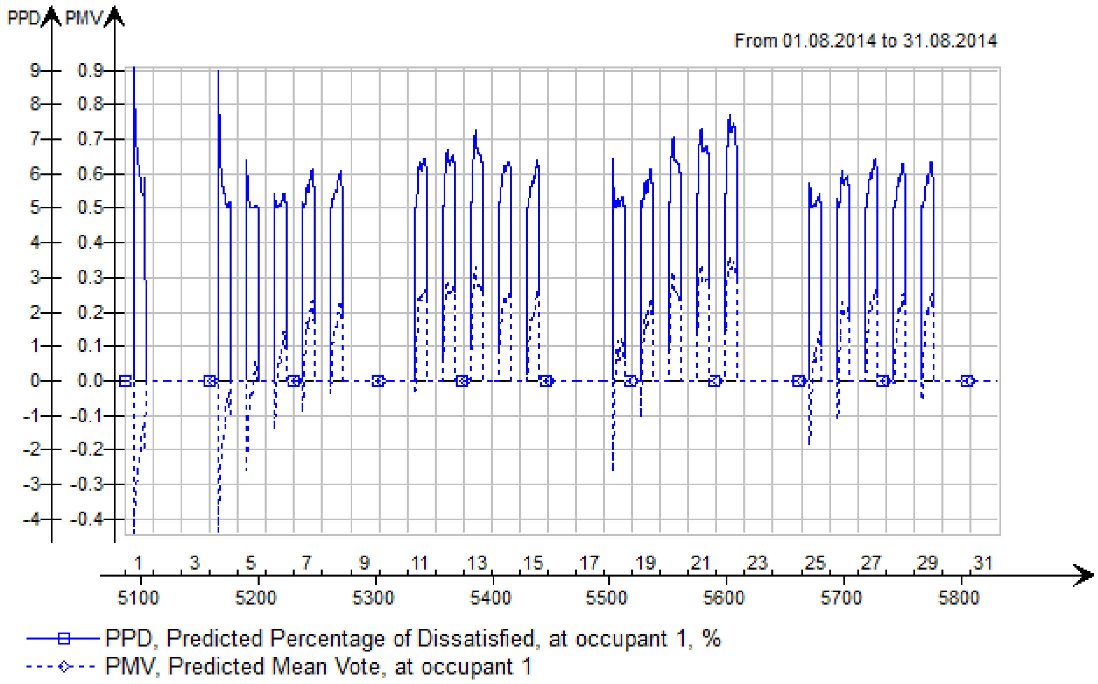


Figure 80: PPD and PMV for Landscape.4241 in Simulation 9

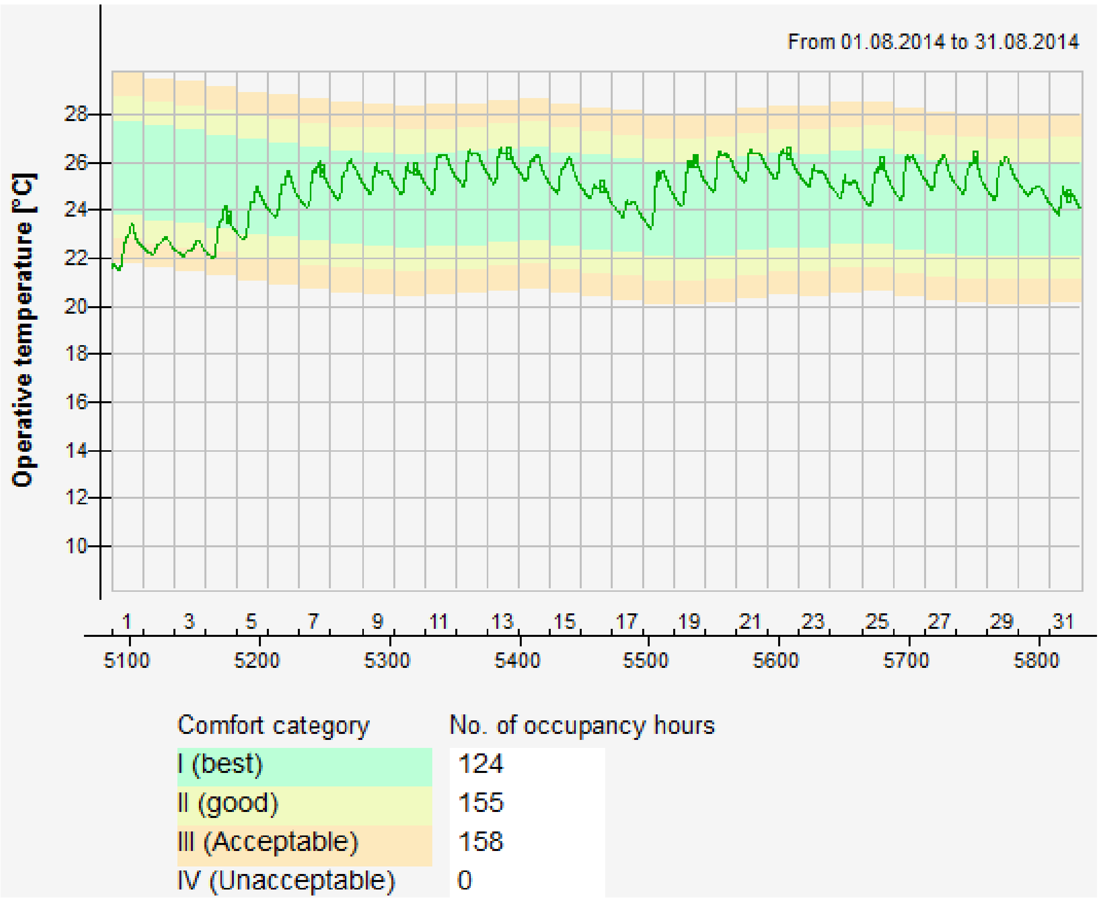


Figure 81: Thermal comfort for Landscape.4241 according to EN 15251 in Simulation 9

Indoor air quality

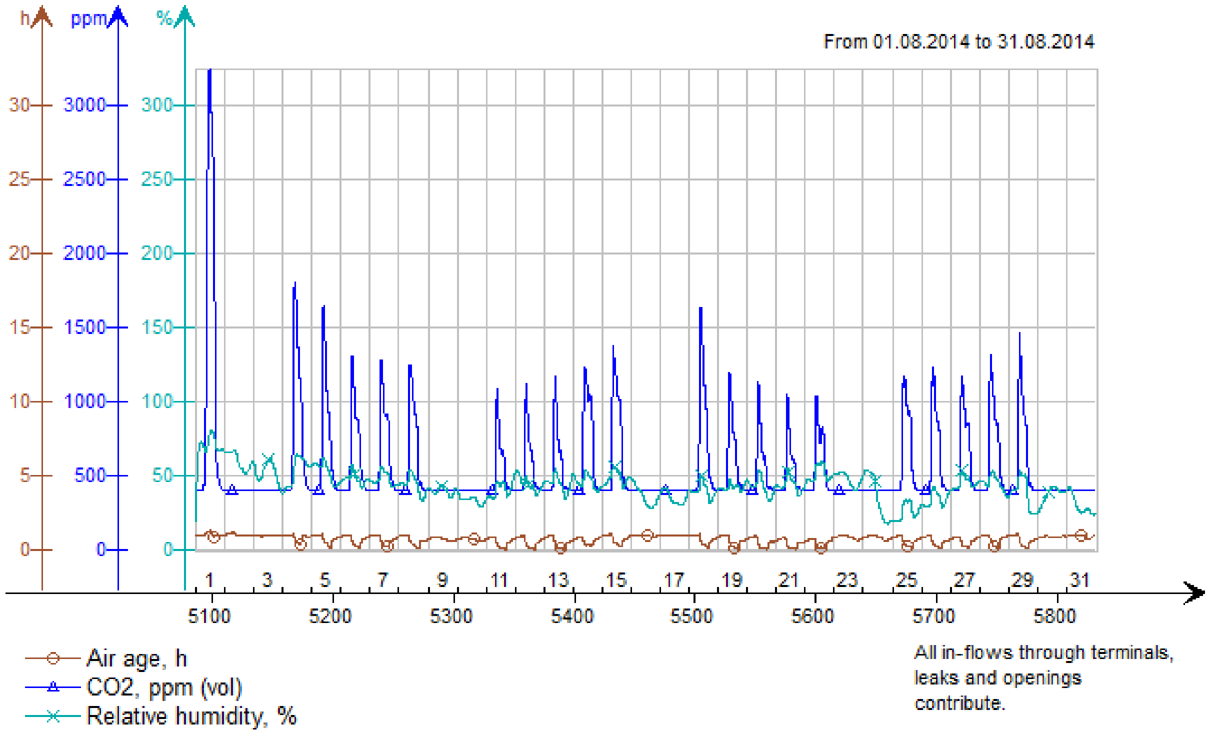


Figure 82: Indoor air quality in Meeting room.4206 in Simulation 9

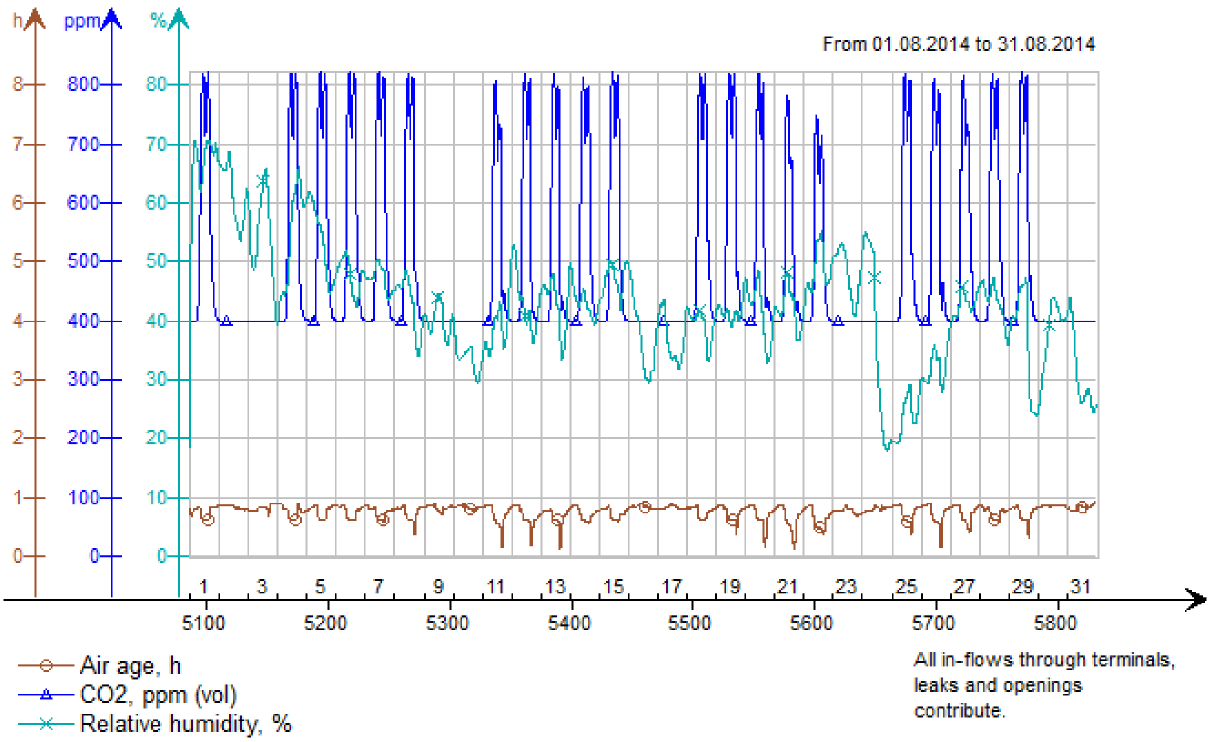


Figure 83: Indoor air quality in Office.4203 in Simulation 9

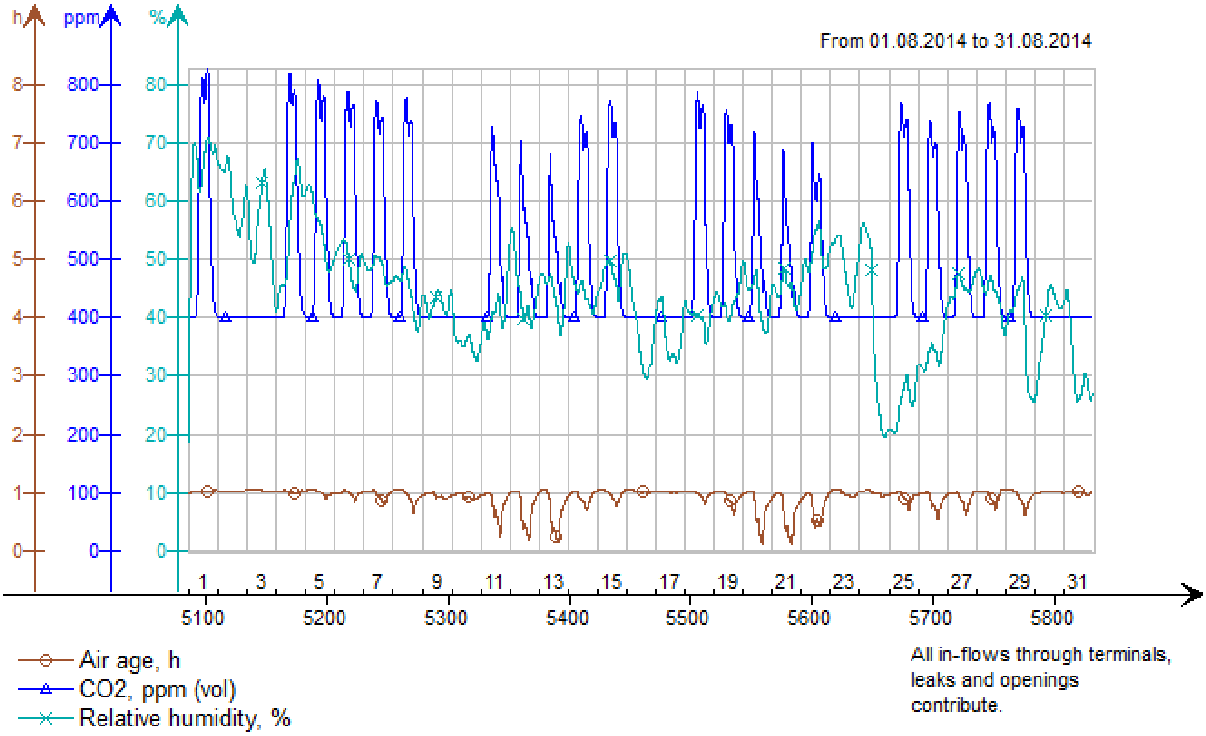


Figure 84: Indoor air quality in Landscape.4241 in Simulation 9

Attachment 11 - Simulation 10

Simulation period 01.08-31.08		
Parameter	**Set point / state**	**Comment**
Cooling set point	26°C	
Doors	Closed/Open	Closed during residence time and open outside the residence time.
Windows	Closed	Always closed
Occupancy Office 4204	1 Person	Occupancy from 08.00-16.00 with a presence of 100 % (30 min lunch break)
Occupancy Meeting room.4206	10 Persons	Occupancy between 09.00-11.00 and 13.00-16.00 with a presence of 100 %.
Occupancy open landscapes	30 Persons	Occupancy from 08.00-16.00 with a presence of 100 % (30 min lunch break)
Air supply temperature	19 °C/13 °C	For the whole day
Run time per day for the air handling units	24 hours	
Installed cooling power at the second floor	0 kW	
Exterior sun shading		Not equipped
Clothing	0.5 Clo	
Air quantities	1.5 x Normal	Building: 1.05 l/(s*m^2) Person: 10.5 l/(s*person)
External window shading	Always drawn	
VAV Control in Meeting room.4206	Temperature and CO_2 controlled	

Table 37: Parameters used in Simulation 10

Main temperatures

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	23.2	23.5
Minimum temperature	21.3	21.5
Maximum temperature	24.4	24.9

Table 38: Main temperatures for Meeting room.4206 in Simulation 10

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	22.3	22.0
Minimum temperature	20.8	20.8
Maximum temperature	23.5	23.1

Table 39: Main temperatures for Office.4203 in Simulation 10

	Air temperature [°C]	**Operative temperature [°C]**
Mean temperature	22.3	22.5
Minimum temperature	20.9	21.0
Maximum temperature	23.4	23.6

Table 40: Main temperatures for Landscape.4241 in Simulation 10

Thermal indoor climate

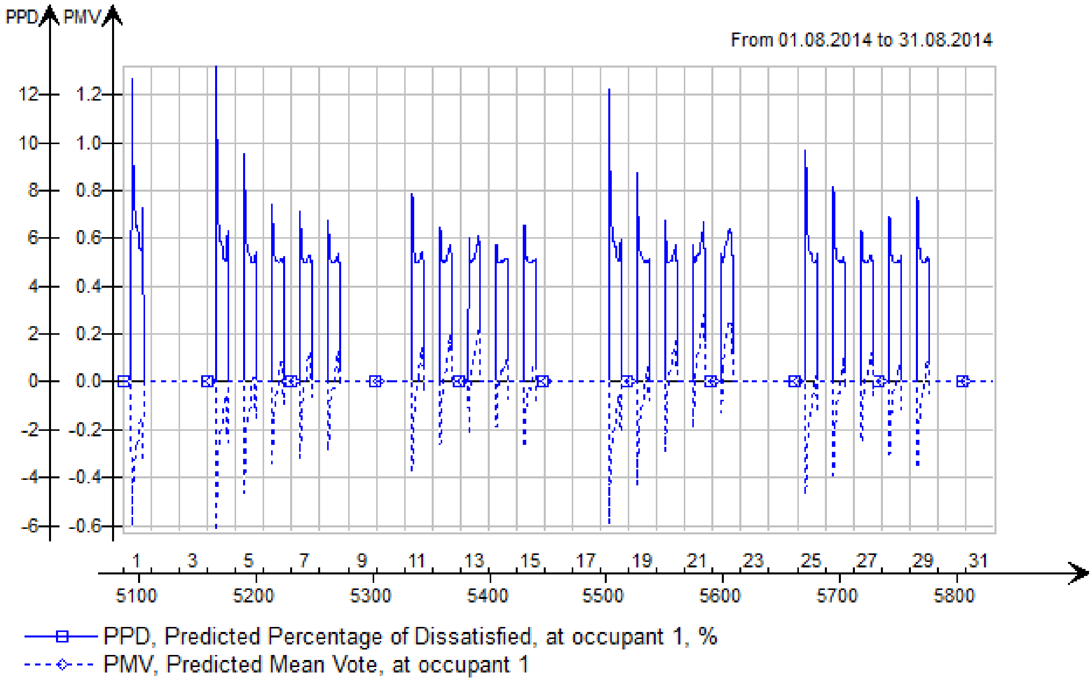


Figure 85: PPD and PMV for Meeting room.4206 in Simulation 10

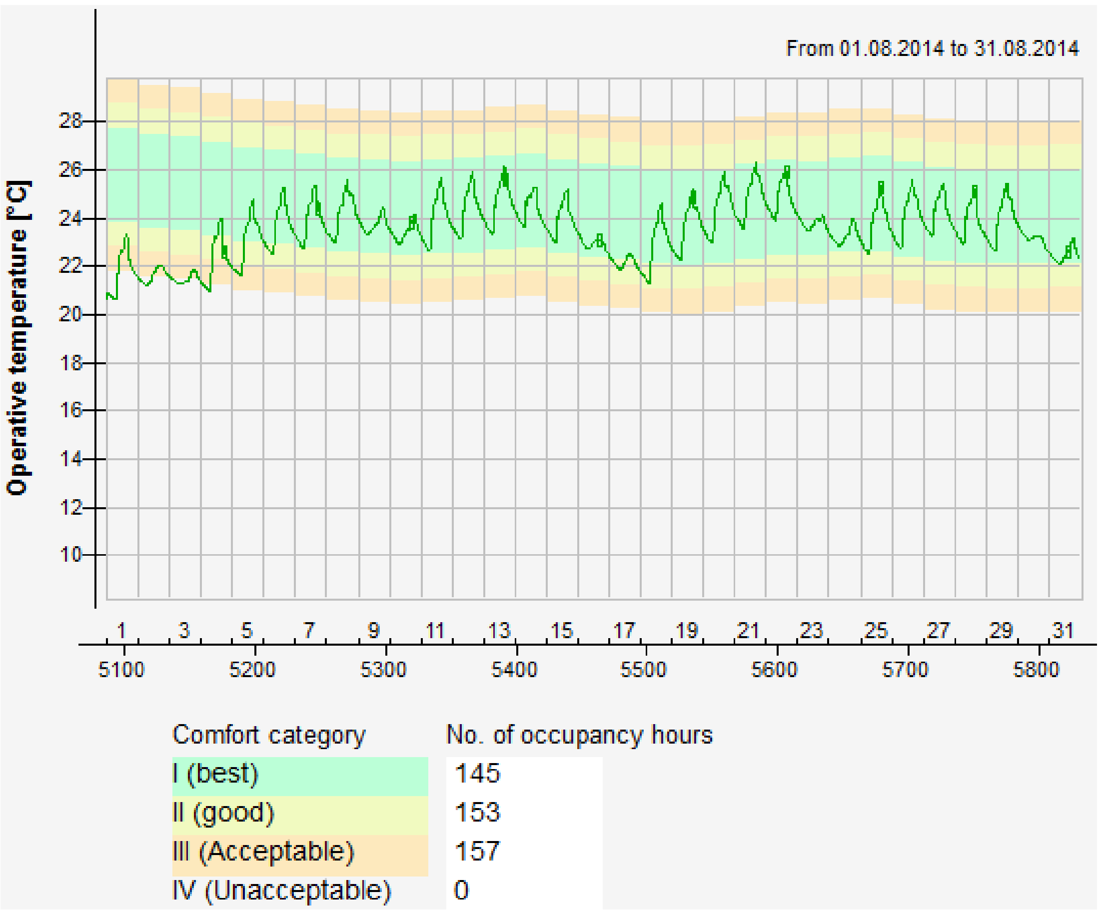


Figure 86: Thermal comfort for Meeting room.4206 according to EN 15251 in Simulation 10

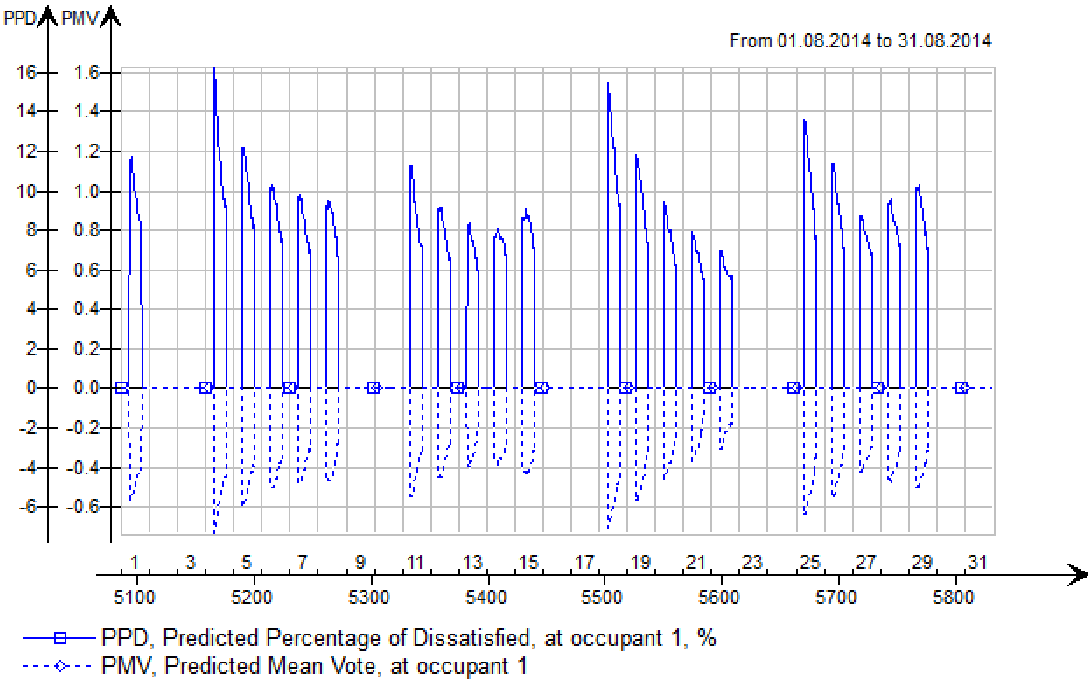


Figure 87: PPD and PMV for Office.4203 in Simulation 10

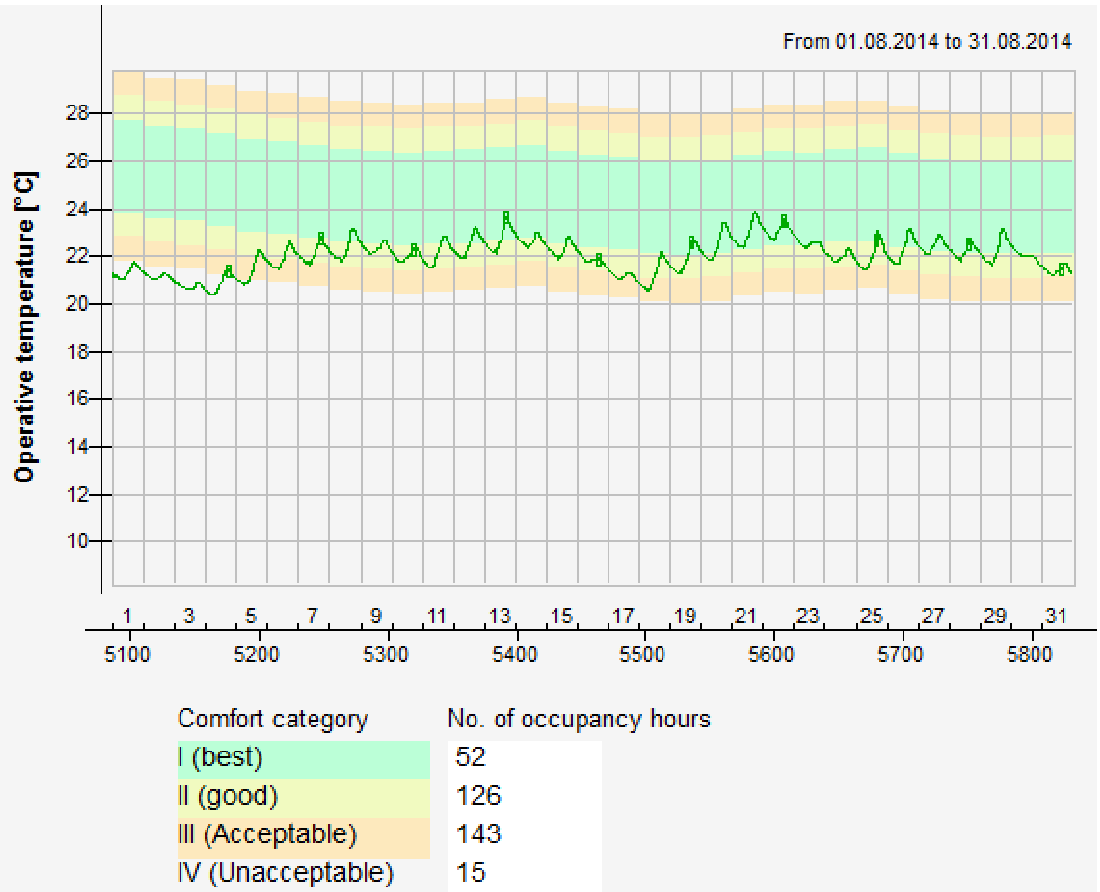


Figure 88: Thermal comfort for Office.4203 according to EN 15251 in Simulation 10

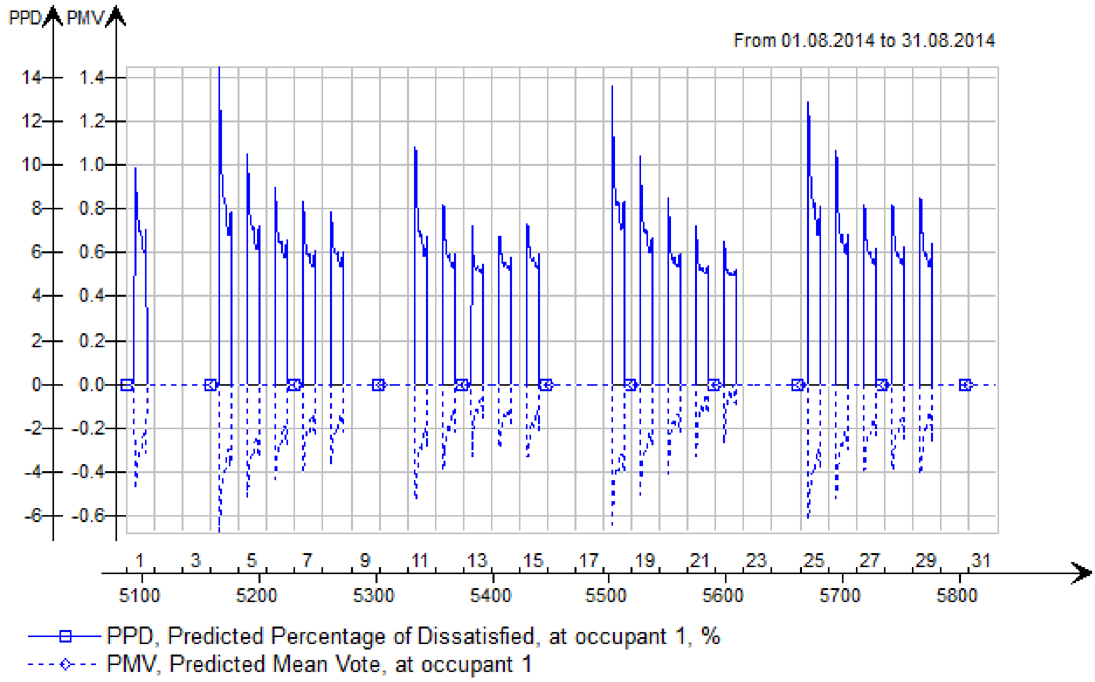


Figure 89: PPD and PMV for Landscape.4241 in Simulation 10

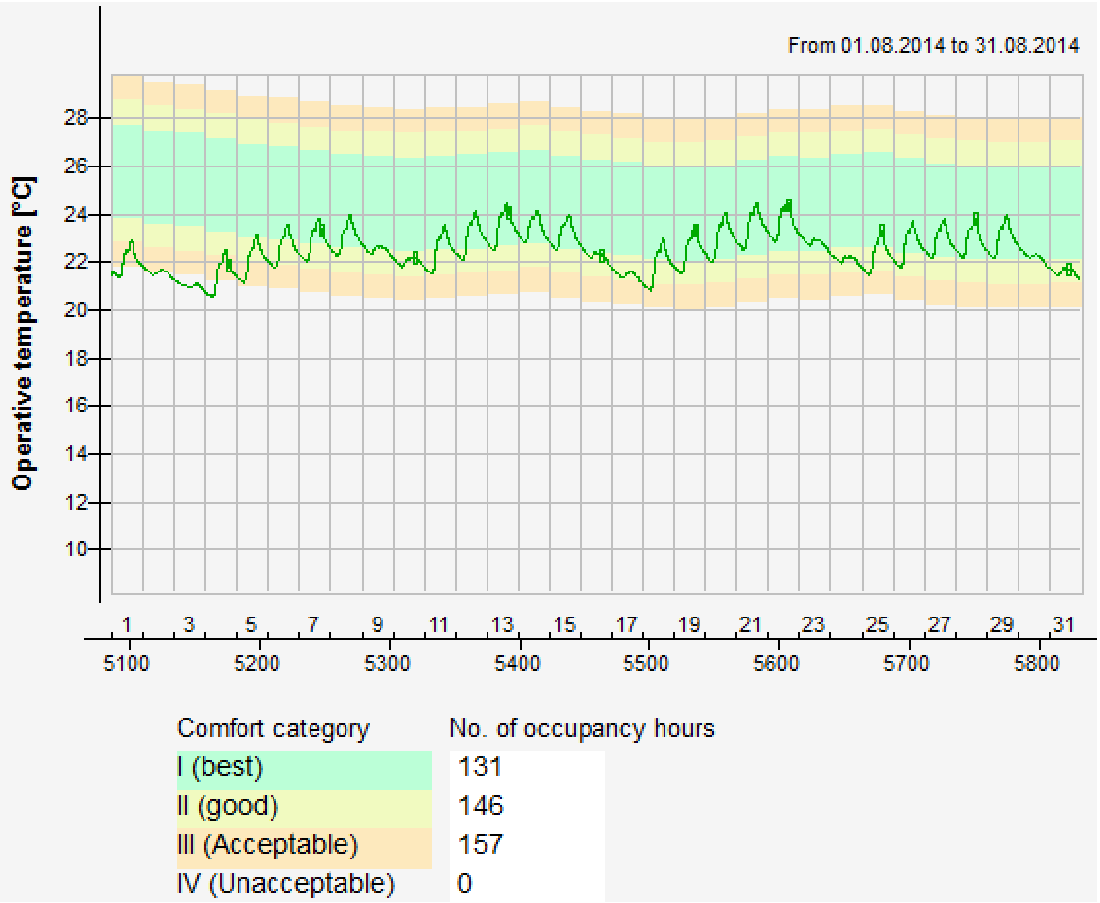


Figure 90: Thermal comfort for Landscape.4241 according to EN 15251 in Simulation 10

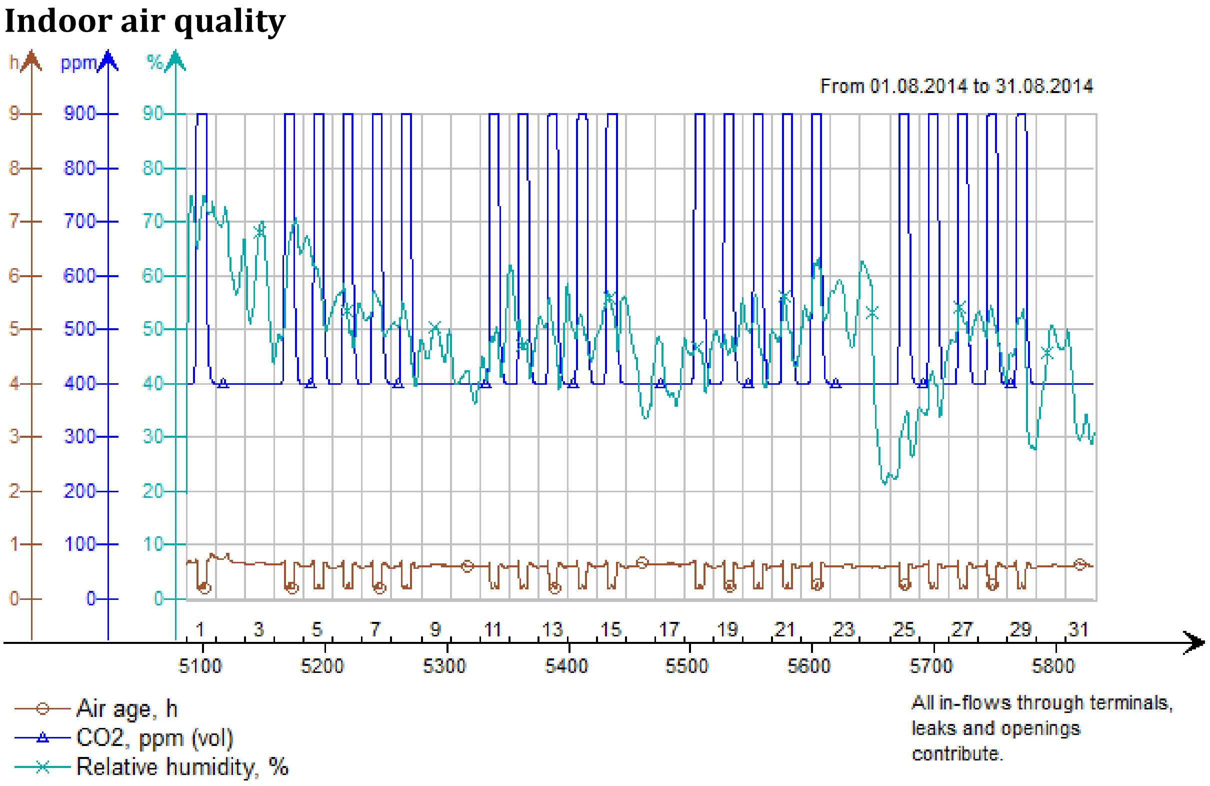


Figure 91: Indoor air quality in Meeting room.4206 in Simulation 10

Attachment 12 - Simulation 11

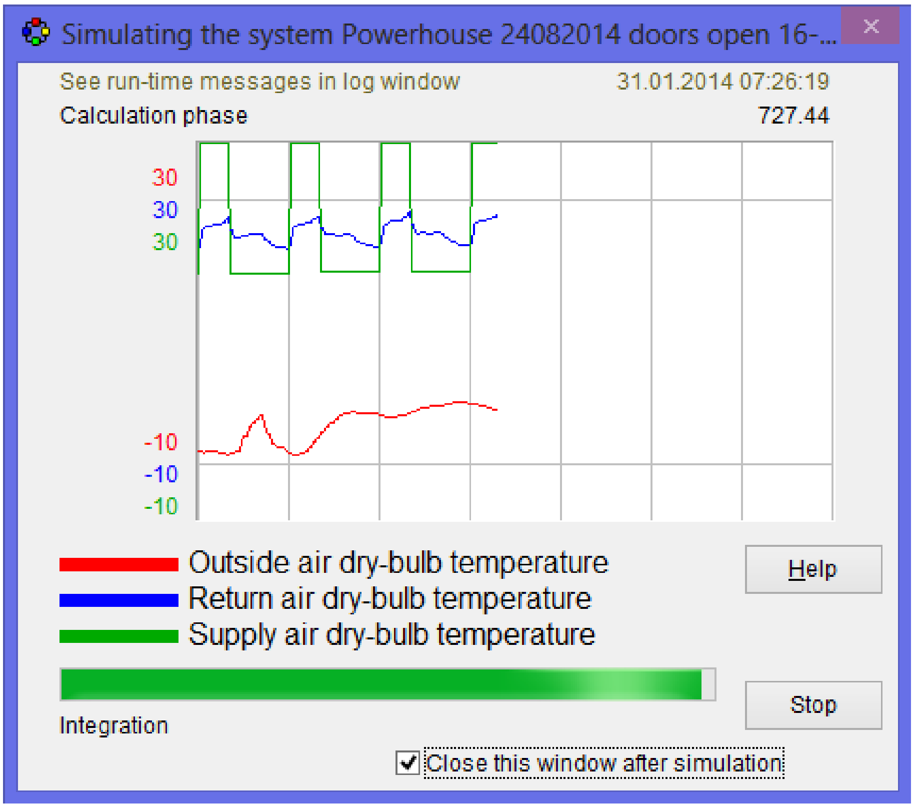


Figure 92: Supply air temperatures in Simulation 11

Simulation period 01.01-31.01		
Parameter	**Set point / state**	**Comment**
Heating set point	22°C	
Doors	Closed/Open	Closed during residence time and open outside the residence time.
Windows	Closed	Always closed
Occupancy Office 4204	1 Person	Occupancy from 08.00-16.00 with a presence of 75 % (30 min lunch break)
Occupancy Meeting room.4206	10 Persons	Occupancy between 09.00-11.00 and 13.00-16.00 with a presence of 50 %.
Occupancy open landscapes	30 Persons	Occupancy from 08.00-16.00 with a presence of 50 % (30 min lunch break)
Air supply temperature	19 °C / 40 °C	Supply air temperature of 40 °C between 00.00-08.00, and 19 °C between 08.00-00.00
Run time per day for the air handling units	24 hours	
Installed heating power at the second floor	12 kW	
Clothing	1 Clo	
Air quantities	Normal	Building: 0.7 l/(s*m^2) Person: 7 l/(s*person)

Table 41: Parameters used in Simulation 11

Main temperatures

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	21.1	21.0
Minimum temperature	19.8	19.7
Maximum temperature	21.9	21.9

Table 42: Main temperatures for Meeting room.4206 in Simulation 11

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	22.6	22.3
Minimum temperature	21.7	21.4
Maximum temperature	23.4	23.1

Table 43: Main temperatures for Office.4203 in Simulation 11

	Air temperature [°C]	Operative temperature [°C]
Mean temperature	23.0	23.1
Minimum temperature	22.4	22.4
Maximum temperature	23.6	23.7

Table 44: Main temperatures for Landscape.4241 in Simulation 11

Thermal indoor climate

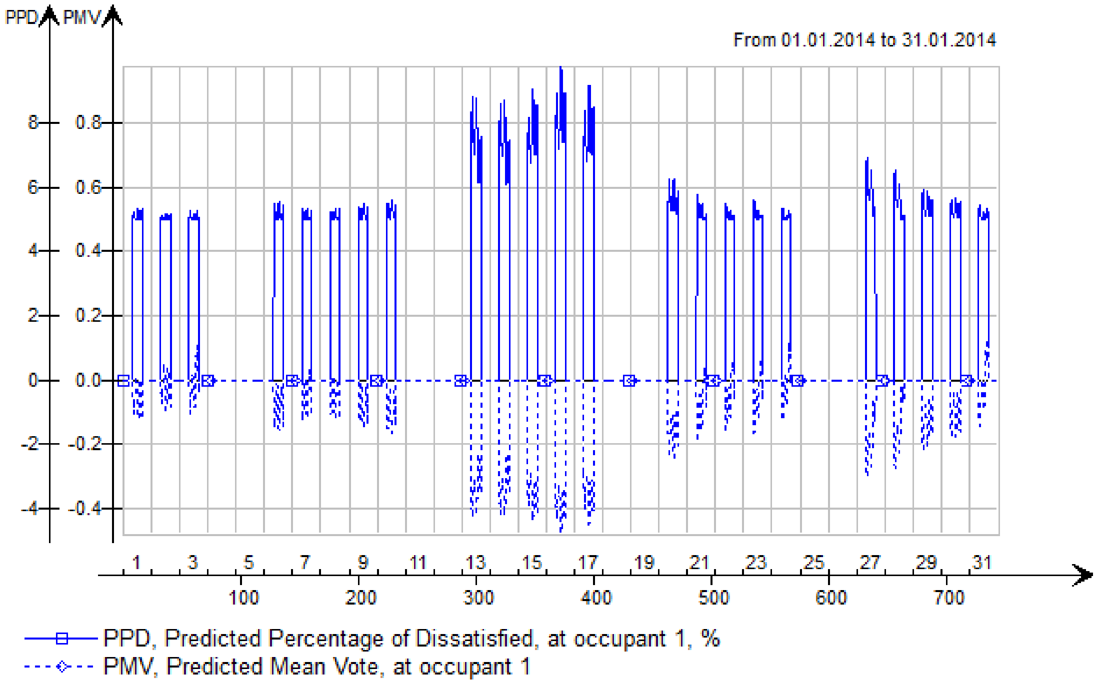


Figure 93: PPD and PMV for Meeting room.4206 in Simulation 11

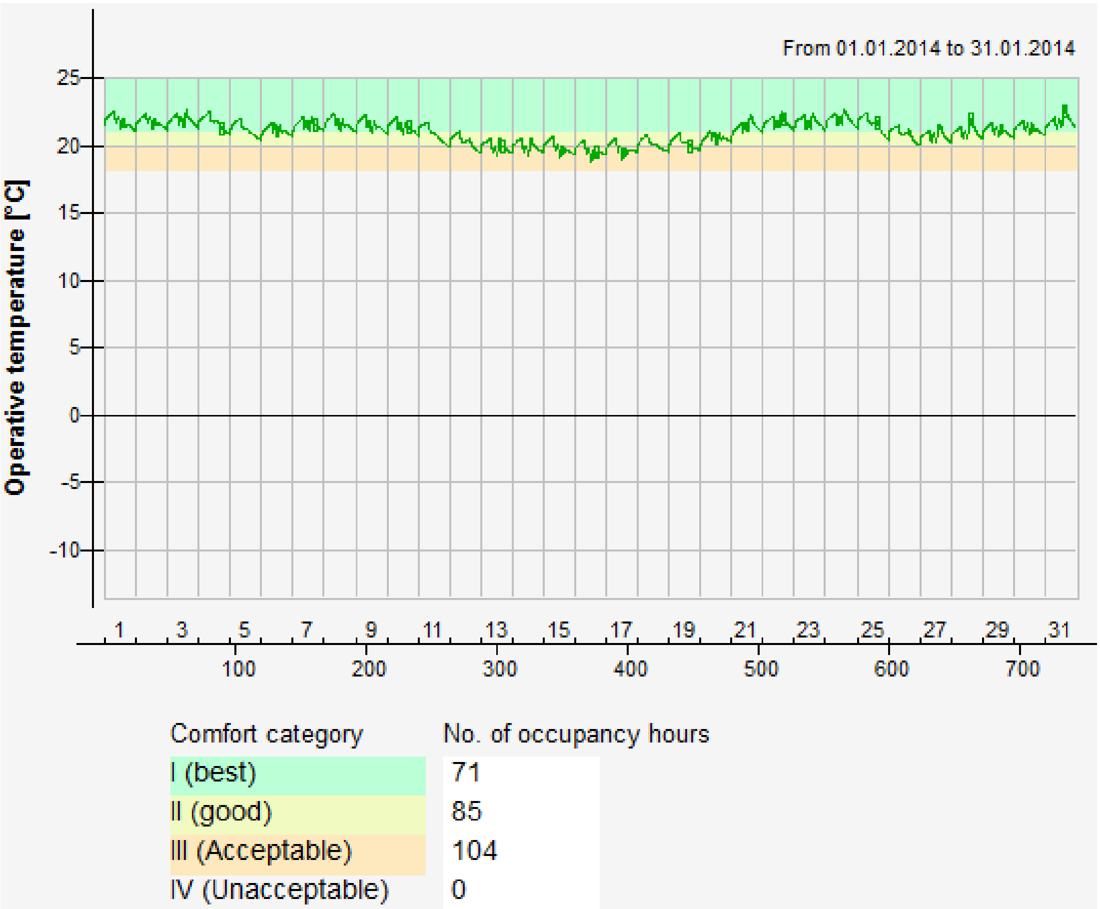


Figure 94: Thermal comfort for Meeting room.4206 according to EN 15251 in Simulation 11

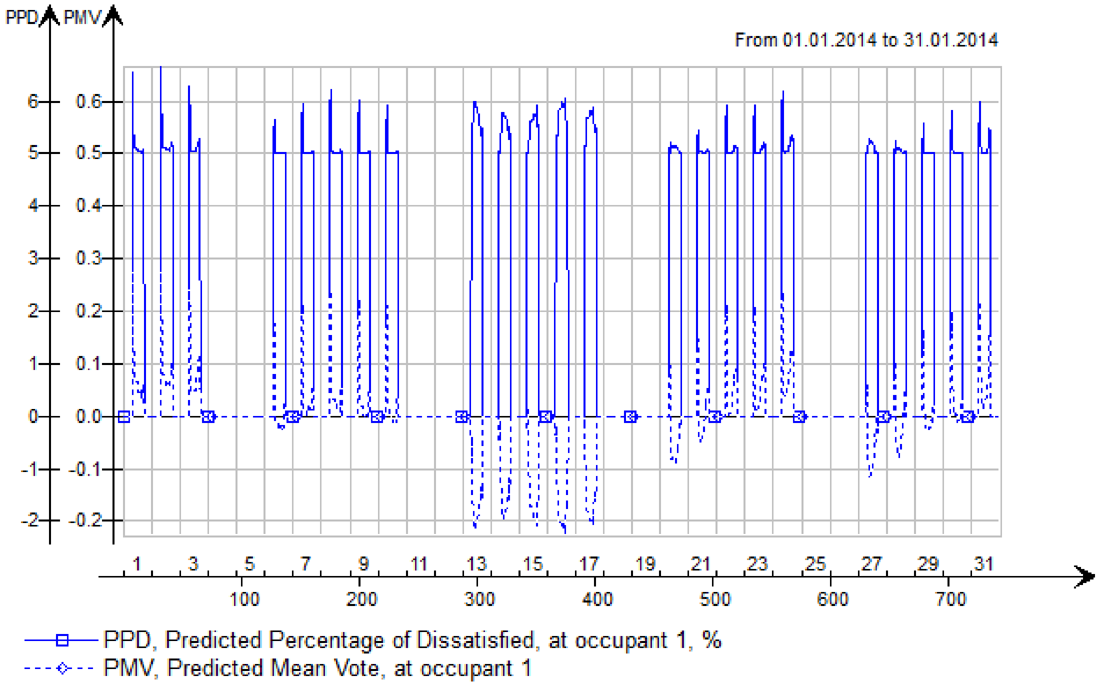


Figure 95: PPD and PMV for Office.4203 in Simulation 11

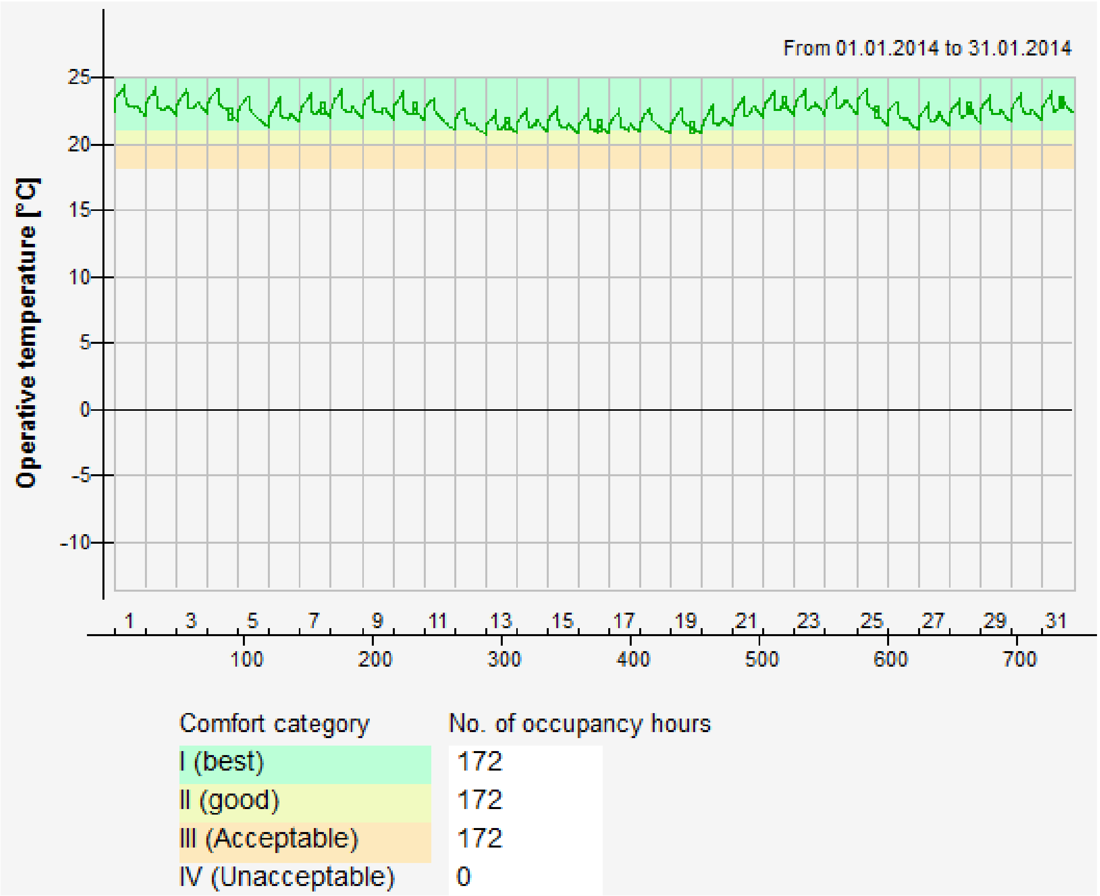


Figure 96: Thermal comfort for Office.4203 according to EN 15251 in Simulation 11

Attachment 13 – Normal air quantities for Building 4

Room/zone	Type of Ventilation	Occupancy	Area [m2]	Max air supply [l/s]	Min air supply [l/s]	Air return [l/s]	Total max [l/s]	Total min [l/s]	Max air supply [l/s*m2]	Min air supply [l/s*m2]
Møte.4102.4103.4104	CAV	3,00	27,56	40,29	40,29	0,00	40,29	40,29		
Møte.4106	**VAV**	**10,00**	**23,70**	**86,59**	**16,59**	**0,00**	**86,59**	**16,59**	**3,65**	**0,70**
Møte.4107.4108.4109.4111.4112	CAV	5,00	46,31	67,42	67,42	0,00	67,42	67,42		
Møte.4113.4114	CAV	2,00	20,58	28,41	28,41	0,00	28,41	28,41		
Datautstyrslab	CAV	0,00	23,79	16,65	16,65	0,00	16,65	16,65		
Kopi.4127	CAV	0,00	13,43	9,40	9,40	40,29				
Sjakt.4126		0,00	7,36	5,15	5,15	0,00				
Bad.4121.4122.4123.4124	CAV	0,00	17,55	12,29	12,29	52,65				
Garderobe		0,00	3,67	2,57	2,57	0,00				
Korridor.4147	**VAV**	**0,00**	**96,09**	**67,26**	**67,26**	**0,00**	**96,67**	**96,67**	**1,01**	**1,01**
Post/Hvilerom.41364138.4139.4141	CAV	3,00	20,31	35,22	14,22	0,00	35,22	35,22		
Trapperom.4144		0,00	25,64	17,95	17,95	0,00				
Trapp.4146		0,00	26,70	18,69	18,69	0,00				
Allrom.4148		1,00	73,22	58,25	51,25	0,00				
Trapp.41		0,00	8,00	5,60	5,60	0,00				
Heis		0,00	5,89	4,12	4,12	0,00				
Landskap.4142	**VAV**	**24,00**	**218,00**	**320,60**	**152,60**	**0,00**	**425,21**	**250,21**	**1,95**	**1,15**
Møte.4202	CAV	1,00	8,83	13,18	6,18	0,00	13,18	13,18		
Møte.4203	CAV	1,00	8,83	13,18	6,18	0,00	13,18	6,18		
Møte.4204	CAV	1,00	8,83	13,18	6,18	0,00	13,18	13,18		
Møte.4206	**VAV**	**10,00**	**23,70**	**86,59**	**16,59**	**0,00**	**86,59**	**16,59**	**3,65**	**0,70**
Møte.4207	CAV	1,00	8,83	13,18	6,18	0,00	13,18	13,18		
Møte.4208	CAV	1,00	8,83	13,18	6,18	0,00	13,18	13,18		
Møte.4209	CAV	1,00	8,83	13,18	6,18	0,00	13,18	13,18		
Møte.4211	CAV	1,00	8,83	13,18	6,18	0,00	13,18	13,18		
Møte.4212	CAV	1,00	8,83	13,18	6,18	0,00	13,18	13,18		
Bad.4219.4221.4222.4223	CAV	0,00	17,55	12,29	12,29	52,65				
Lager.4216.4218		0,00	11,87	8,31	8,31	0,00				
Sjakt.4226		0,00	7,36	5,15	5,15	0,00				
Kopi.4227	CAV	0,00	13,43	9,40	9,40	40,29				
Heis		0,00	5,89	4,12	4,12	0,00				
Trapperom.4243		0,00	25,64	17,95	17,95					
Trapp.4146		0,00	26,70	18,69	18,69					
Landskap.4201.4246.4247	**VAV**	**0,00**	**126,20**	**88,34**	**88,34**	**0,00**	**164,25**	**164,25**	**1,30**	**1,30**
Møte.4228	CAV	1,00	9,13	13,39	6,39	0,00	13,39	13,39		
Møte.4229	CAV	1,00	3,60	9,52	2,52	0,00	9,52	9,52		
Møte.4231	CAV	1,00	6,72	11,71	4,71	0,00	11,71	11,71		
Møte.4239	**VAV**	**7,00**	**9,38**	**55,56**	**6,56**	**0,00**	**55,56**	**6,56**	**5,93**	**0,70**
Garderobe.4237.4248	CAV	0,00	9,24	6,47	6,47	0,00	6,47	6,47		
Trapp.41		0,00	8,00	5,60	5,60	0,00				
Landskap.4241	**VAV**	**30,00**	**280,40**	406,28	196,28	**0,00**	**411,88**	**201,88**	**1,47**	**0,72**
				0,00	0,00					
Møte.4302.4303.4304	CAV	3,00	27,58	40,31	19,31	0,00	40,31	40,31		
Møte.4306	**VAV**	**10,00**	**23,63**	**86,54**	**16,54**	**0,00**	**86,54**	**16,54**	**3,66**	**0,70**
Møte.4307.4308.4309.4311.4312	CAV	5,00	46,33	67,43	32,43	0,00	67,43	67,43		
Heis		0,00	5,89	4,12	4,12	0,00				
Trapperom.4342		0,00	25,64	17,95	17,95	0,00				
Trapp.4146		0,00	26,70	18,69	18,69	0,00				
Lager.4316		0,00	3,65	2,55	2,55	0,00				
Bad.4317.4318.4319.4321	CAV	0,00	17,55	12,29	12,29	52,65				
Sjakt.4323		0,00	7,36	5,15	5,15	0,00				
Kopi.4324	CAV	0,00	13,43	9,40	9,40	40,29				
Korridor.4344		**0,00**	**134,30**	**94,01**	**94,01**	**0,00**	**164,16**	**164,16**	**1,22**	**1,22**
Møte.4326.4327.4328	CAV	3,00	19,96	34,97	13,97	0,00	34,97	34,97		
Møte.4338	**VAV**	**7,00**	**9,38**	**55,56**	**6,56**	**0,00**	**55,56**	**6,56**	**5,93**	**0,70**
Garderobe.4336.4345.	CAV	0,00	9,99	6,99	6,99	0,00	6,99	6,99		
Trapp.41		0,00	8,00	5,60	5,60	0,00				
Landskap.4341	**VAV**	**30,00**	**280,40**	**406,28**	**196,28**	**0,00**	**411,88**	**201,88**	**1,47**	**0,72**
				0,00	0,00					
Heis		0,00	5,89	4,12	4,12	0,00				
Trapperom.4437		0,00	19,10	13,37	13,37	0,00				
Trapp.4146		0,00	26,70	18,69	18,69	0,00				
Lager.4426		0,00	3,65	2,55	2,55	0,00				
Bad.4421.4422.4423.4424	CAV	0,00	17,55	12,29	12,29	52,65				
Landskap.4441.4401.4442	**VAV**	**0,00**	**74,07**	**51,85**	**51,85**	**0,00**	**102,87**	**102,87**	**1,39**	**1,39**
Møte.4402.4403.4404	CAV	3,00	27,72	40,40	19,40	0,00	40,40	40,40		
Møte.4406	**VAV**	**10,00**	**23,70**	**86,59**	**16,59**	**0,00**	**86,59**	**16,59**	**3,65**	**0,70**
Møte.4407.4408	**VAV**	**16,00**	**42,55**	**141,79**	**29,79**	**0,00**	**141,79**	**29,79**	**3,33**	**0,70**
Møte.4411.4412.4413.4414	CAV	4,00	61,98	71,39	43,39	0,00	71,39	71,39		
Møte.4417	**VAV**	**6,00**	**44,41**	**73,09**	**31,09**	**0,00**	**73,09**	**31,09**	**1,65**	**0,70**
Møte.4418	**VAV**	**25,00**	**49,48**	**209,64**	**34,64**	**0,00**	**209,64**	**34,64**	**4,24**	**0,70**
Garderobe.4435.443	CAV	0,00	7,69	5,38	5,38	0,00	5,38	5,38		
Møte.4432.4433	CAV	2,00	11,99	22,39	8,39	0,00	22,39	22,39		
Teknisk rom.4409		0,00	51,98	36,39	36,39	0,00				
Kopi.4427	CAV	0,00	11,14	7,80	7,80	33,42				
Trapp.41		0,00	8,00	5,60	5,60	0,00				
Landskap.4416.4440	**VAV**	**6,00**	**163,60**	**156,52**	**114,52**		**206,30**	**164,30**	**1,26**	**1,00**
Totals		236,00	2624,18			364,89	3448,64	2137,93		
Landskap.4416.4440										
Maximum air return	3083,75	18,85								
Minimum air return	1773,04	10,84								
Ventilation per occupant [l/s per. person]		7	**Ventilation per square meter [l/s per. m2**				0,7			

Table 45: Air quantities for the zones in Building 4

Attachment 14 – Evaluation of the thermal indoor climate

Percent of occupancy hours in each comfort category				
Comfort category	Unacceptable (IV)	Acceptable (III)	Good (II)	Best (I)
Simulation 1	86 %	13 %	1 %	0 %
Simulation 2	32 %	65 %	3 %	0 %
Simulation 3	17 %	80 %	4 %	0 %
Simulation 4	8 %	70 %	19 %	3 %
Simulation 5	11 %	76 %	13 %	0 %
Simulation 6	2 %	54 %	35 %	10 %
Simulation 7	1 %	46 %	43 %	11 %
Simulation 8	0 %	39 %	38 %	23 %
Simulation 9	0 %	45 %	44 %	11 %
Simulation 10	0 %	35 %	34 %	32 %
Simulation 11	0 %	40 %	33 %	27 %

Figure 97: Evaluation of the thermal comfort in Meeting room.4206

Percent of occupancy hours in each comfort category				
Comfort category	Unacceptable (IV)	Acceptable (III)	Good (II)	Best (I)
Simulation 1	43 %	52 %	4 %	0 %
Simulation 2	2 %	93 %	4 %	0 %
Simulation 3	0 %	95 %	5 %	0 %
Simulation 4	1 %	92 %	6 %	0 %
Simulation 5	0 %	75 %	24 %	0 %
Simulation 6	1 %	36 %	34 %	28 %
Simulation 7	1 %	35 %	33 %	31 %
Simulation 8	2 %	37 %	34 %	27 %
Simulation 9	1 %	35 %	33 %	31 %
Simulation 10	4 %	43 %	38 %	15 %
Simulation 11	0 %	33 %	33 %	33 %

Figure 98: Evaluation of the thermal comfort in Office.4203

Percent of occupancy hours in each comfort category				
Comfort category	Unacceptable (IV)	Acceptable (III)	Good (II)	Best (I)
Simulation 6	0 %	39 %	38 %	23 %
Simulation 7	0 %	36 %	36 %	28 %
Simulation 8	0 %	35 %	34 %	31 %
Simulation 9	0 %	36 %	35 %	28 %
Simulation 10	0 %	36 %	34 %	30 %

Figure 99: Evaluation of the thermal comfort in Landscape.4241