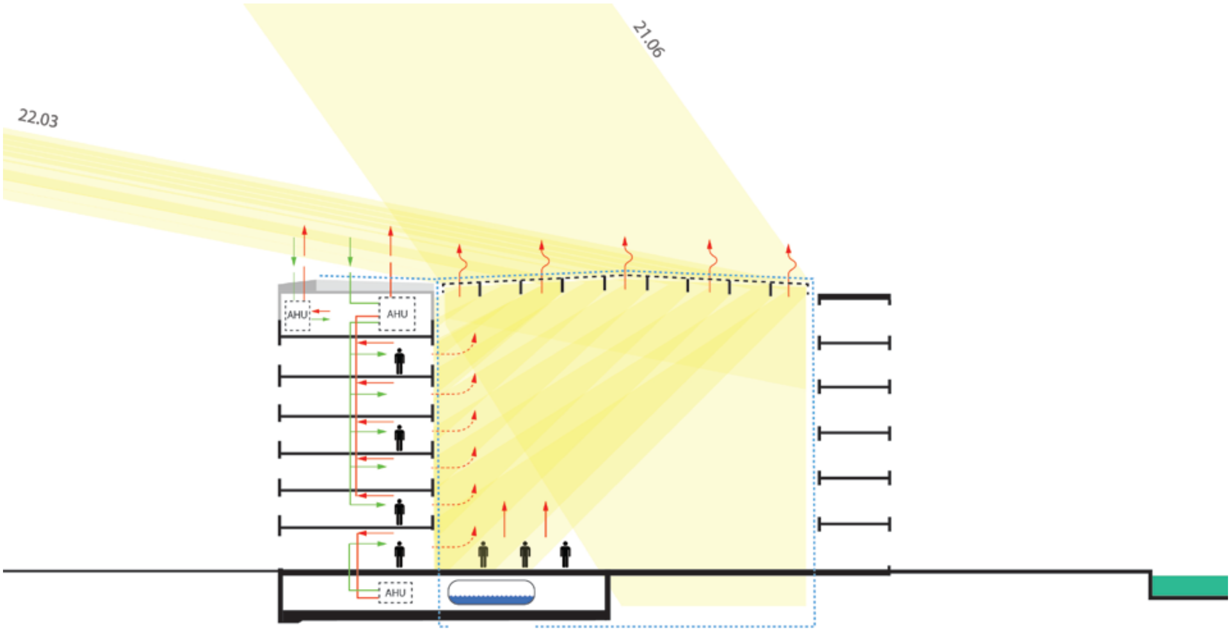
Lund University

Course: Integrating Daylight and Ventilation
Author: Anna Olsson, Magdalena Stefanowicz, Mihail Todorov, Xueting Wang
E-mail address: anna.olsson.861@student.lu.se, magdalena.stefanowicz.276@student.lu.se, mihail.todorov.841@student.lu.se, xueting.wang.373@student.lu.se
Study programme: Master Programme in Energy-efficient and Environmental Building Design, 120 ECTS
Tutors: Marie-Claude Dubois, Saqib Javed, Lund University
Scope: 19.000 words inclusive of appendices
Date: 2014-09-25



Project report
within Master of Energy-efficient and Environmental Building, Integrating Daylight and Ventilation, 15 points

Energy-efficient Office Building

Anna Olsson, Magdalena Stefanowicz,
Mihail Todorov, Xueting Wang

Abstract

The objective of this study is to introduce design process of energy efficient retrofit of an existing office building located in Malmo, Sweden. The building's initial conditions in terms of energy use, daylight and moisture safety are perceived as moderate or bad, for which quantitative and qualitative evaluations of the simulations are made. The energy use, moisture safe design, daylight factor, daylight autonomy are analysed with respect to steady-state calculations and several simulation software. Results show a building with a potential for energy efficient and daylight improvements. Highest possible level of architecture quality in respect to parametric studies conducted for energy efficiency, indoor climate, daylight autonomy, glare risk and moisture safe design, leads to the final design of the building. For the proposed design, electric lighting, mechanical ventilation and space heating are introduced with consequently low energy use in mind.

Keywords: Daylight, daylight factor, daylight autonomy, energy use, energy efficiency, electric lighting, glare, hybrid ventilation, indoor climate, integrated design process, moisture safety, natural ventilation, space heating.

Acknowledgements / Foreword

Acknowledgement is given to the Hans Eliasson Foundation, for providing computers and simulation software to be able to complete the assignment.

Table of Contents

Terminology / Notation

Acronyms / Abbreviations

BBR	Boverkets Byggregler, Swedish Building Regulations
BREEAM	Building Research Establishment Environmental Assessment Method
Cooling demand	Annual needed energy to keep the inside temperature under a certain threshold
DF	Daylight Factor
DHW	Domestic Hot Water
DA	Daylight Autonomy
FEBY	Forum för Energieffektiva Byggnader
GWR	Glazing to window ratio
HVAC	Heating, ventilation and air conditioning
IDP	Integrated Design Process
IPCC	Intergovernmental Panel on Climate Change
LD	Lighting dependency
N	North
NE	North-East
NNE	North-North-East
NNW	North-North-West
NW	North-West
NZEB	Net Zero Energy Buildings
q_{50}	Airtightness of an envelope at standardized pressure difference of 50 Pascal
RH	Relative Humidity
S	South
SE	South-East
SMHI	Swedish Meteorological and Hydrological Institute
SSE	South-South-East
SSW	South-South-West
SW	South-West

Mathematical notation

U	Thermal conductance (W/m^{2o}C)
λ	Thermal conductivity (W/m^{o}C)
E	Illuminance (lm/m2 or lux)
I	Luminous Intensity (cd)
L	Luminance (cd/m2)
r	Distance (m)
θ	Angle (Degrees)

1 Introduction

Today many office buildings are struggling to meet the building regulations regarding the energy performance. As a result of this, the office buildings are in a need of holistic refurbishment to be able to meet the demands of the regulations. The challenge of this is established by the assignment, where an existing office building in Malmö is going to be optimized.

1.1 Background and problem motivation

The assessed building was built in the 1960s as the head office of BRIO. Today, the function of the BRIO building has changed, where offices are rented out individually floor by floor. The study aims to implement energy-efficient measures to improve architecture quality of the building and to reduce the total energy demand significantly. Consequently, the building has to be refurbished to meet Swedish requirements for energy usage, ventilation, moisture safety and daylight.

1.2 Overall aim and concrete and verifiable goals

The study of the assignment aims to meet the requirements according to the building regulations and aims set within the assignment. The goals for each area are specified as follows:

- Daylighting according to BREEAM, exemplary level.
- Ventilation system according to Swedish regulations for offices.
- Energy use and thermal comfort according to Swedish passive house criteria, stated in FEBY12.
- The heating system should be updated for the optimized building.
- Moisture analysis should be made for the building components

1.3 Scope

The present study objective is to preserve the aesthetic profile of the building even though it has to be optimized according to the stated project aims. The collected information regarding the existing building comes from architectural drawings, a visit of the building and assumptions based on common building principles. Due of the lack of ingoing information, some assumptions had to be made, which could lead slight difference between the reality and actual building.
Since the knowledge of how the building will be used was limited, regarding usage and occupancy, these had to be assumed. Excluded from the study is how the ground floor restaurant area is going to be used.

1.4 Contributions

To be able to make complex study of the building, the workload of the different simulation tools was distributed within the group. However, the whole group was involved in the project process and the discussions. The simulations made for energy analysis were done by Mihail Todorov and the heat load coefficient calculations were performed by both Mihail Todorov and Anna Olsson. The moisture safety analysis and dimensioning of the heating system were done by Anna Olsson. The ventilation calculations were carried out by Xueting Wang. The daylight studies, the lighting design and the conceptual architecture modelling were made by Magdalena Stefanowicz.

2 Methodology / Model

Simulations and analyses in the following studies were performed using the weather climatic data for the neighboring city of Copenhagen, Denmark. The exception was made for moisture analysis, where Lund, Sweden was analyzed.

2.1 Site analysis and development of the area

BRIO building is located on Nordenskiöldsgatan 6 in West Harbor district of Malmö, Sweden. In the past few years the district has been transforming its character from a shipyard and industrial area to education, culture and business district.

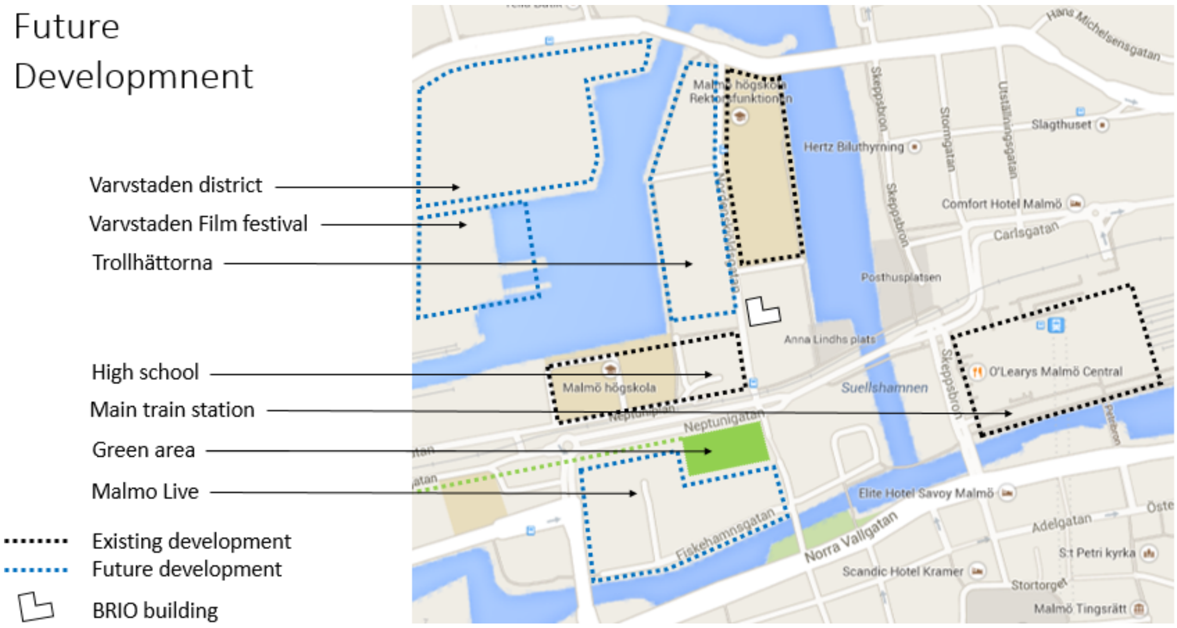


Figure 1, Map of future development in Western Harbour

In the close neighborhood of the BRIO building – area called Trollhättorna, municipality plans are to allow new 4-6 storeys development, instead of the existing 2-3 storeys buildings.

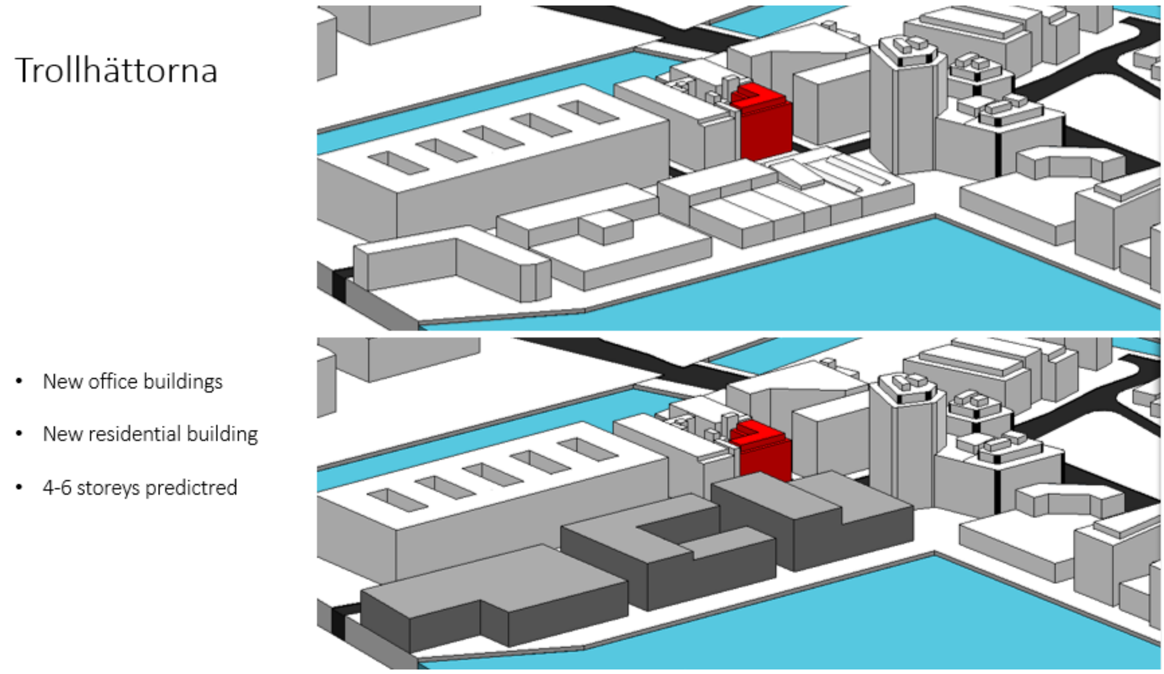


Figure 2, Picture with the future buildings, Trollhättorna

The potential of Western Harbor is closely related to its attractive location in the city. The district, with close relation to water and short distance from the city center, is provided with various kinds of transportation access, both existing and planned, as shown on the figure below.

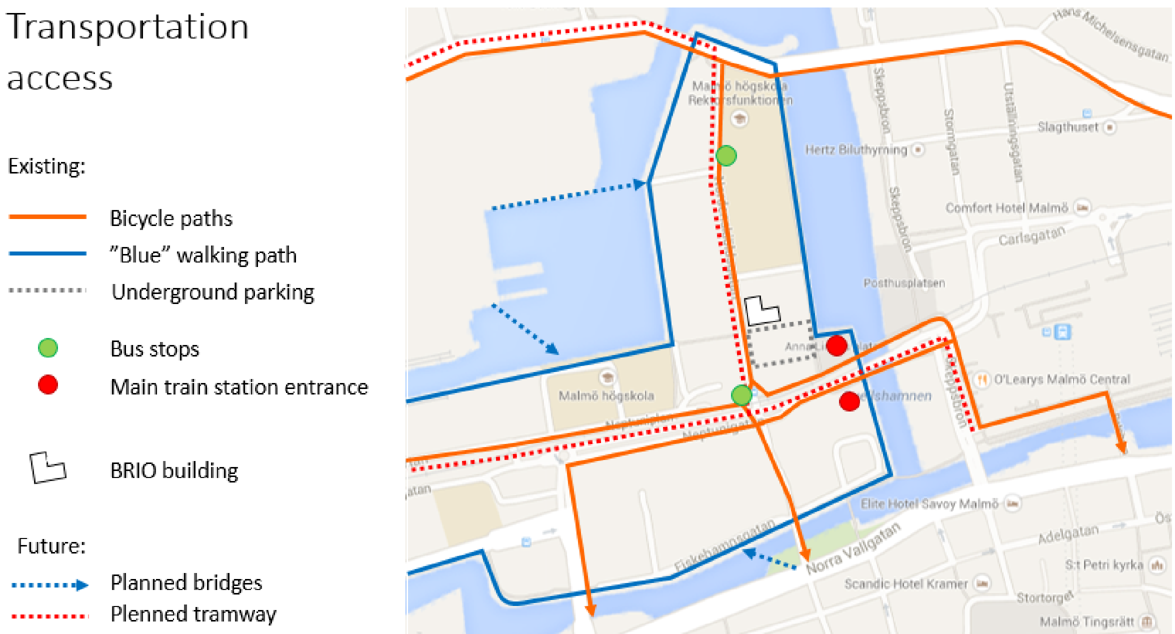


Figure 3, Map of Transportation access in Western Harbour

2.2 Climate analysis

To establish the climatic conditions of the site, analysis was performed with reference to temperature, relative humidity, cloudiness, local shading from the surrounding buildings, incident solar radiation on the building and wind behavior.

Temperature

The analysis of the temperature were carried out with "Ecotect Analysis" 2011. In the following chart the minimum, maximum and average temperatures are given for each month of the year.

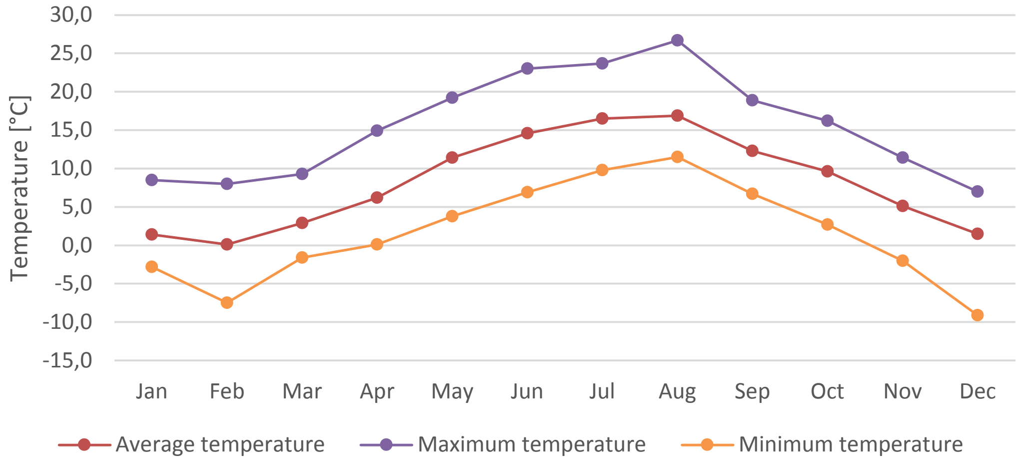


Figure 4: Diagram for the temperature

Relative Humidity

The analysis for the relative humidity were made in "Ecotect Analysis" 2011. The analysis gave the results for 9am and 3 pm and thereafter an average was calculated, the outcome from which is presented in the diagram below.

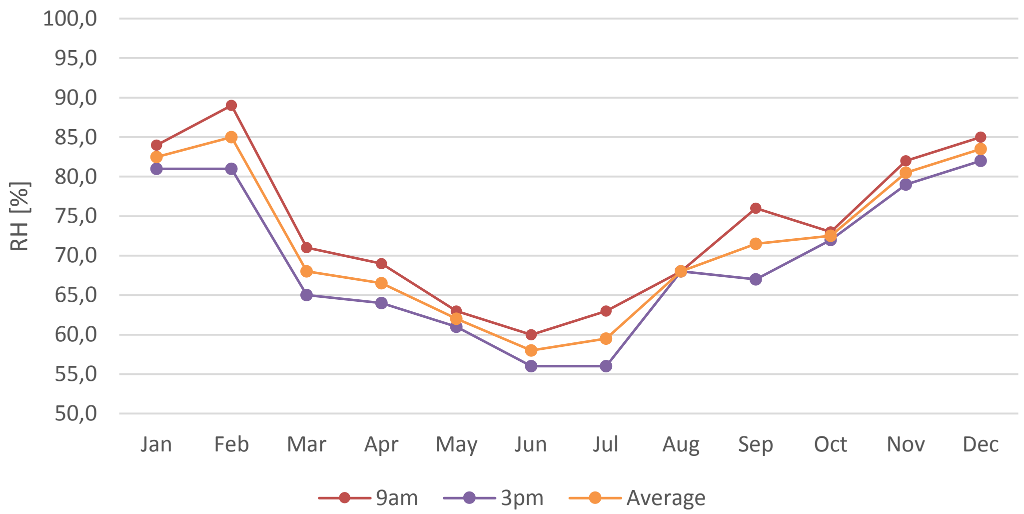


Figure 5: Diagram of Relative Humidity

Psychometric Chart

In the psychometric chart the relation between the temperature and the relative humidity is presented. "Ecotect Analysis" 2011 was used for the analysis where the activity level was set to medium. In the chart below the results for the annual values are given.

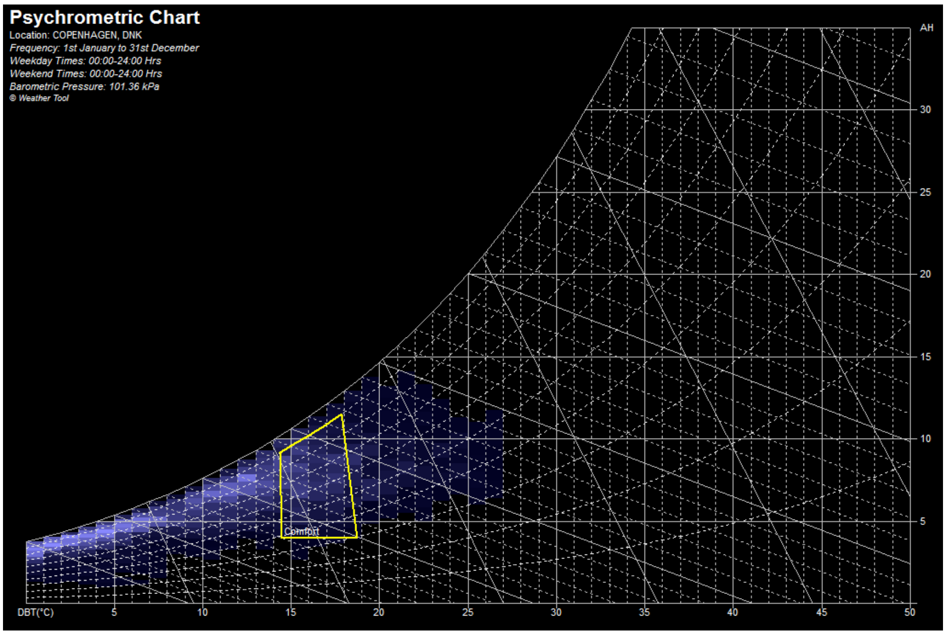


Figure 6: Psychometric Chart (2, 2011)

Cloudiness

Cloudiness appearance in Malmö was analyzed to assess the possibility of utilizing the outdoor spaces. Results given by SMHI ([1], 2014) shows, however, low attractiveness of the outdoor surrounding due to the 70% of cloudiness appearance during the year.

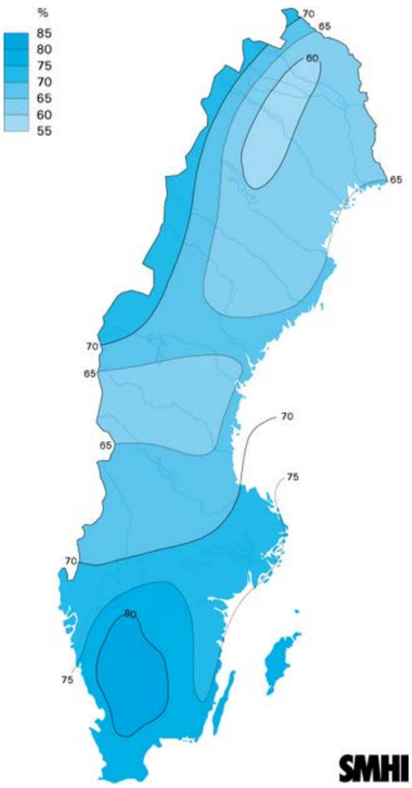


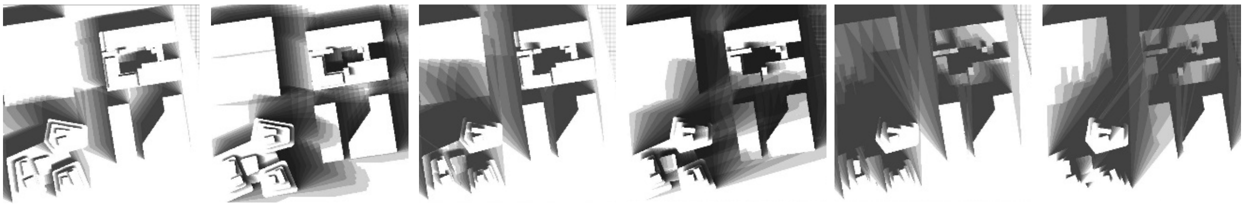
Figure 7: Percentage of cloud appearance in Sweden ([1], 2014)

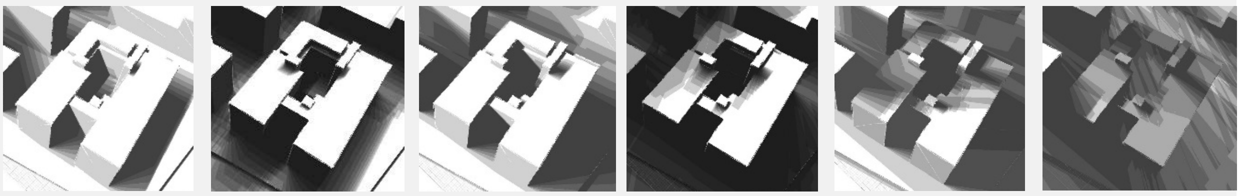
Shadows and sun path

Firstly, a seasonal pattern of shadows were simulated for both the top view of the BRIO plot and the axonometric view of the courtyard. The results are gained separately for the morning hours 9-12 and afternoon hours 12-17.

Table 1: Annual shadows pattern in top view and axonometric view to the atrium.

21st June		21st Marc, 23rd September		22nd December	
0900-1200	1200-1700	0900-1200	1200-1700	0900-1200	1200-1700





Secondly, a more detailed sun path diagram was gained for an annual shadows pattern in the courtyard and on the roof surface of the BRIO building. The results are shown in diagrams below:

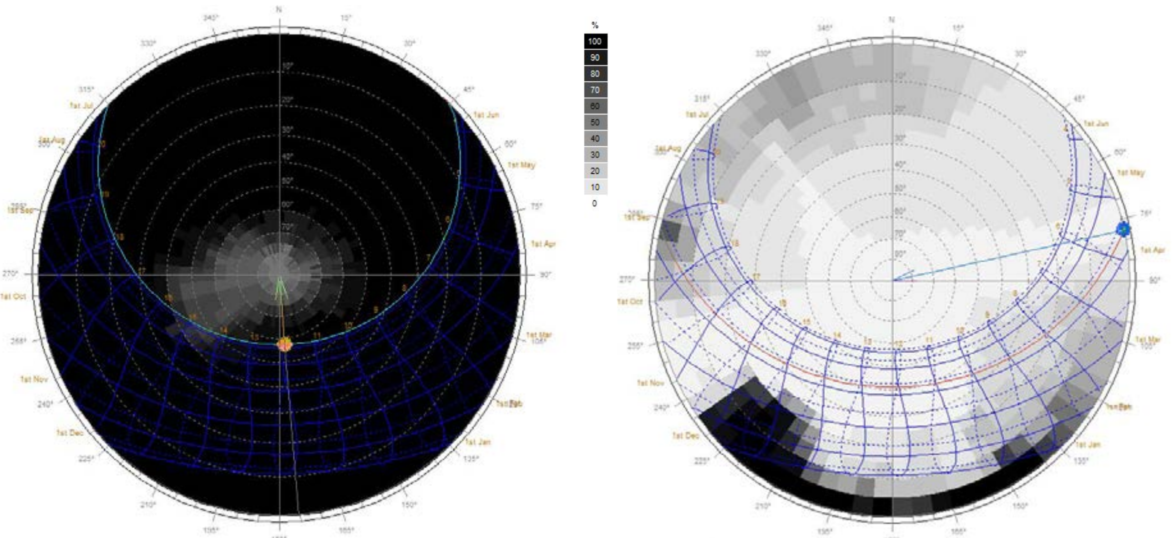


Figure 8: Sun path diagram of annual shadows pattern in the courtyard,and on the roof of BRIO building, accordingly.

Finally, the annual sun path was analyzed in "Ecotect Analysis" 2011, in order to realize the actual height of the sun. The Stereographic Diagram is shown below.

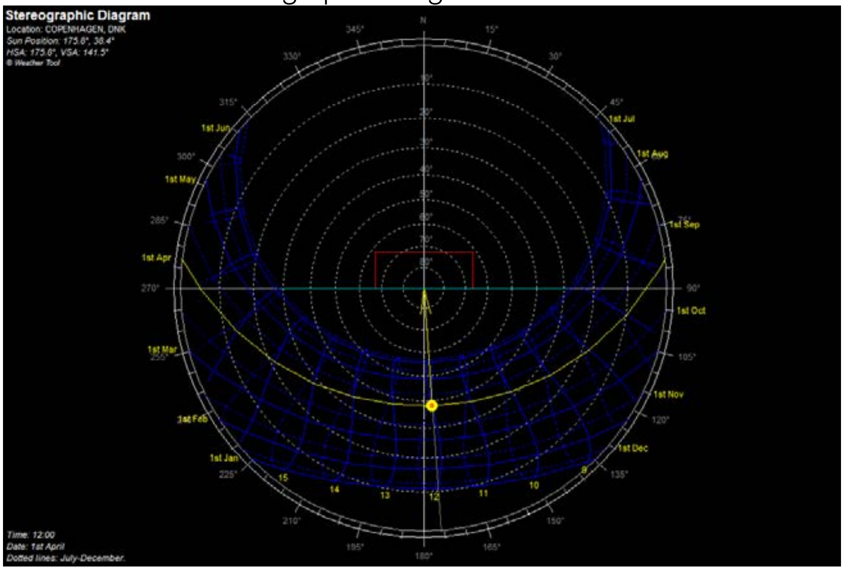


Figure 9: Annual sun path, "Ecotect".

Solar radiation

Solar radiation was simulated for axonometric view of the building BRIO in "Ecotect". The results were gained for winter hour period from October to April and summer hour period from May to September, shown in figures below:

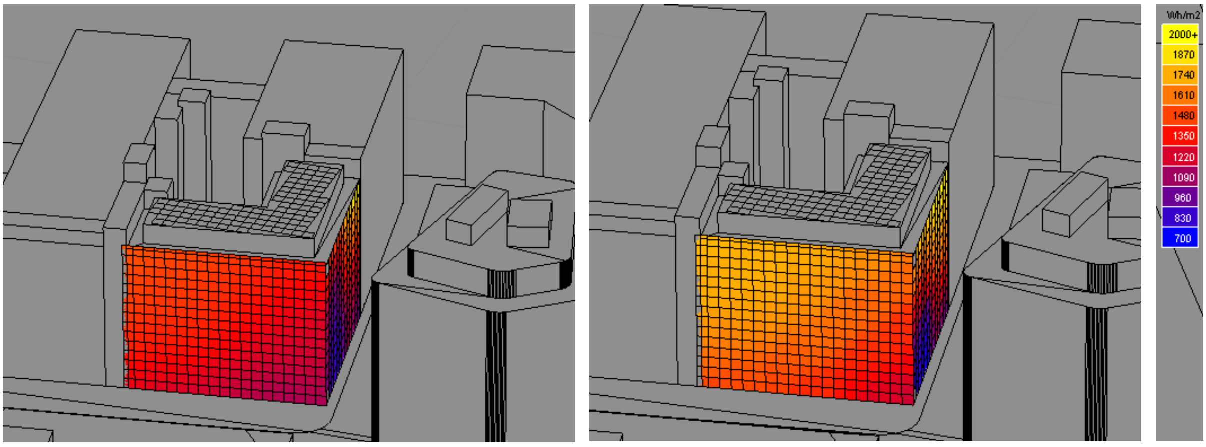


Figure 10 Solar irradiation on Brio facade, October to April and May to September, accordingly.

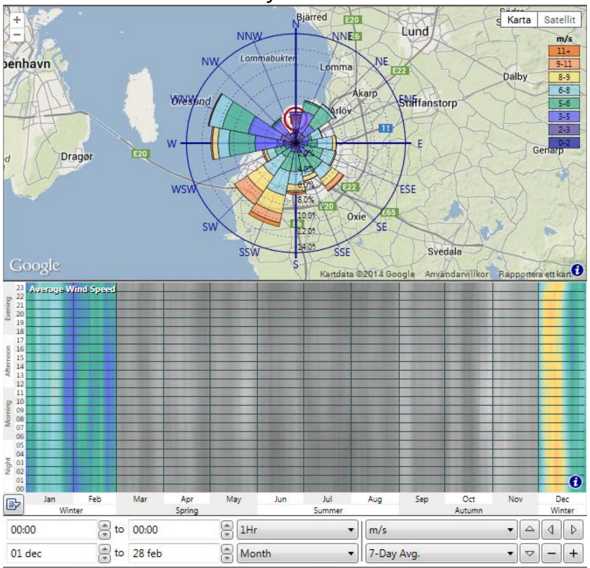
It can be seen that the lower storeys of the south facade were affected by the surroundings and receive relatively low irradiation. The solar irradiation ranges in summer period almost twice of the winter hour period.

Wind

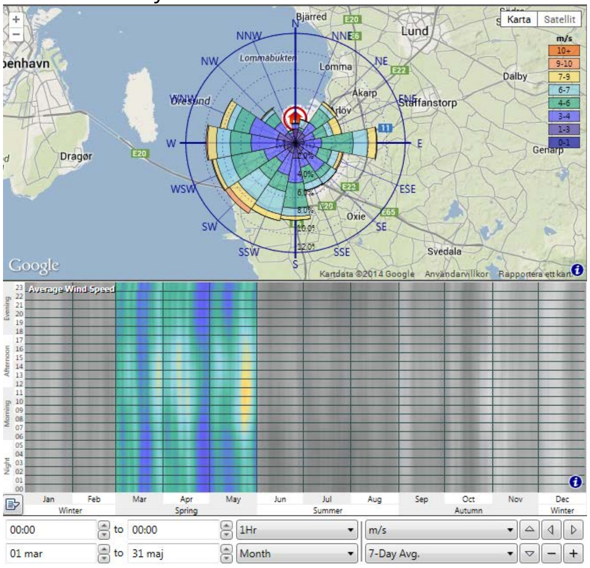
The BRIO building is located in the vicinity of the west coast, where the prevailing winds are coming from. "Autodesk Vasari" was used to determine the dominant wind direction and analyze the wind pattern of the site.

Table 2 Wind roses

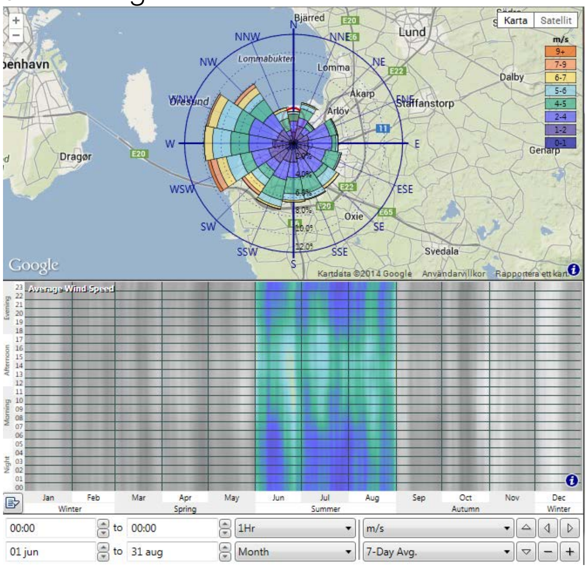
December – February



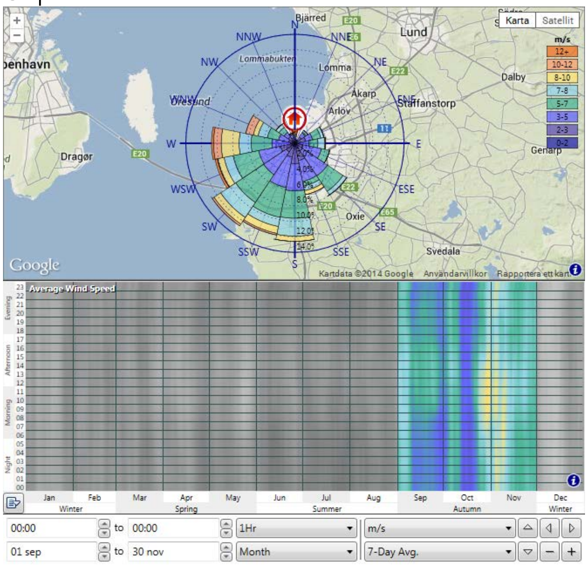
March – May



June – August



September – Novemeber



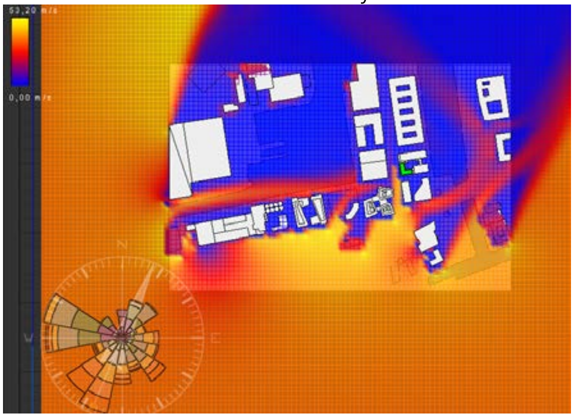
The predominant winds in Malmö are mainly coming from W and SW, however during each season winds change their direction:

- Winter: SSW, W, WNW (>11 m/s)
- Spring: W, SW, E (>10 m/s)
- Summer: W, WSW, WNW (>9 m/s)
- Autumn: SW, SSW, S (>12 m/s)

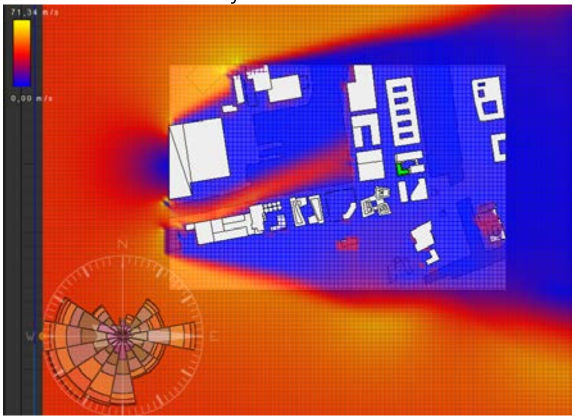
The BRIO building is well surrounded by buildings of similar height or higher. The wind tunnel analysis was performed at a standard height of 10 m. According to the analysis no turbulence seems to occur between the buildings, nor is any major wind funnel effect created around the BRIO building.

Table 3 Wind tunnels

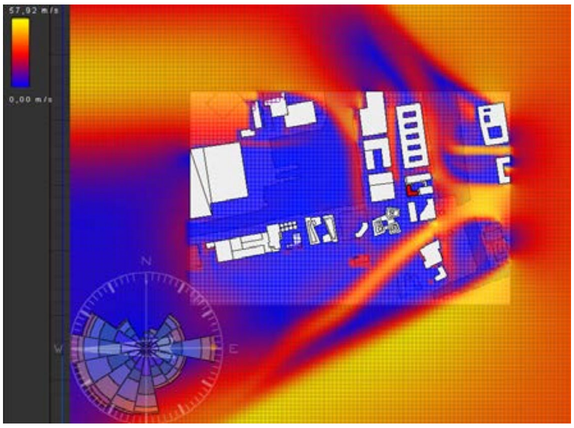
SSW wind December - February



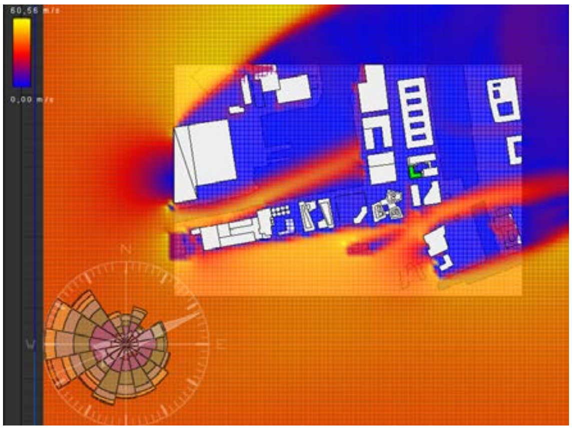
W wind March – May



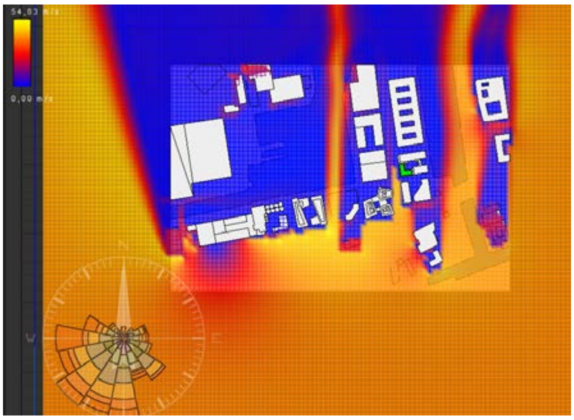
E wind March – May



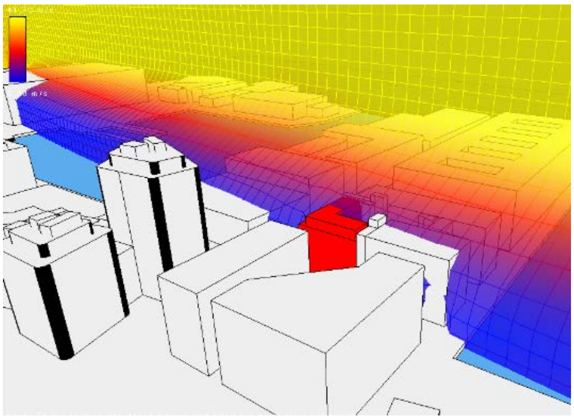
WSW wind June – August



S wind September – November



W wind 3D tunnel



Climate change

Climate change effect on the BRIO building's climatic zone was estimated according to the report "Climate Change 2013. The physical Science Basis" released by Intergovernmental Panel on climate change IPCC (3, 2013). In the following study, the most pessimistic scenario, RCP 8.5 for 2081-2100, was analyzed.

Firstly, the temperature change was analyzed in terms of global warming and urban heat island. The estimated high temperature of 32C in summer time in the center of Malmö was recognized for 2081.

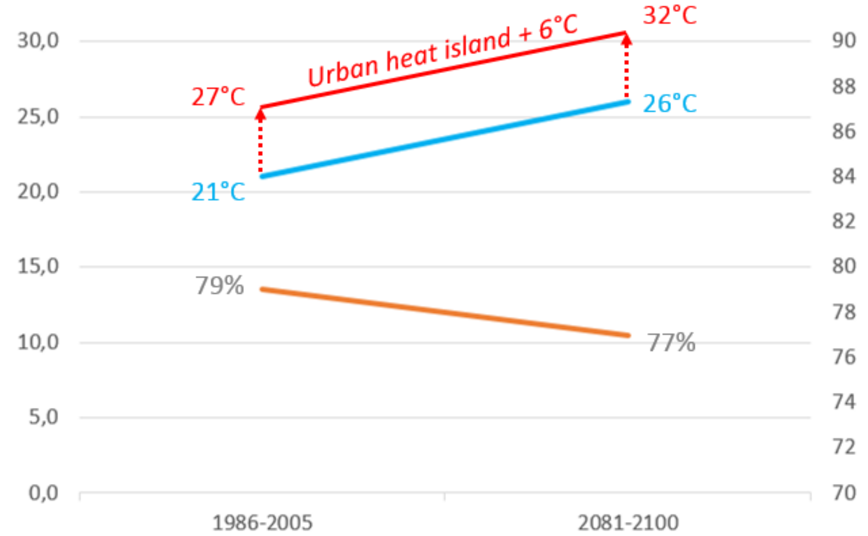


Figure 11: Urban heat predictions in Malmo

Secondly, the change in average precipitation together with global mean sea level rise was analyzed. By using actual SMHI data for precipitation in Malmö in July 2013 ([1], 2014) and the RCP 8,5 scenario, precipitation values were estimated, as follows.

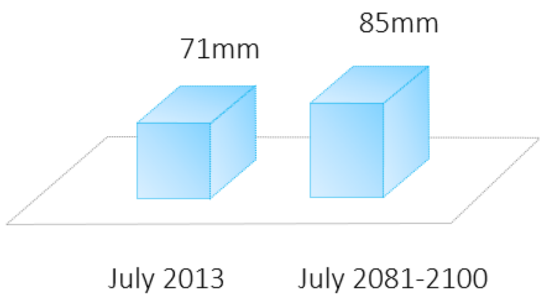


Figure 12: Precipitation raise expected in 2081-2100 in comparison to July 2013.

In other words, the volume of rainwater which falls on the BRIO plot [764m2] is predicted to raise from 53m3 in July 2013 to 65m3 in July 2081.

2.3 The BRIO building, geometry and material properties

Originally the office was the headquarters of the BRIO company producing wooden toys. With the time, the building lost its original function and became exhibition space for BRIO products. Today, it is one the few original buildings in the area which needs to be provided with modern standards of the office buildings.

Figure 13, BRIO Building

The BRIO building is a part of the block with a courtyard inside and it has two adiabatic walls to the North and East. The building's elevation is 21m. It consists of 6 usable floors, additional 7th floor used for HVAC installations and a basement. The building is located in a dense urban layout, with the opposite buildings of 21m height to the East and planned 16m high building to the West.

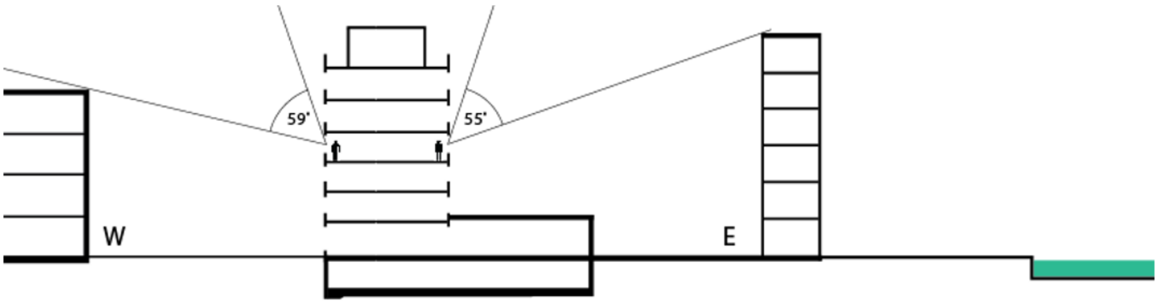


Figure 14: Visible sky angles from the 3rd floor to the West and East.

The ground floor consists of: a reception, a technical zone with toilets, 2 elevators, 2 shafts and a staircase, and a restaurant with technical facilities In comparison with other floors, ground floor is enlarged with additional 1 storey outbuilding which has been used as a restaurant hall. Floors 1-5 are equally planned office floors. Each of them consists of an open office area oriented to the West, individual offices oriented to the West and South, 2 meeting rooms, a technical area with 2 blocks of toilets, 2 elevators, 2 shafts and number of small magazine rooms. Ground floor and a typical office plans are shown below.

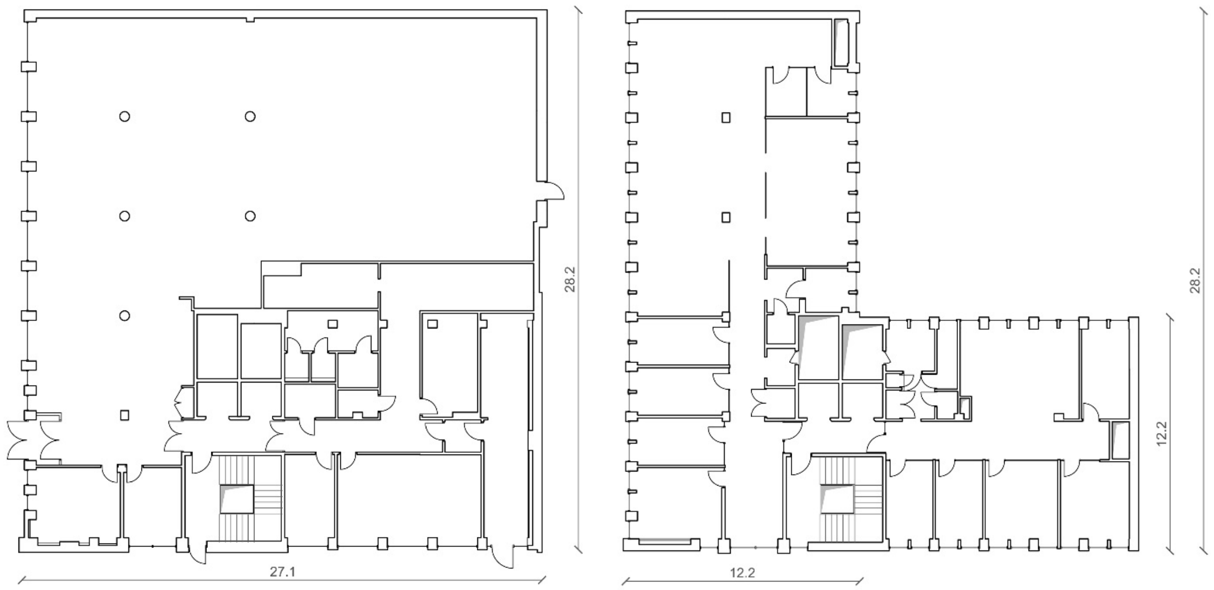
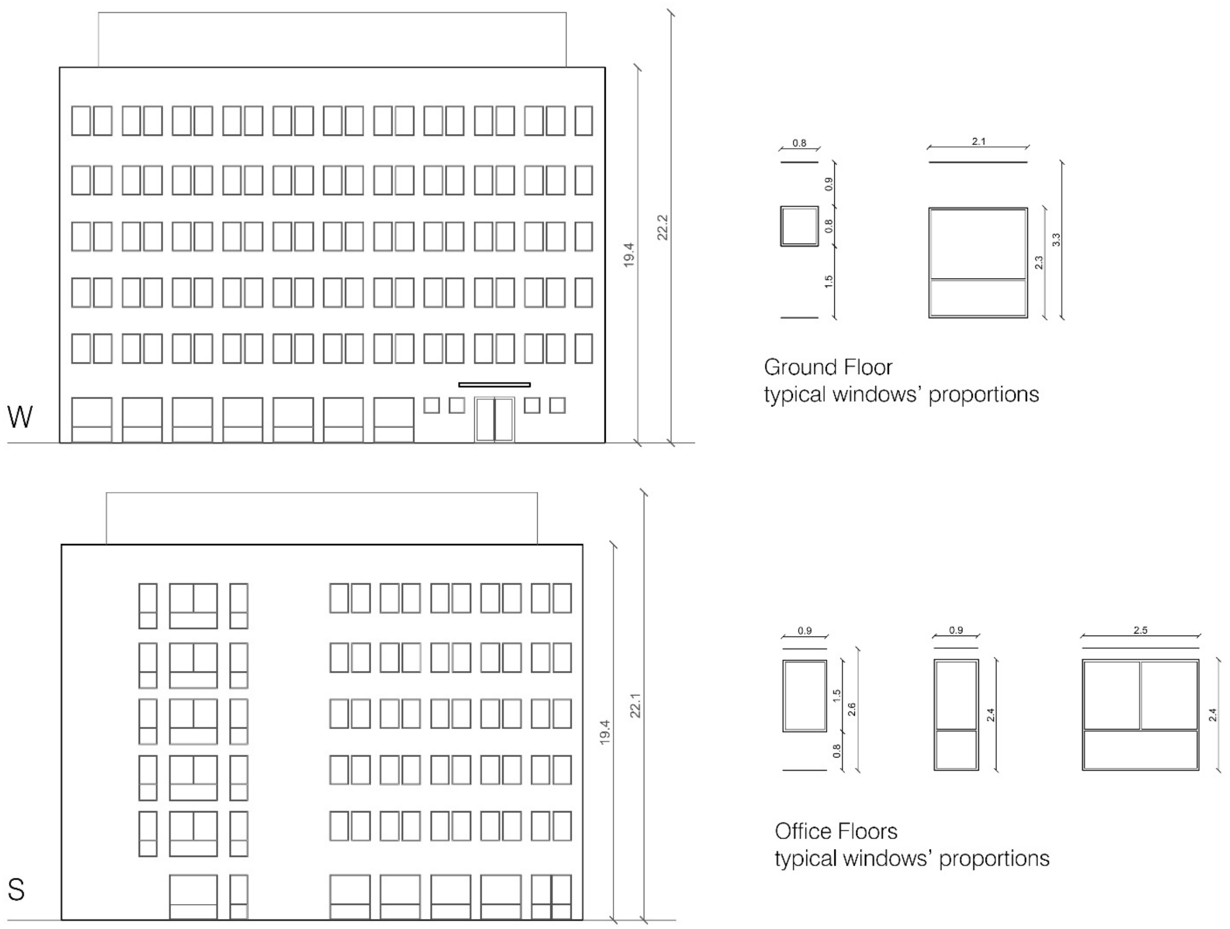


Figure 15: Existing functional plans of the ground floor and typical office floor, accordingly.



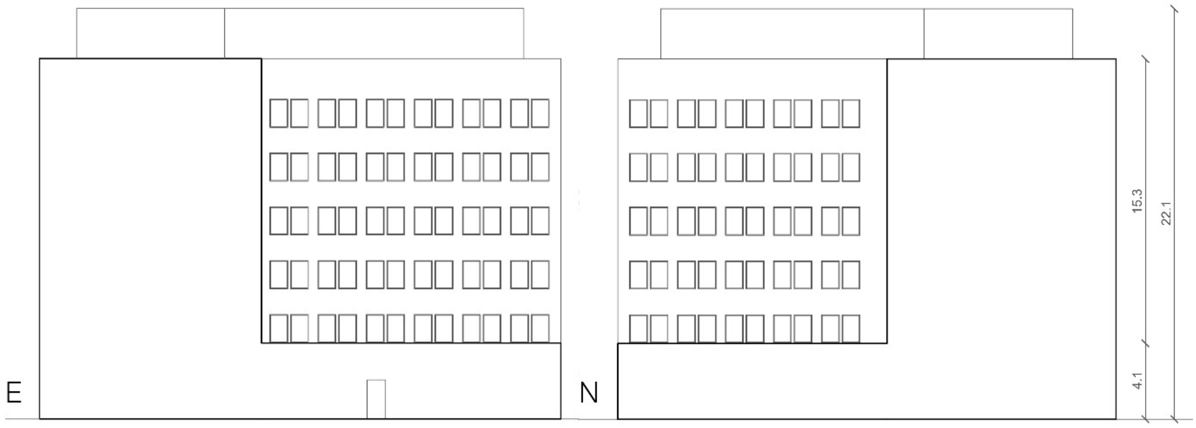


Figure 16: Existing facades with adiabatic walls in view and typical windows' proportion in zoom.

Construction details and thermal properties

The BRIO building has no noted acknowledgment of the existing construction. To establish the construction details, the book *Så byggdes husen 1880-2000* (Reppen Laila, u.d.) was used and the investigation at the site was done.

External and interior walls

The external wall of the building is a typical Swedish cavity wall, which is constructed with a supporting structure of concrete columns. Outside the columns and between, there is an insulation layer within a wooden frame construction. As a façade material red brick is used, which is also fixed to the wooden frame by wall-ties (kramlor), creating an air gap between the brick and insulation layer. Because of the differences of the exterior wall structure, the U-value varies greatly depending on where in the building it is measured.

The interior walls are all assumed to be built out of concrete, which in some cases has been covered with a layer of plaster.

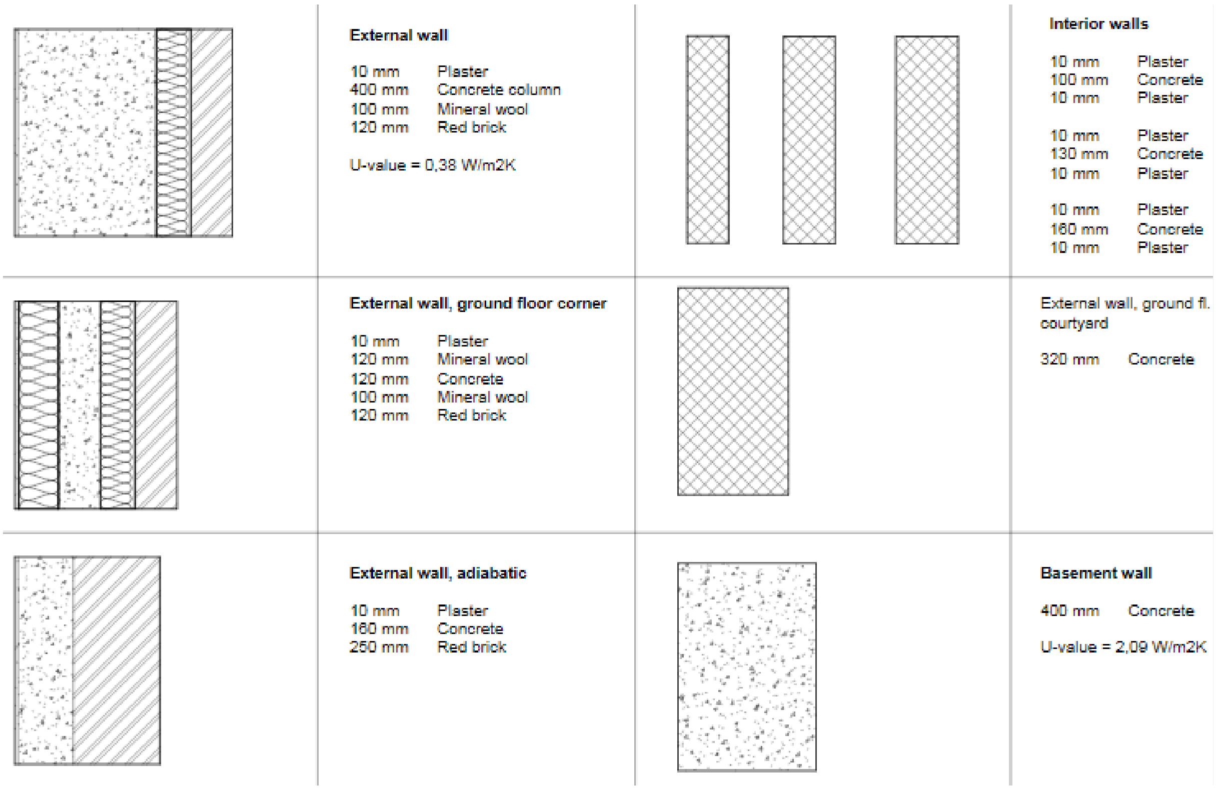


Figure 17: External and internal wall constructions

Roof

The building has two types of roofs, one for the office building and restaurant and one over the ventilation room. Details are shown below.

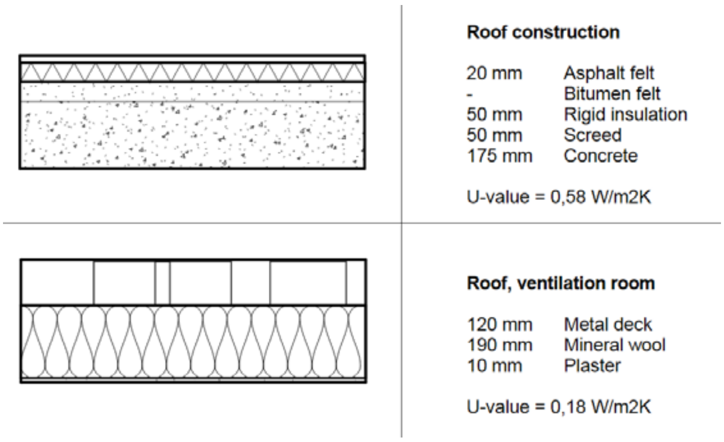


Figure 18: Roof construction

Floor

All the slabs and story partitions are out of concrete and function as heat storage for the building.

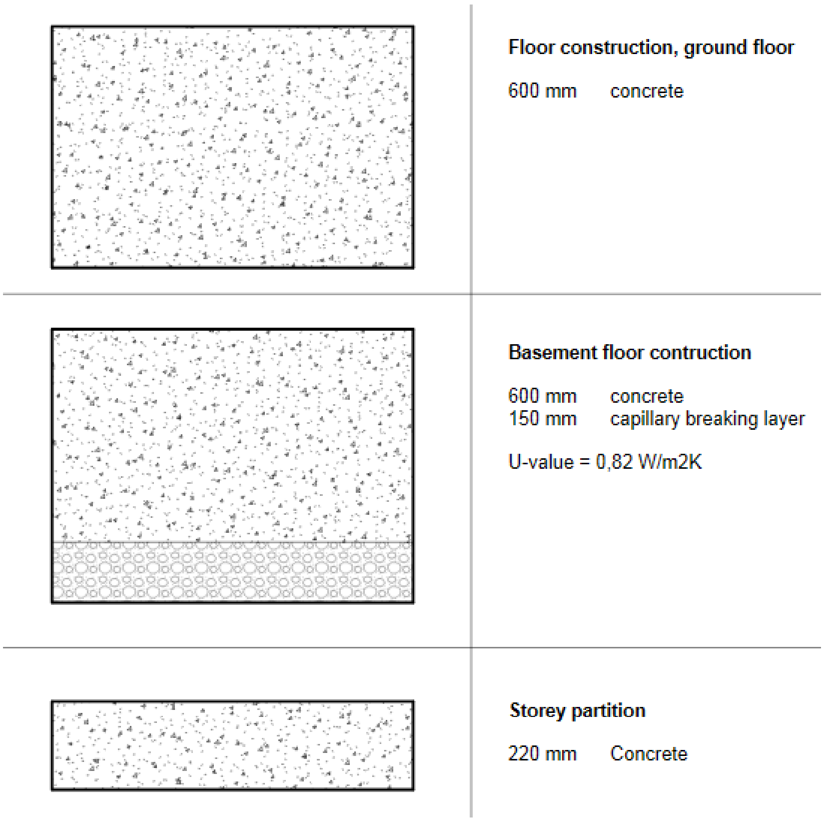


Figure 19: Floor construction

Windows

The building has windows of different sizes. The most common size, 950 x 1520 mm, is presented in the picture below. It is assumed that all windows are double glazed with an additional bronze coated outer glass for visual comfort. The exact material properties are presented in the picture below.

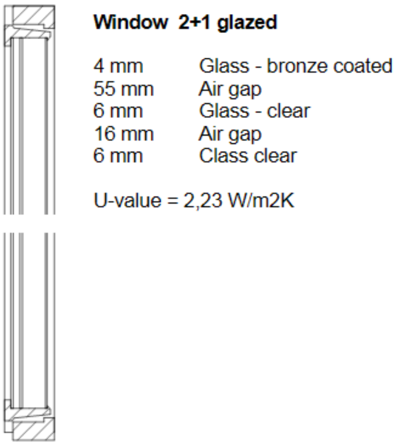


Figure 20: Window construction

The glazing to wall ratio was calculated for each façade to establish an average value of GWR of the building, which is 19,9%. Adiabatic walls were included in the calculation.

Table 4: Average GWR calculation

Facade	GWR [%]	Glazing Area [m2]	Wall Area [m2]
West	31,1	170	547
South	24,7	129	523
North	12,0	63	523
East	11,5	63	547
Average	19,9	425	2140

Surface material properties

The material properties (reflectance of materials) of the interior were adopted according to standard reflection factors, while the exterior materials' properties have been estimated based on standard values.

Table 5: Reflectance of the solid surfaces

Interior surfaces	Reflectance, R
Floor	0,2
Wall	0,5
Ceiling	0,8
Sill	0,5
Interior Frame	0,8
Exterior surfaces	
Painted façades	0,35
Brick facades	0,25
Asphalt and bituminous materials	0,15
Reflective facades	0,5
BRIO Exterior Window Frame	0,3

Table 6: Glazing transmittance and transmissivity values

Interior Glazing	Transmittance, Tvis	Transmissivity
Partition walls	0,88	0, 96
Exterior Glazing		
BRIO coated glass	0,45	0,49
BRIO clear glass on the ground floor	0,8	0,87
Clear glass facades	0,8	0,87

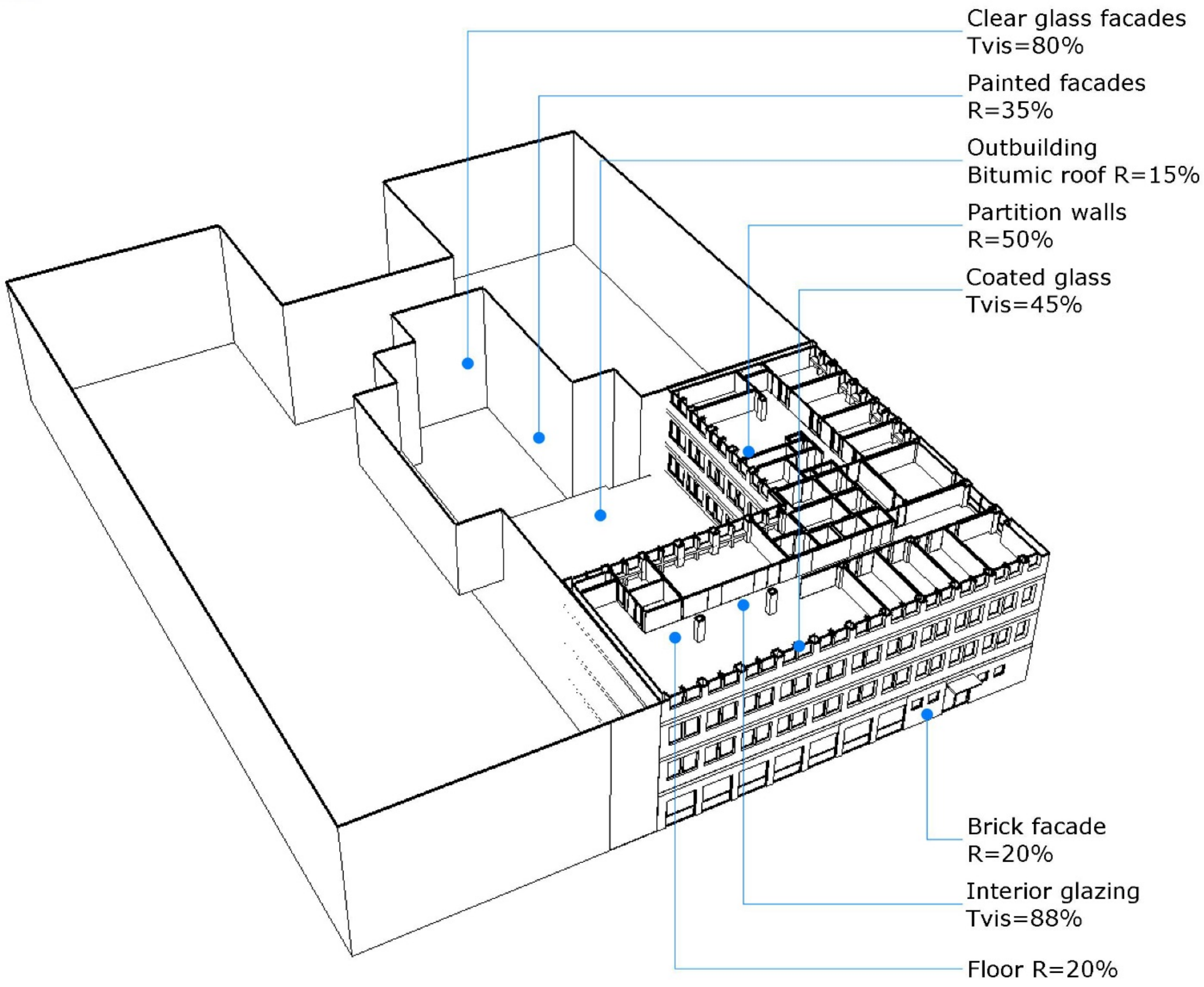


Figure 21: Exterior and interior solid surfaces location.

2.4 Base case

All simulations were performed for model that includes the future development of the Western Harbor, see figure 2.

2.4.1 Daylight

"DIVA4Rhino"

"DIVA4Rhino" is a simulation tool, based on "Radiance", dedicated to analyze daylight and energy modeling as a plug-in for the Nurbs modeler – "Rhino" and the algorithmic modeler "Grasshopper". "DIVA" has been developed at the Graduate School of Design at Harvard University. "DIVA" provides the possibility of analyzing daylight by: Radiation Maps, Climate-Based Daylighting Metrics such as Daylight Autonomy and Annual Glare Analysis.

Initially, to evaluate basic daylight conditions in the building, simulations were performed for the model without furniture and with generic material properties (See Table 5, 6). Daylight level was evaluated by daylight factor and continuous daylight autonomy.

In order to achieve precise results, DF simulations were performed with six bounces and grid of 1m located 0,85m over the floor surfaces, for the floor area excluding the shafts and staircase. While DAcons simulations were performed for five bounces and 2m grid across two section lines, as shown below:

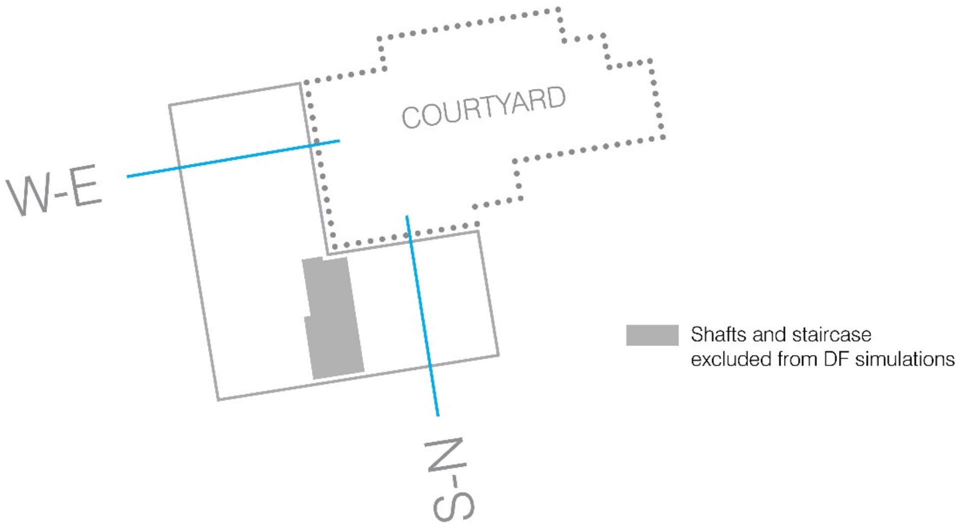


Figure 22: Daylight analyzis scheme.

"DIALux"

"DIALux" is a simulation tool, developed by DIAL. It provides possibility of planning electric lighting in the buildings, with consideration of surrounding model and daylight conditions. It also gives possibility for real time tuning of light scenes, which means exact adjustments after calculation in order to achieve more satisfying and energy efficient solutions.

2.4.2 Energy Use

Steady-state calculations

In Sweden the criteria for passive houses, zero-energy houses and minienergi houses were established by the Forum for Energy Efficient Buildings (FEBY). FEBY 12 was used to carry out the hand-calculation for the existing and refurbished building. This specification includes functional requirements for heat losses (transmission, ventilation and infiltration), the levels for energy demand in relation to energy source and other requirements and recommendations for health properties (Anon., 2012-09-27). A pre-made Excel sheet was used as a complementary calculation for determining the heat losses and the heating load. Furthermore, both methods neglect solar and internal heat gains.

Calculation of Heat loss rate, VFT (FEBY 3.1)

The building is situated in climate zone III, for this climate zone the max VFT_{DVUT} is allowed to be 15 W/m^2A_{temp}. To be able to carry out the calculation appendix 2 – Calculating heat loss rate (VFT) in the FEBY12 document was used. To be able to carry out the calculation appendix 2 – Calculating heat loss rate (VFT) in the FEBY12 document was used.

Moreover, the requirement for delivered yearly energy to the building in climate zone III is allowed to be 45 kWh/m^2A_{temp}. To be able to carry out the calculation chapter 3.2 – *Delivered yearly energy to buildings* in FEBY12 document was used.

$$VFT_{DVUT} = H_T \cdot \frac{(21 - DVUT)}{A_{temp}} [W/m^2 A_{temp}]$$

H_T = Heat loss coefficient [W/K]

$$H_T = U_m \cdot A_{omsl} + \rho \cdot c \cdot q_{läck} + \rho \cdot c \cdot d \cdot q_{vent} \cdot (1 - v) [W/K]$$

$$E_{delivered} = E_{electricity} + E_{district\ heating} + E_{cooling} + E_{other} \left[kWh/m^2 A_{temp,} year\right]$$

Other requirement:
5.1 Design outdoor winter temperature (DVUT) and inside temperature 21°C within the building envelope

5.2 The building's interior temperature for the period April-September should be calculated and reported.
6.1 Air leakage, q_{50} through the building envelope can be up to 0,3 l/s,m^2
6,2 The buildings average U-value for windows and glass partitions, for passive houses, should be limited to 0,8 W/m^{2}K

"DesignBuilder"

The performance of dynamic energy simulations were undertaken by using "DesignBuilder" (version 3.4), which uses the "EnergyPlus" simulation engine. "DesignBuilder" provides a range of environmental performance data such as: energy consumption, comfort conditions, and seasonal temperature distribution.
In order to get a better understanding of the indoor thermal comfort, temperature data was assessed for the period of occupied hours (2500h) in a year. Evaluation of the temperature distribution of the most representative storeys in the building was made on the basis of annual temperature and summer period (April to September). The summer design week (03-09 August) and the winter design week (10-16 February) were also considered. The simulations for the total energy consumption and peak loads were performed for the whole building. All simulations are based on the zones of the building which are heated, excluding the unheated basement and ventilation room.

The values used for the input data are based on (Flodberg, 2012), site visit assumptions and initially given data. Fixed values that were directly used in the results such as DHW of 2 kWh/m2, year was set, due to recommendation given by FEBY 12. Fixed values used in the results for fans and facility electricity, respectively of 9 and 11 kWh/m2, year, were taken from (Flodberg, 2012). For more information on the modelling in "DesignBuilder" see Appendix B Base case model.

Table 7 Key input setting for "DesignBuilder"

Key settings	Basement	All floors	Ventilation room	Comments
Occupancy schedule	Office_CarPark	Office_OpenOff (7:00-19:00)	Light plant room	"DesignBuilder"
Occupancy rate	None	0,0500	None	FEBY 12
Heating temp.	None	21/21°C	None	FEBY 12
Cooling temp.	27/28°C	24/26°C	25/28°C	Assumption
Nat. ventilation	None	None	None	Assumption
Minimum fresh air	0,35 l/s/m2	7 l/s + 0,35 l/s/m2	None	BBR
Computers	None	7 W/m2	None	Calculation
Office equipment	None	2 W/m2	20 W/m2	Kaisa Flodberg
Construction	Wall-2,09 W/m2K Floor-0,8 W/m2K	Wall-0,38 and 0,35 W/m2K Roof-0,58 W/m2K	Wall and roof-0,18 W/m2K	Assumption from drawings
Airtightness	~0,5-0,7 ach	~0,5-0,7 ach	~0,5-0,7 ach	Assumption
Openings	None	U-value – 1,68 g-value – 0,28 Tvis – 0,37	None	Assumption from site visit
General lighting	8 W/m2	8 W/m2	8 W/m2	Assumption
Target illuminance	100lx	500lx	100lx	

HVAC	Hot water radiator + mech. supply and extract	Hot water radiator + mech. supply and extract	None	Assumption
Mech. Ventilation schedule	Sum per person, floor area / ON	Sum per person, floor area / ON	Sum per person, floor area / ON	Assumption
Heating	None	On (5:00-17:00)	None	"DesignBuilder"
Cooling	None	On (5:00-17:00)	None	"DesignBuilder"
Heat recovery	70%	70%	None	Assumption

2.4.3 Moisture Analysis

"WUFI"

The "WUFI" program allows the user to simulate and calculate the heat- and moisture transport in the climate envelope of the building. "WUFI" considers standard material properties, moisture storage functions and the liquid transport functions when assessing the moisture load of the building. Included in the simulation are factors such as driving rain and solar radiation, which makes more accurate studies for the behavior of the building element that is exposed (Anon., 2013).

Input Data for "WUFI"
"WUFI"-analysis settings were based on the worst case scenario, which is a conclusion of the previous analysis of the climate were the building is situated.

Settings used for the "WUFI" analysis:

- The worst case for the driving rain direction is west.
- The inclination was set to 5°and the roof is tilting towards north.
- The relative humidity at the start is set to 80 %
- The indoor temperature is 20 °C
- The analysis is made for a ten year period.
- The analysis start in October – which is assumed to be the worst case.
- The indoor climate according to EN 15026.
- The building is set to be higher than 20 m.

2.5 Parametric study

Parametric study focused on the energy-efficiency and daylight results was carried out in two stages, shown in the diagram below:

Stage 1: Main design parametric study.
Stage 2: Detailed parametric study of the chosen design.

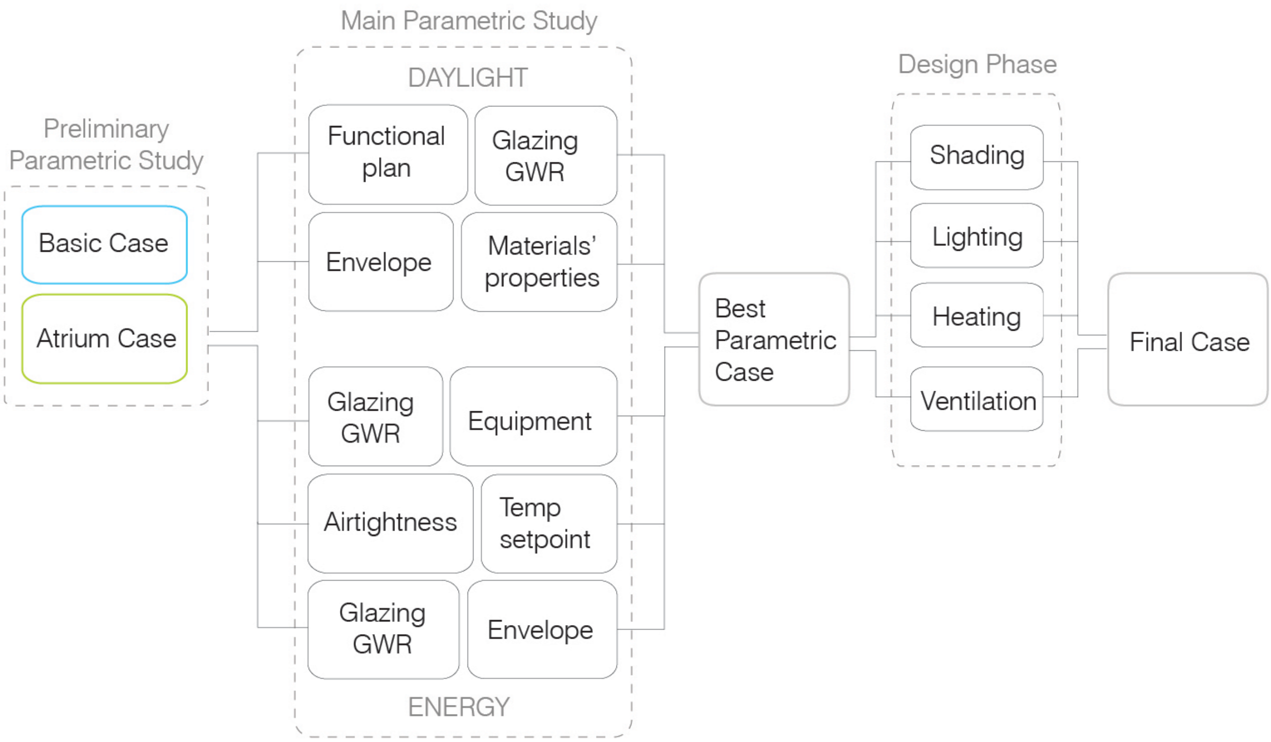


Figure 23: Systematic diagram of the project phases.

2.5.1 Main design parametric study [Base Case vs. Atrium Case]

As a first step, the main design improvement of the BRIO retrofitting, an atrium over the courtyard, was analyzed in comparison to the base case. The main purpose of this study was to see how the atrium affects energy consumption, indoor thermal climate and daylighting conditions in the BRIO building.

An atrium was introduced to the BRIO office building as a design conclusion of ”Pros and Cons” studies of the BRIO building and its surroundings.

Pros

Shallow plan depth
Heavy building (thermal mass, fire safety)
2 adiabatic walls (reduced envelope heat loss)
Courtyard - potential for attractive indoor space
Brick façade
District heating available
Installation core in the middle of the building (kitchen, WC installation pathway)
Attractive view from the roof
Basement
L-shape access
Good window distribution
Attractive location

Cons

Bad envelope (high U values)
Window (coated glass, deep frame)
Low ceiling height (2,7m)

Courtyard – wind circulation problems in spring (snow drifting)
Many windows
No attractive commons spaces
Not visible entrance

Thermal bridges
Dependency on mechanical ventilation
West/East sun problems
Driving rain on the western facade
Dense surroundings, no attractive views

2.5.1.1 Design concept

An atrium was assumed to be a design elements with potential to improve daylight, energy balance and architecture qualities in the building. The correctness of the assumptions was tested in the next studies. Schematic drawings of potential benefits of an atrium are shown below:

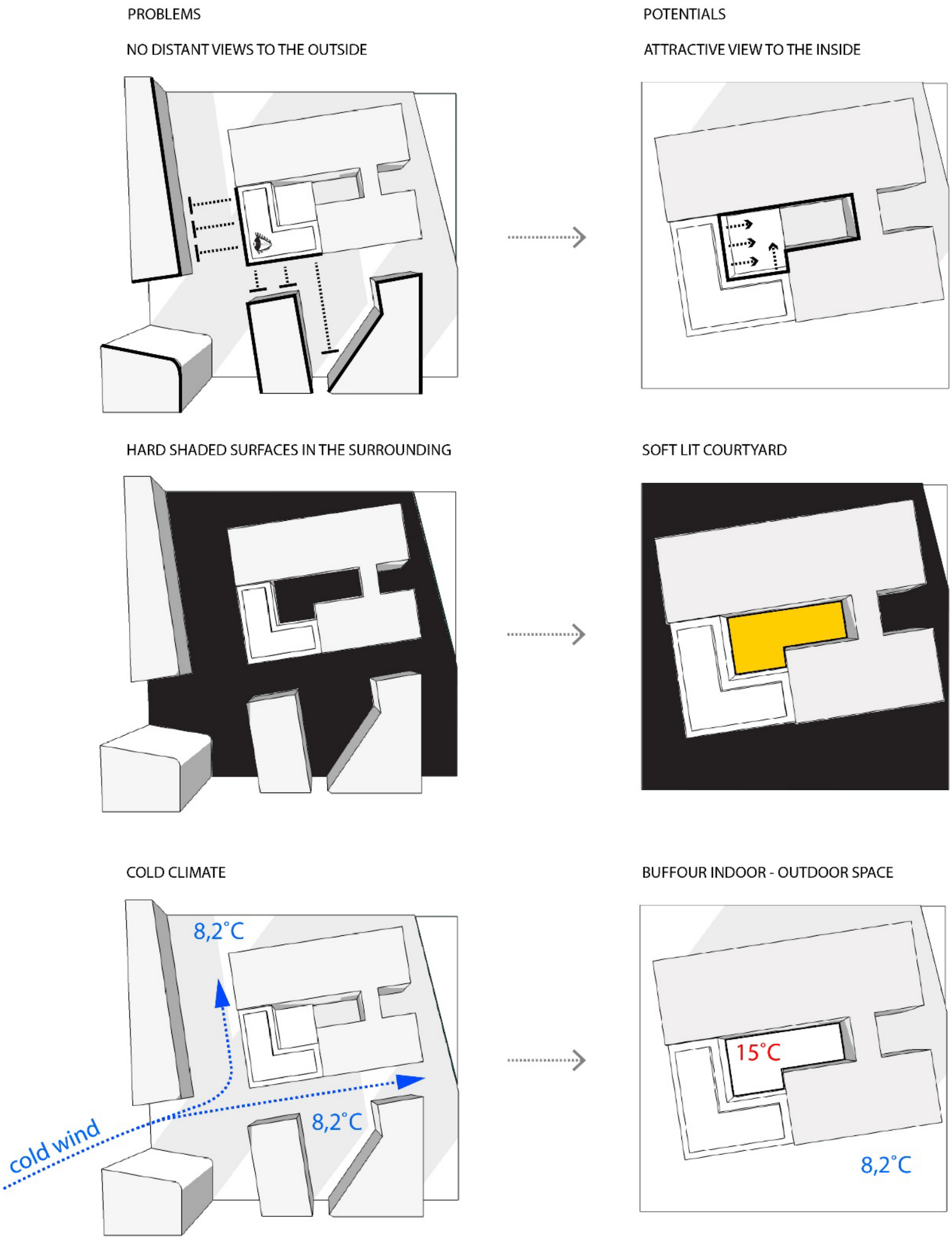


Figure 24: Surroundings and climate context of BRIO building.

An atrium became a conceptual measure of introducing better compactness to the building. The volume of the building has been both increased on the top floor and decreased on the ground floor. An extension of the restaurant was removed, while existing AHU extension on the roof was enlarged into a functional floor.

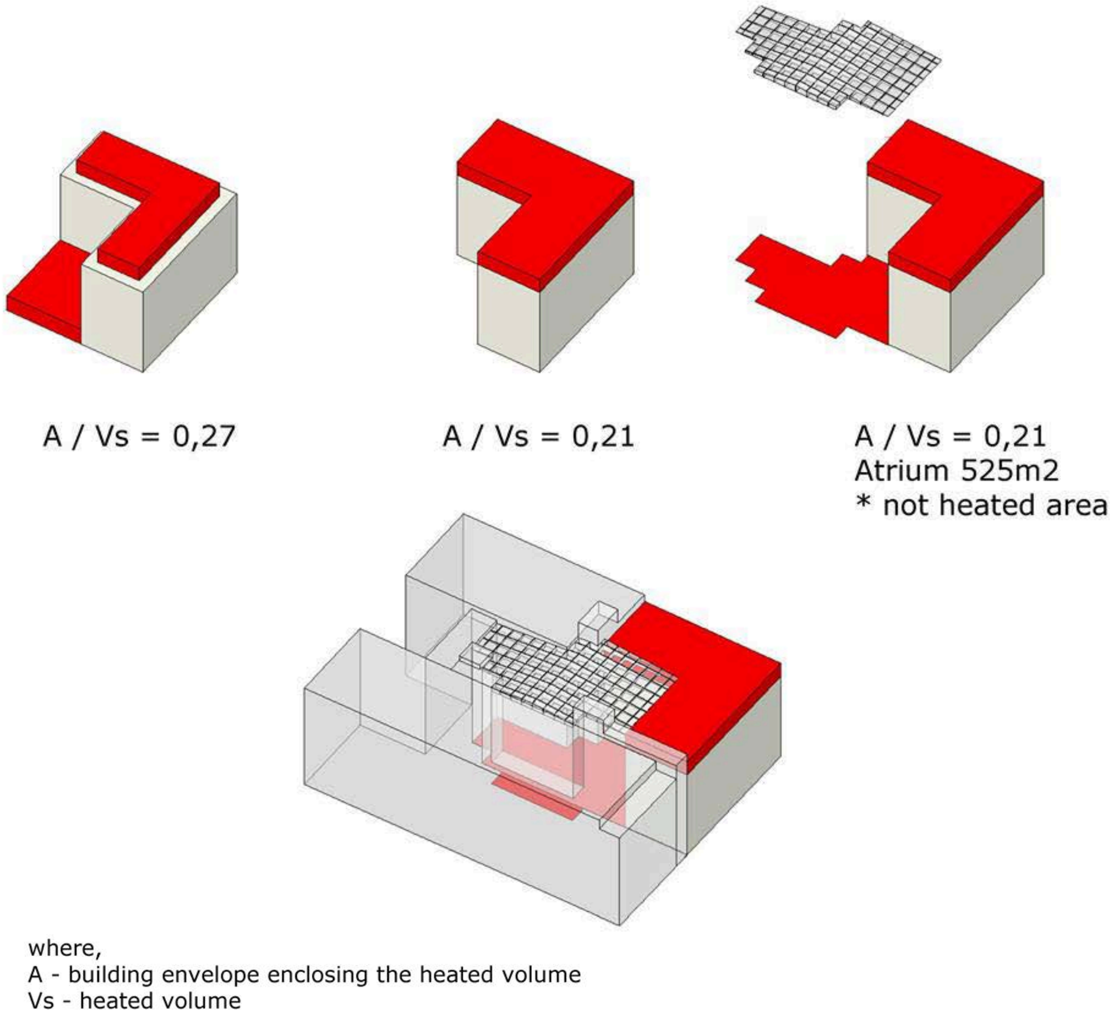


Figure 25 Design concept step-by-step

Atrium Construction

Construction of the atrium has been designed to simplify and unify both the structure details, but also the architecture expression of the new design elements. However, detailed structure design was not a part of the study, therefore specific solution has not been designed or calculated. Some of the considered construction are shown in the following references.

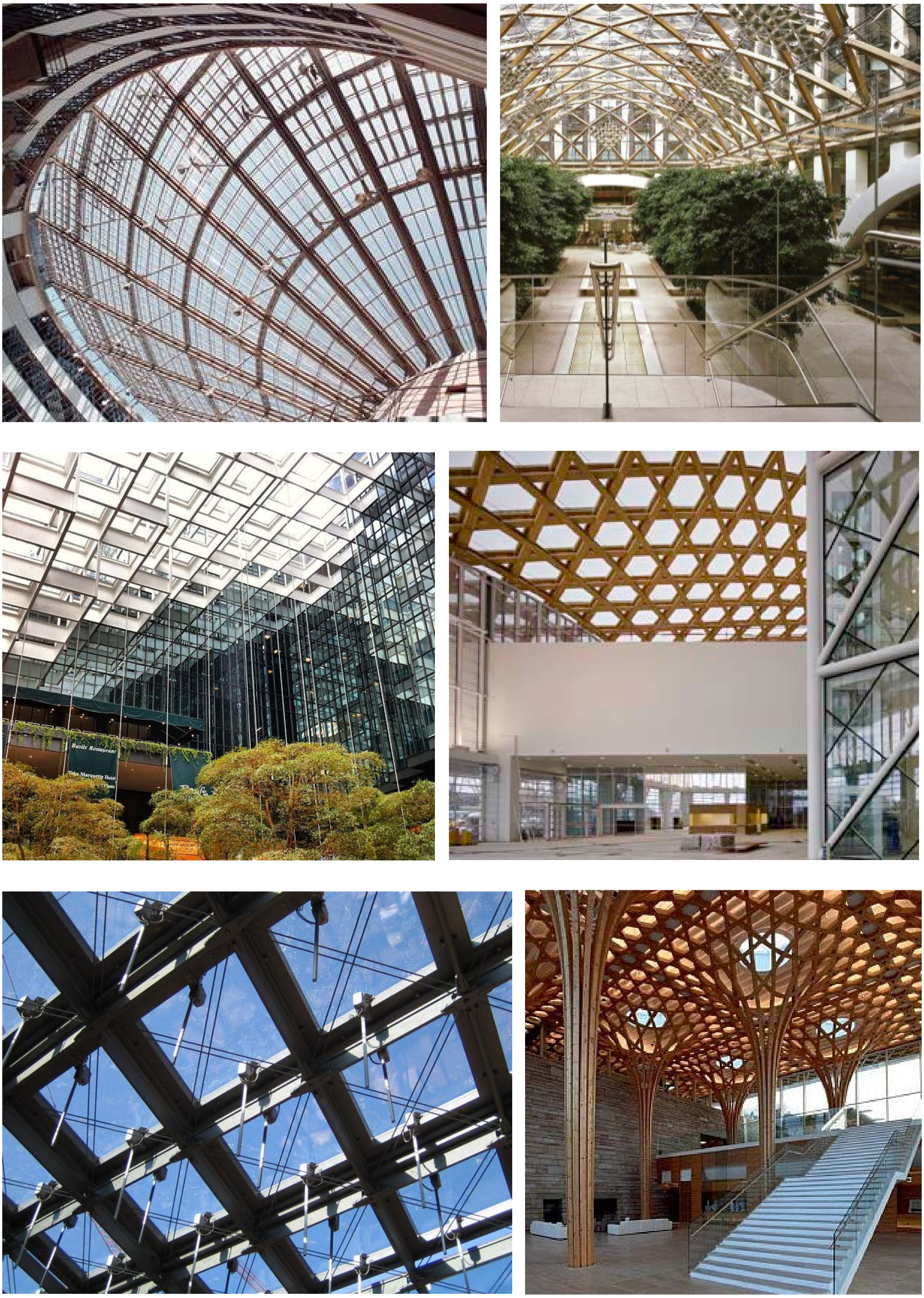


Figure 26 Examples of atrium with wooden and steel roof construction, (Archdaily, 2014)

The supporting structure of the atrium is planned to be built out of wooden beams. For the exterior, glazed construction metal framing is considered.

Rainwater harvesting

The climate change aspects of significant rise in average precipitation were taken into consideration. The atrium roof has a large area, which represents a great potential for rainwater harvesting. This will optimize the water usage of the office building and will be used for suitable application, such as toilets. The rainwater is planned to be collected from the gutters and transported via the downpipes to a storage tank in the basement, where it will be stored until required for usage. To improve the quality of the rain-water there will be a filter-unit in each downpipe.

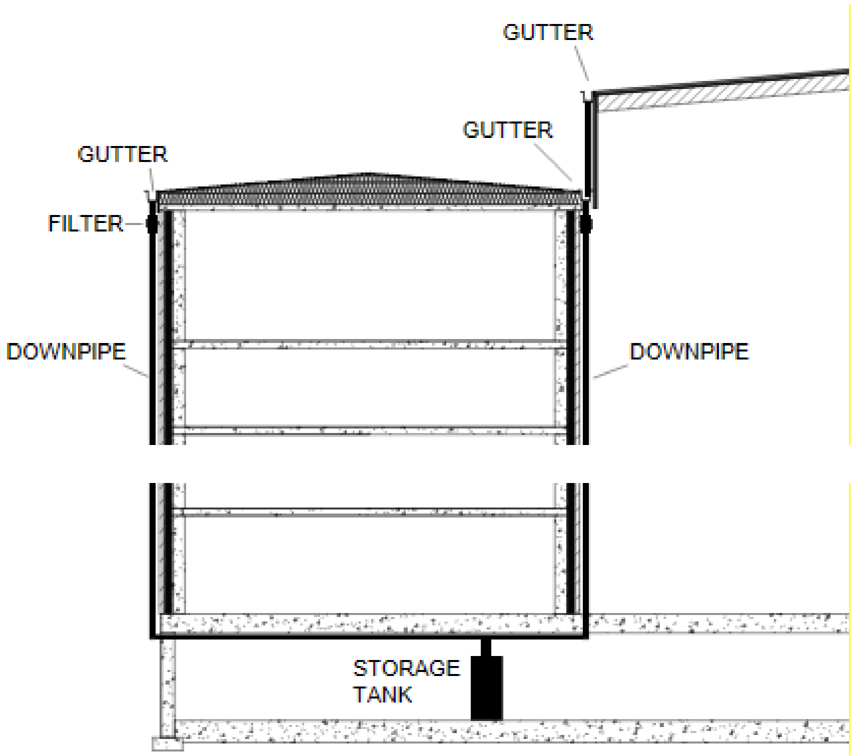


Figure 27, Basic concept of rain water harvesting system

2.5.1.2 Daylight

In terms of daylight, the atrium was introduced to the model together with higher reflectance of the court-yard's walls.

Table 8: Surface characteristics in Base case and Atrium Case

	Base Case	Atrium Case
Surface reflectance, R		
Painted facades in the courtyard	0,35	0,9
Courtyard floor	0,15	0,5
Glazing visual transmittance, Tvis		
Atrium roof glazing	-	0,8

Daylight factor and daylight availability studies were made for 1st and 5th floors which are assumed to be the most demanding in terms of both studies.

2.5.1.3 Energy Use

At this stage of the project the atrium was introduced to the energy calculations. The atrium would not be conditioned in any way, except for the utilization of the stack natural ventilation principle. The main principle of ventilating the atrium space is done by air coming through flaps in BRIO's atrium facing windows. A simplified method using "CIBSE AM10 Design tool for isolated spaces", was used to size the necessary openings, so each of them provides at least 0,35 l/s m2 air flow (see Table 9). The calculation is based on:

q	Required flow rate (m3/s)
N:	Number of openings
C_d	Discharge coefficient (0.25)
T_{out}	Outside temperature (C)
T_{in}	Inside temperature (C)
h	Height of opening (m)
A	Size of opening (m2)

$$\frac{q}{C_d} \times \sqrt{\frac{(T_{in} + 273)}{(|x| \times (T_{in} - T_{out}) \times g \times h))}}$$

Table 9 Natural ventilation openings

Openings	Percentage opening area	Schedule
Interior windows	8% per window	Office schedule (all year)
Top atrium windows winter Top atrium windows summer	5% per window 20% per window	Office schedule (all year) Office schedule (summer)
Roof top atrium	20% per window	Office schedule (summer)

The occupancy of the atrium was assumed to be 0,16 people/m2. The occupation schedule was divided into three parts for two periods of the year. The atrium would have an occupation schedule starting at 8:00 until 12:00, from 12:00 to 14:00 and from 14:00 until 19:00, where for the two periods, winter (1.10-31.03) and summer (1.04-30.09), different occupation rate fractions were considered (see table XX). Lighting was neglected at this point.

The operation schedule for the restaurant was kept the same as the offices, but the occupancy and the equipment were changed (see Table 10). The conference room was assumed to operate three days a week at full occupancy of 60 people, between 9:00-12:00 and 13:00-17:00 (see table XX for the exact settings). See Appendix B **Atrium case model** for information about the model.

Table 10 Atrium case key input data

Parameter	Atrium	Conference room	Restaurant
Occupancy schedule	Winter (8-12: 25%/12-14: 75%/14-19: 25%) Summer (8-12: 25%/12-14: 100%/14-19: 25%)	Monday, Wednesday, Friday 9-12 and 13-17	Generic office
Occupancy rate	0,16 people/m2	0,20 people/m^2	0,20 people/m^2
Heating temp.	No heating	21/21°C	21/21°C
Cooling temp.	No cooling	24/26°C	24/26°C
Nat. ventilation	Temperature set point 0°C (operate all the time)	None	None
Equipment	None	2 W/m2	
Minimum fresh air	0,35 l/s/m2	7 l/s + 0,35 l/s/m2	7 l/s + 0,35 l/s/m2
Openings	Double LoE (e2=1) 6/6 clear g = 0,48 Tvis = 0,75	U-value – 1,68 g-value – 0,28 Tvis – 0,37	U-value – 1,68 g-value – 0,28 Tvis – 0,37

	U-value		
General lighting	None	8 W/m2	8 W/m2
HVAC	No mechanical ventilation	Hot water radiator + mech. supply and extract	Hot water radiator + mech. supply and extract

See figures Figure 28, Figure 29 and Figure 30 for distribution of thermal zones in the Atrium case.

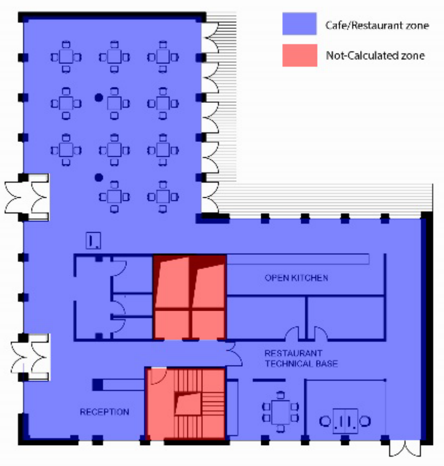


Figure 28 Ground floor

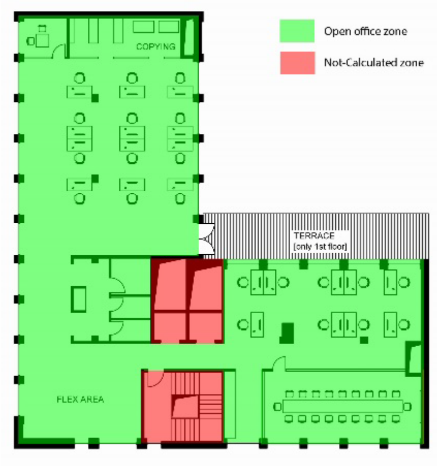


Figure 29 First - Fifth floors

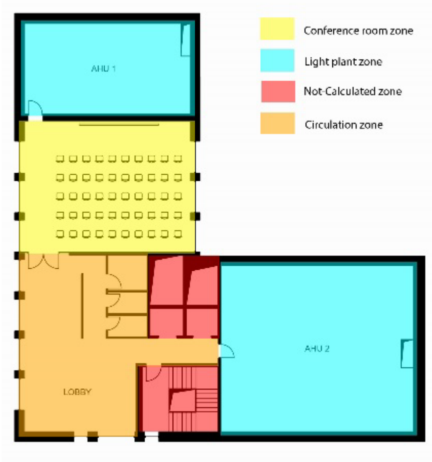


Figure 30 Sixth floor

2.5.2 Detailed parametric study of the chosen design

Next, the case selected in the main design parametric study was analyzed in terms of more detailed parameters.

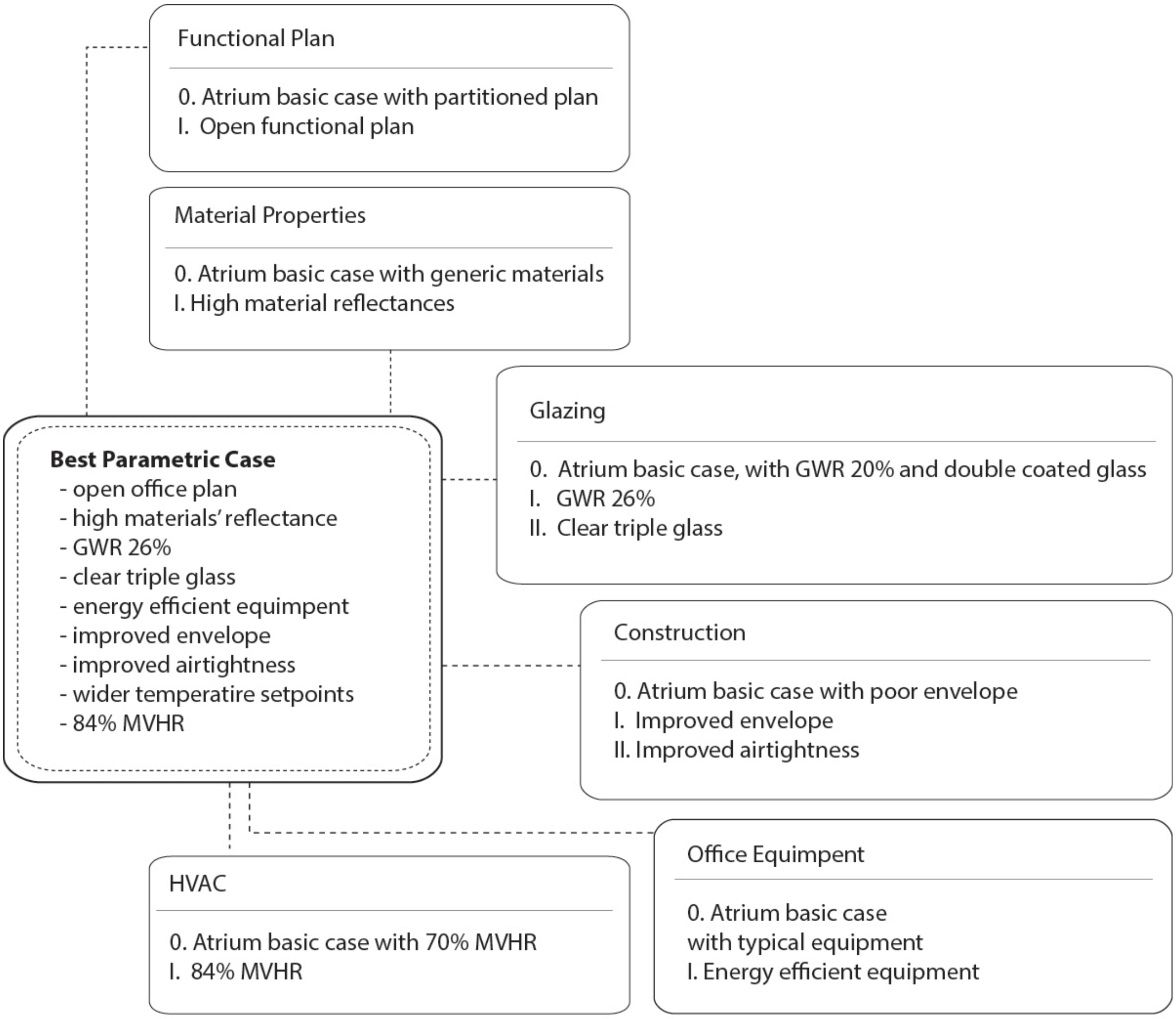


Figure 31 Detailed parametric study scheme

2.5.2.1 Daylight

DF and DAcons simulations were performed for the 1st and 5th floor, for the following parameters.

Functional Plan

Functional plan simulations were performed for one variation of an open office functional plan in comparison to the atrium base case with initial partitioned plan.

- *Atrium Case with partitioned functional plan oriented to the street*
- *Variation 1: Open office plan oriented to the atrium*

The open office variation of the functional plan was intentionally designed to improve the daylight even distribution, raise the daylight levels in the working area and reduce the risk of glare. The schematic concept of the functional plan is shown below.

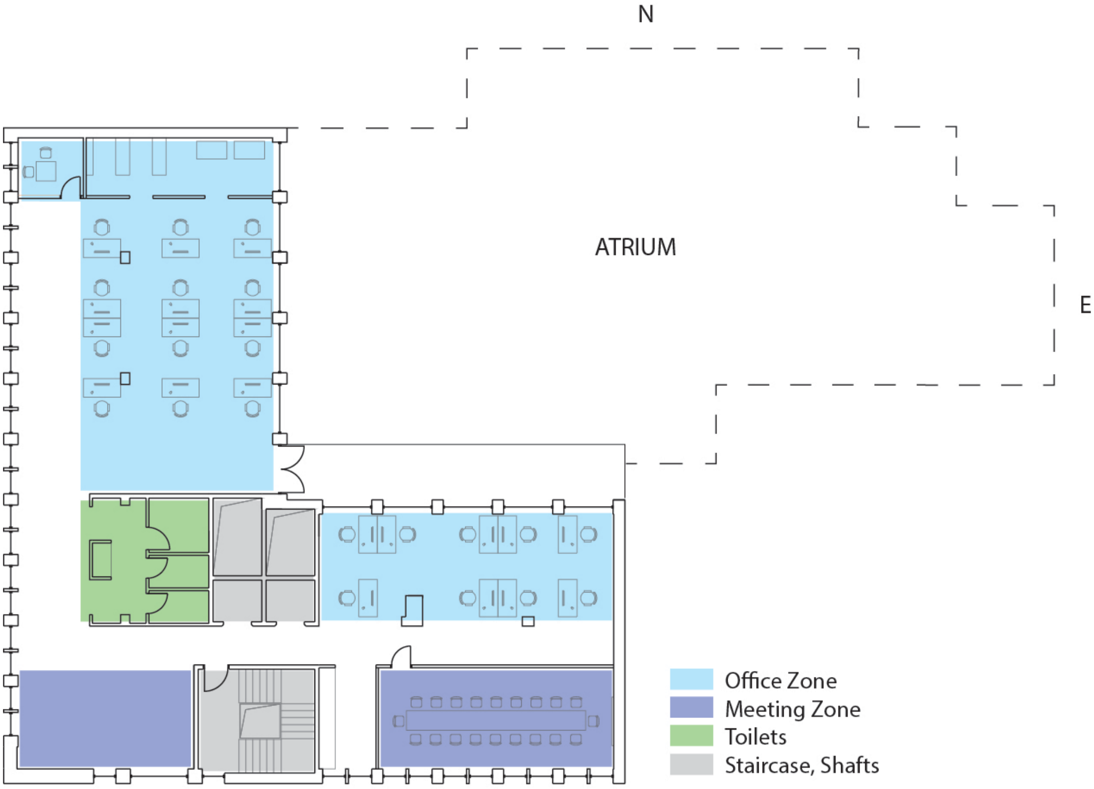


Figure 32: Variation 1: Open office plan oriented to the atrium. Typical office floor.

Daylight simulation results were gained in terms of daylight factor and daylight availability.

Materials Properties

Simulations were performed for one variation of materials optical properties in comparison with the basic case:

- *Atrium Case with generic materials' reflectance*
- *Variation 1: With high surfaces materials' reflectance*

Table 11: Comparison of some of the solid surfaces' reflectance: Atrium Case and Variation 1

	Reflectance	
Interior surfaces	Base Case	Variation 1
Floor	0,2	0,5
Wall	0,5	0,9
Ceiling	0,8	0,9
Sill	0,5	0,9
Interior Frame	0,8	0,9

Results were gained in terms of daylight factor and daylight availability.

Glazing

Simulations were performed for two variations of glazing type and GWR in comparison with the base case, see figure 33.

- *Atrium Case with coated glass and average GWR of 20%*
- *Variation 1: with average GWR of 26%*

- *Variation 2: with clear triple pane glazing*

Table 12: Comparison of glazing properties

Exterior Glazing	Transmittance T_{vis} [-]
Coated double pane	0,45
Clear triple pane	0,72

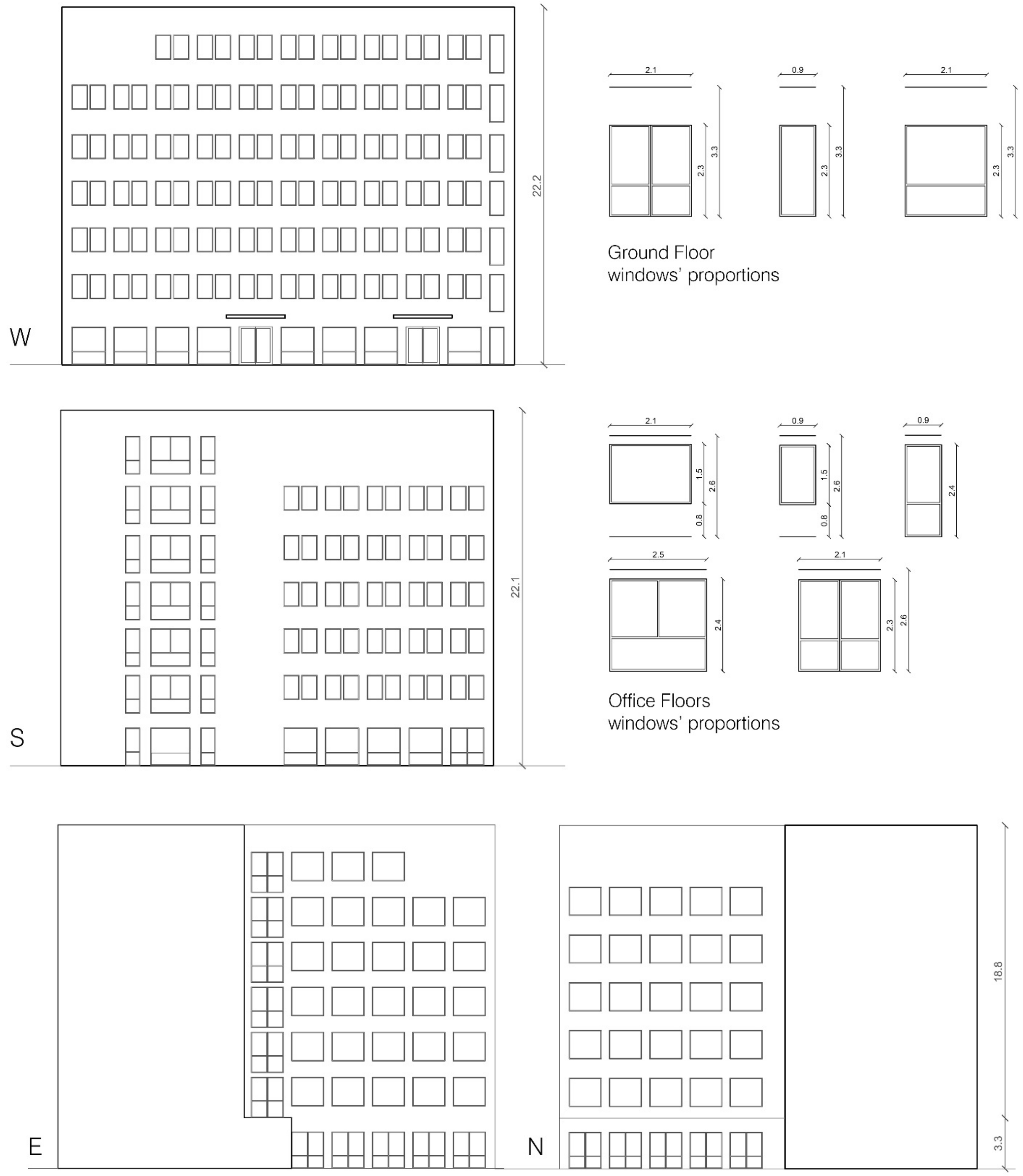


Figure 33: Variation 1: average GWR of 26%. Facades with adiabatic walls in view and windows' proportion in zoom.

The average and individual façade's GWRs are shown in the table below:

Table 13: GWR calculation for the new façade design

Facade	GWR [%]	Glazing Area [m2]	Wall Area [m2]
West	33,5	209	623
South	25,7	153	595
North	19,0	113	595
East	23,8	148	623
	25,6	623	2436

Results were gained in terms of daylight factor, daylight availability.

Construction

Daylight factor and daylight availability simulations were performed for 1 variation of construction elements.

- *Atrium Case with original wall construction*
- *Variation 1: Exterior wall with additional 10cm of insulation*

As a result of parametric study, balanced combination of parameters was chosen to create a satisfying case, in terms of daylight factor and daylight availability design – called best parametric case.

Table 14 Parameters for Best case

1	Functional plan	Open office oriented to the atrium
2	Glazing	GWR 26%, triple glazing
3	Materials' properties	High reflectance of surface materials
4	Construction	Additional 10cm of insulation

In next phases of daylight study, the best case was analyzed in terms of daylight comfort, electric lighting design and BREEAM exemplary level evaluation.

2.5.2.2 Energy Use

As one of the steps for improving the exterior wall, for energy use purposes, the western and southern facades were to be refurbished. During this phase the brick with its supporting structure and insulation beneath would be taken down, while the wooden structure and insulation would be replaced with steel studs.

The strategy would be to take down the brick as carefully as possible so that it could be reused for the improved wall. The reason for reusing the brick is that the existing brick colour would be hard to find on a newly produced brick.

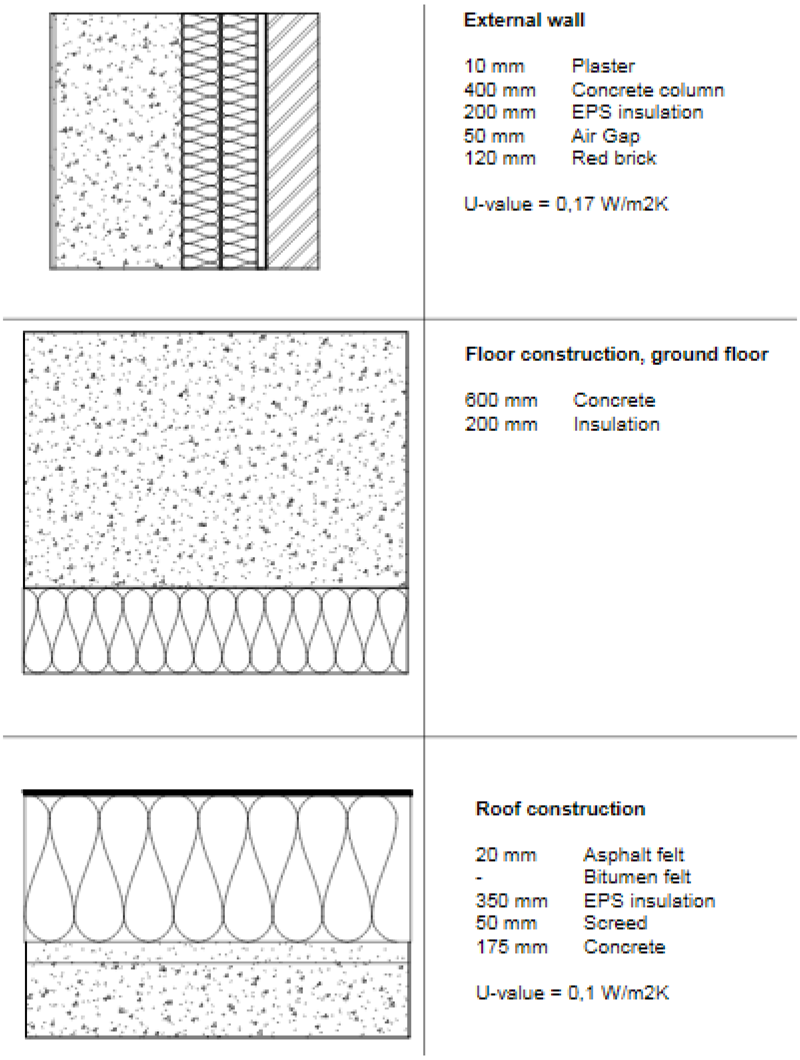


Figure 34: New construction of improved components

In order to assess what improvements would be most beneficial for meeting the FEBY 12 requirements, a few parameters were investigated.

Table 15 List of parameters studied

Nr.	Parameter - BRIO	Comment
1	Airtightness	0,6 ach at 50Pa
2	Window U value Windows to the atrium	0,80 W/m2K 1,50 W/m2K
3	Improvement of the building envelope	Floor to basement – 0,16 W/m2K Wall – 0,17 and 0,18 W/m2K Roof – 0,094 W/m2K
4	Temperature set point/setback	21/17°C – heating / 24/28°C – cooling
5	Efficient equipment	2 W/m2 for computers
6	GWR	26%

The walls facing the atrium (U-value and airtightness), were left non-optimized, due to design concept considerations.

For the Best case of the parametric study, the parameters Nr. 1, 2, 3, 5 and 6 were used.

2.5.2.3 Lighting

In order to analyse potential savings for electrical lighting, the representative 5th floor of BRIO building was divided into office area and remaining areas. Each area was considered with the required illuminance values in mind shown in the table below:

Table 16, Required illuminance levels according to DIN V 18599, table 4

Room description	Maintenance value of illuminance, *Em* [lx]
Open plan office	500
Meeting/ conference room	500
Foyer	300
Circulation area	100
Common rooms	300
Sanitary installations	200

According to the table above, the minimum required illuminance levels for specific areas within BRIO office floors are shown on the diagram below:

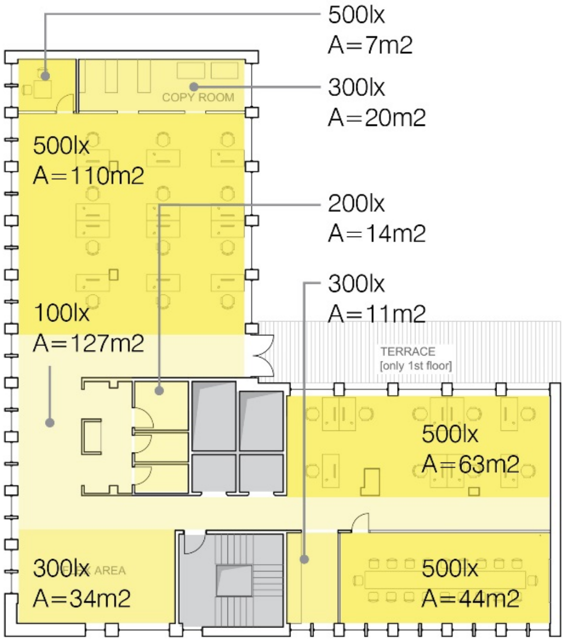


Figure 35: Illuminanece maintenance levels on the typical office floor, according to requirements.

All the floors were considered to have similar lighting demand. The energy saving measures were considered in terms of lamps, luminaires and the use of task lighting in the offices. Consequently, the lighting study was divided into ambient lighting and task lighting.

Ambient lighting

Design and calculation of lighting system in all the rooms on office floor except shafts, lift and staircase were performed in “DIALux”. Three types of LED luminaires have been used for different types of room, as shown in the table below:

Table 17: Luminares used on the typical floor lighting design.

Type of luminaire	Philips BPS640 W21L125 1xLED24/840 MLO-PC	Sharp DL18D8310W70S4 YUNA LED Downlight - 18 W / 1,000 lm / 3,000 K / white / 70° / DALI	Sharp DL28S8417W70S4 YUNA LED Downlight - 28 W / 1,700 lm / 4,000 K / white / 70° / switchable
Open office	✓		

Conference room	✓		
Meeting room	✓		
Corridor		✓	
Flexible room			✓
Copy room			✓
Toilets			✓

Characteristics of the chosen luminaires are shown in Appendix G **Electric lighting**.

Task lighting

In the second part, additional task lighting for the open offices was considered in order to achieve required illuminance level of 500lux. LED task lighting Luceplan BAP LED by Philips is proposed, with initial input power of 10W/lamp for each of 21 workstations.

Total energy load of electrical lighting was calculated as a sum of ambient lighting load and task lighting load.

2.5.2.4 Shading

In order to design interior shading devices, if appropriate, the glare risk analysis were conducted for the final case building design. The most exposed working places, which are the desks oriented to the West and conference room to the South, were analysed on the 5th floor. It has been considered that 6th floor, the conference floor, is provided with both exterior and interior automatically controlled shading devices from the first moment. More specific glare analysis for the 6th floor are however recommended.

Glare analysis

Illuminance ratio studies were performed at 9am, 12am and 4pm for summer solstice, autumn and spring equinox and at 9am, 12am and 3pm for winter solstice. Next, the most critical situations were studies by point-in-time glare analysis and annual glare for the screens indicated on the plan above.

Measure points for point in time glare and annual glare simulations are shown on diagrams below:

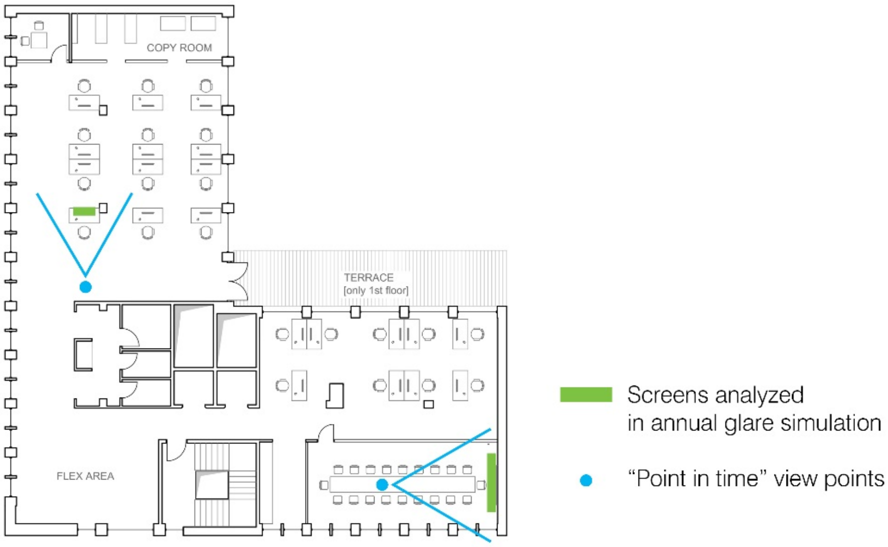


Figure 36 Glare analysis view points and analysed screens plan.

Annual glare was analyzed for two bounces and grid of 0,1m on the computers' screens, which were chosen accordingly to the most exposed locations.

Interior shading

In order to simulate the actual pattern of shading devices use, Conceptual Dynamic Shading function in "DIVA" was used. The analysed ideal shading reflects direct sunlight and allow 25% of diffuse sunlight inside. The screen control is however limited, which means that they are all down or all up at the same time. The dynamic simple system blinds was simulated for operation time 09.00-17.00.

The dynamic shading is controlled by occupants, according to the Lightswitch algorithm. The location of the work plane sensors are shown below:

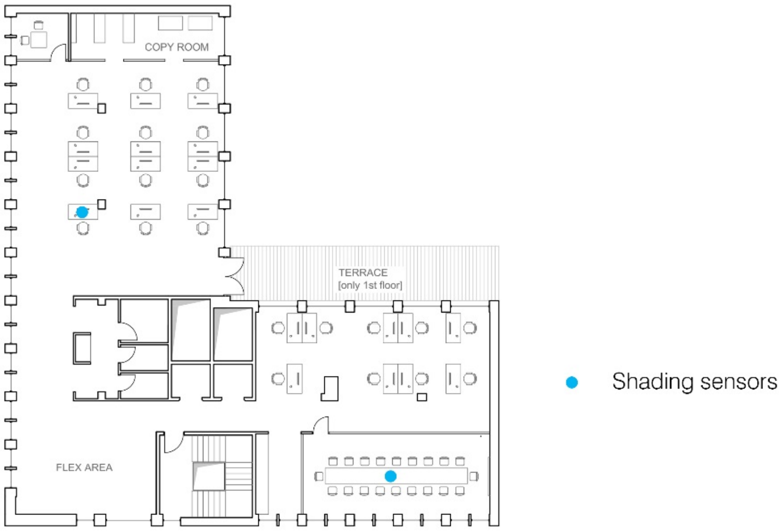


Figure 37: Location plan of interior shading sensors, for estimating the annual schedule.

Exterior shading

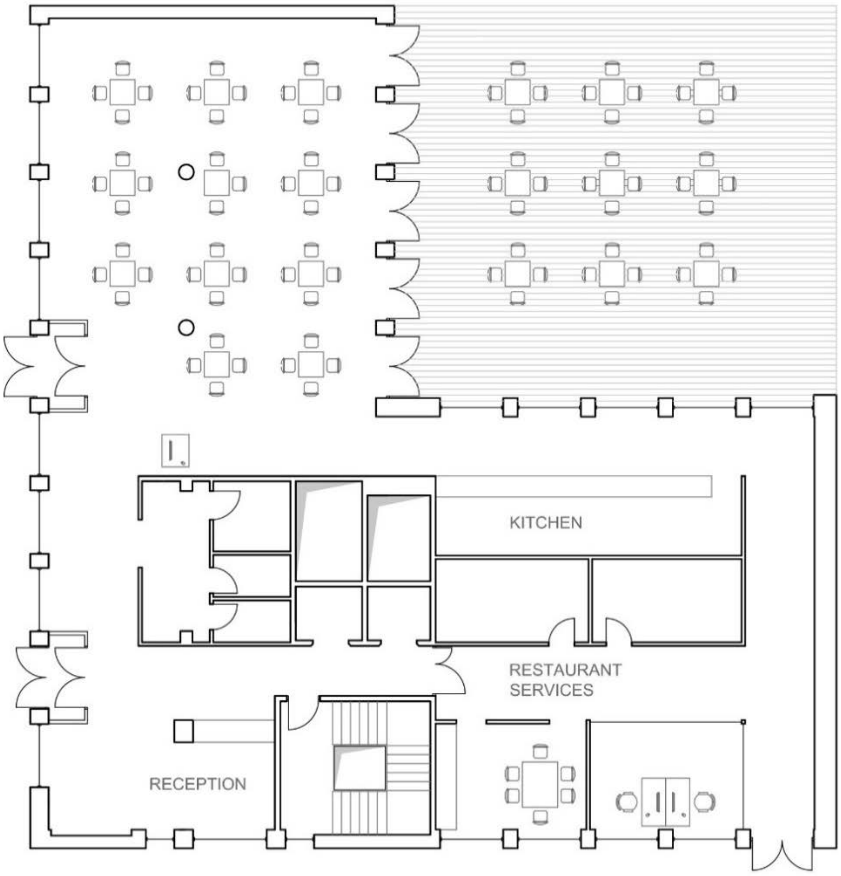
Preliminary ventilation flow studies of the new design of the building, has been made to evaluate the need and character of an exterior shading devices on the facades.

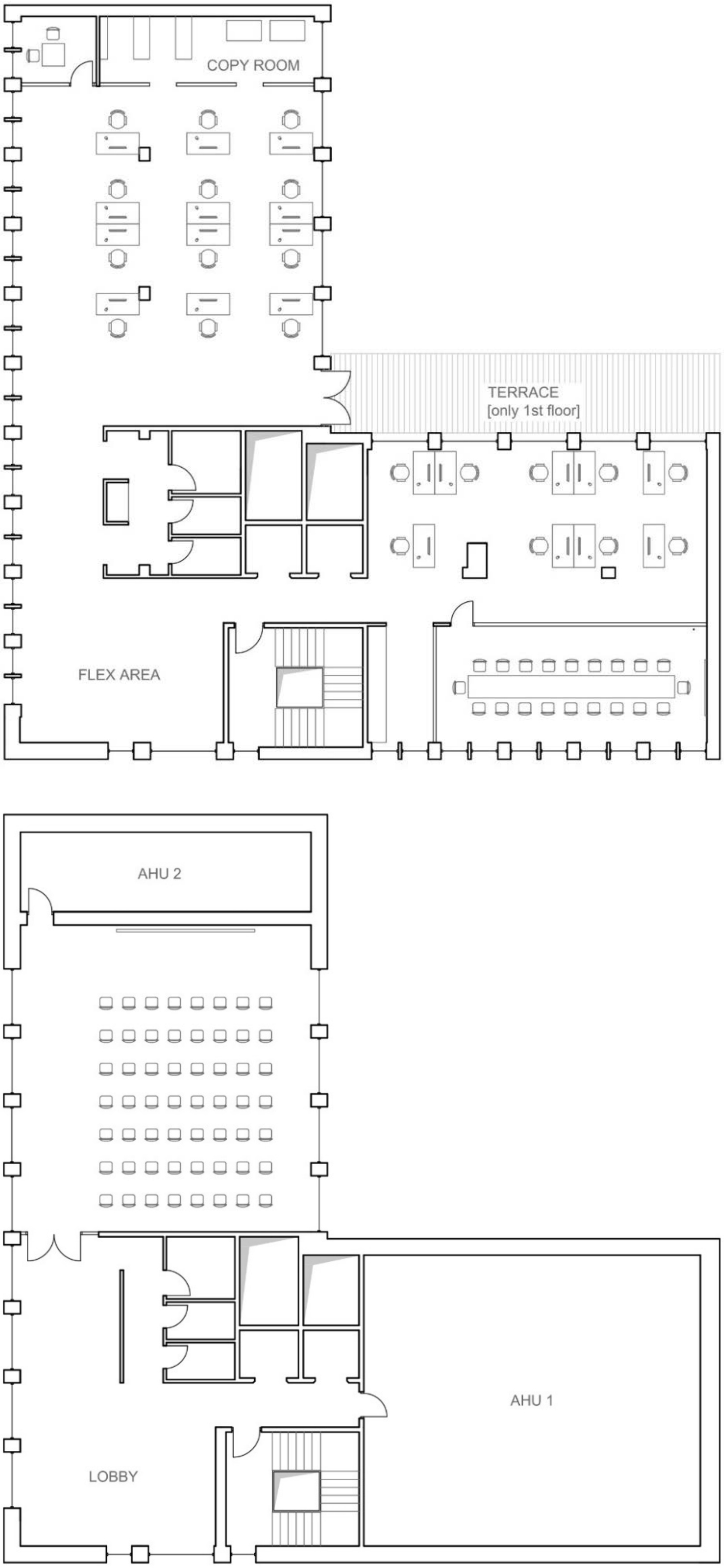
In order to minimize the decreasing effect of exterior shading on daylight conditions, both a material study in “DIVA” and sun path analysis based on Stereographic Diagram, see Figure 9.

2.6 Final case

The Final case consisted of the utilization of balanced parameters and designs in terms daylighting and lighting, energy use and moisture safety. At that stage, BREEAM evaluation and energy use evaluation for the final case were conducted.

It is important to mention, that the final case simulations were performed for the new functional plans of the ground floor, 1st floor and 6th floor, which are shown below.





Figur 38, New functional plans of the ground floor, 1st floor and 6th floor, accordingly.

2.6.1 Daylighting

BREEAM assessment

The final case with sufficient exterior shading devices was assessed according to BREEAM exemplary level of 3,15% DF for the 80% of lettable office area. The considered area of 265 points on 1m grid is shown on the diagram below:

Figure 39: Lettable area of the typical office floor

2.6.2 Energy use

Using the Best parametric study case as a starting point, optimizations for shading, electric lighting and heat recovery were further investigated to complete the Final case. Regarding the fan electricity, the result was calculated on the basis of the SFP-factor calculations.

Table 18 Additional parameters

Nr.	Parameter - BRIO	Comment
1	Shading	Exterior roller screen
2	Electric lighting	4 W/m2
3	Heat recovery	84% efficiency

Analysis of thermal properties for critical construction details

To ensure that the will not be any risk of thermal bridges in the construction, an analysis of this will be carried out in "HEAT2". In this analysis the critical building connections will be assed and checked, which are the connections between the roof-wall, window-wall, floor slab-wall and ground slab-wall. For the calculations the outside temperature of -1 °C and the inside temperature of 0 °C

Analysis of thermal properties for critical construction details

To optimize the building, some changes has been made to the construction which could, if not properly handled, cause problems for the thermal properties. Because of this a study of the critical areas were carried out. In the following the major thermal bridges will be presented. These are the connections between the roof-wall, window-wall, floor slab-wall and ground slab-wall. The investigation of the thermal bridges has been produced by the simulation program "HEAT2". For the calculations the outside temperature of -1 °C and the inside temperature of 0 °C.

2.7 HVAC

2.7.1 Mechanical Ventilation zone division

The ventilation system was divided according to the function of the conditioned room, its service time and usage frequency. The rooms which need to be air-conditioning treated are shown on Figure.40. Extract air system was considered for the toilets.

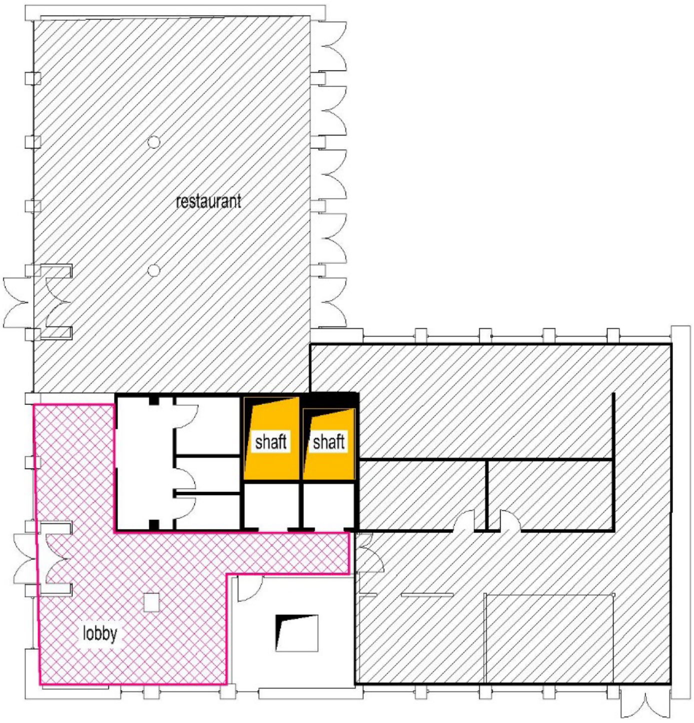


Figure 40 Air conditioned zone

All air system was adopted. There are also other options such as all water system, combined air-water system and refrigerant system, all works well in the office building. And the all-water system have its assets on saving spaces, since water is a higher heat capacity medium, but requiring several air-water exchange terminals mounted. VAV system was applied to realize a demand controlled ventilation system. Through this way to reduce the power required for annual system operation.

Municipal district cooling and heating network, which are easily accessible for BRIO building and of low costs, were obtained as cooling and heating sources for the system.

2.7.2 Air Flow design and calculation

According to Swedish regulation for working places, the minimum air intake should be 7l/s, p plus 0,35l/s, m^2 for the conditioned floor area. “TEKNOsim” was used to calculate the required air flow rate fulfilling a P25 comfort requirement. The maximum operative temperature for the worst day from May to August and the persistent dissatisfied percentage from April to September were checked.

Three types of exterior shading devices were tested, which are window awnings, screens and projections over the window, when calculating west-faced opening office and south-faced conference room in standard floor. Shadow type with which the room require a lowest airflow supply were selected.

The flows calculated for the model does not take the impact of atrium indoor climate into account. It was assumed that temperature in the atrium are lower than exterior temperatures during ventilation operation hours in summer.

The strategy of organizing air path is to have the controlled supply air flow rate higher than the exhaust airflow rate assuring the air conditioned area under a positive pressure. The toilets area in this case are located in inner zone, which means are of less heat gains in summer that could be taken away by flooded air from positive pressure zone.

2.7.3 Selection of diffusers and Ductworks layouts

Air distribution pattern was decided for the building, taking the low ceiling height into consideration. Mixed flow pattern was chosen due to relative low air quality requirement for office buildings, compared to cleaning rooms. The tool “ProAir” from “Swegon” was used to select air terminals, supply as well as exhaust devices. Devices were chosen considering the following criteria:

- Air velocity not exceed 0.25m/s in occupied zone in summer and 0.15m/s in winter
- The throw between 0.75 and 1 of the room length.
- CO_2 content not exceed 1000ppm.
- The noise level in the diffusers below 30dBA for 50% opening state
- Pressure drop across a supply air terminal at 50% opening state was controlled below 50pa, most of which under 30pa. Commissioning pressure drop for the terminal was also checked to assure normal operation state.

The ductwork layouts were designed to achieve low pressure drop along the pathway. Round duct was adopted. The central located shafts balanced reach to each branch, which reduces the length of ductworks. The number of duct fitting bends and the T-crossings was reduced. A balanced air flow rate splitting from the tee could help to archive a low pressure loss in the tee.

Ducts connected with AHU1 was split into two vertical branches. Reason for doing this is considering the wall between shaft left and right must be load-bearing one which not allowed to break down.

Intake and outlet location were selected considering choosing an opening fresh area to gain fresh air and avoiding short circuits between air inlet and outlet.

2.7.4 Total pressure drop

The total pressure drop of the duct system include friction losses along the ducts and the local pressure drop in fittings. The friction losses along the duct was designed and calculated when drawing the ducts on "AutoCAD MEP" by flow velocity control. The local pressure drop in the junctions were calculated by the tool "ASHRAE duct fitting database". A low velocity duct system was considered, 4-5m/s in the main duct, and 2-4m/s in the branch duct. The ducts in shaft are at the same dimension all the way up.

Pressure losses were calculated for each duct path and the critical path was picked with the worst pressure consumed.

2.7.5 AHU selection and Coils design

Given the airflow rate calculated for each AHU division system, the units were selected according to "Swegon" brochure. The category "Gold RX" with rotary heat exchanger was selected. The related heat recovery factor for the corresponding AHU was looked up from "Swegon" brochure Gold AHU efficiency.

The coils design for the units were conducted in Mollier diagram. In the calculation, for summer, outdoor temperature of 24.9℃ and relative humidity of 58%. For winter, outdoor temperature of minus 13.5 ℃ and relative humidity of 99%. The designed indoor environment with temperature in 22 ℃, relative humidity in 55%. The supply temperature for the two air-handling units are 18℃.

2.7.6 SFP-factor

An air distribution system with a low SFP can facilitate a low level of annual fan energy use. A SFP of less than 1kW/(m^3/s) was tried to achieve. Detail equation and calculation are shown in appendix J.

"ProUnit" tool from "Swegon" was also used to select air-handling units and check the SFP factor. In "ProUnit" the operation time of the system was also considered. To reach a SFP factor below 1 kW/(m^3/s), bigger size AHU are selected.

2.8 Moisture safety

To ensure that there was not any moisture problems in the refurbished office building a risk assessment was made. This analysis focused on the climate envelope, and therefore the exterior walls, the roof for the office building and for the atrium were analyzed.

2.9 Space heating system

The existing space heating system is assumed to function well, but needs redesign for the new heating demand. A new circulation pump for the system should be chosen, thus the calculation of pressure drops in the system is needed. The calculations were carried out according to the recommendations in "*Projektering av VVS installationer",* by Catarina Warfvinge and Mats Dahlblom (5). For a more ingoing explanation of the equation, see appendix F.

According to the book, two criteria should be fulfilled, when dimensioning the pipes:

- The velocity of the water should be between 0,5 – 0,7 m/s. The assumption is that the water velocity should be 0,6 m/s.
- The pressure drop per meter, R should be around 100 Pa/m

For calculating the pressure drop in pipe system, the following equation was used:
$\Delta p = \sum \Delta p_f + \sum \Delta p_e + \sum \Delta p_a \; [Pa]$

$\Delta p_f = Pressure\ drop\ in\ straight\ pipes\ [Pa]$
It is assumes that the $\Delta p_f = R \; \rightarrow 100\ Pa/m$

$\Delta p_e = Pressure\ drop\ in\ components\ [Pa]$
$\Delta p_a = Pressure\ drop\ over\ appliance\ [Pa]$

$$Power\ need\ for\ the\ radiators, P_{rad} = \rho \cdot q \cdot c_p \cdot \Delta T\ [kW] \rightarrow q = \frac{P_{rad}}{\rho \cdot c_p \cdot \Delta T}\ [kW]$$

The supply and return temperature of the water are estimated to be: 55-35 °C

Pressure drop over the appliance:
Since the existing radiators and their installations are already in place, their pressure drop is not known. Because of this an assumption for the Δp_a needs to be made, even though this is very individual for each system. This assumption is done from the *Dimensioneringsbroschyr* by Purmo (6). The Δp_a for the thirteen radiators is assumed to be around 50 000 Pa.

3 Results

3.1 Base case

3.1.1 Daylight

DF and DAcons results were attained for each of 6 floors of the BRIO office building. Specific results for each of the floors are shown below:

Daylight factor

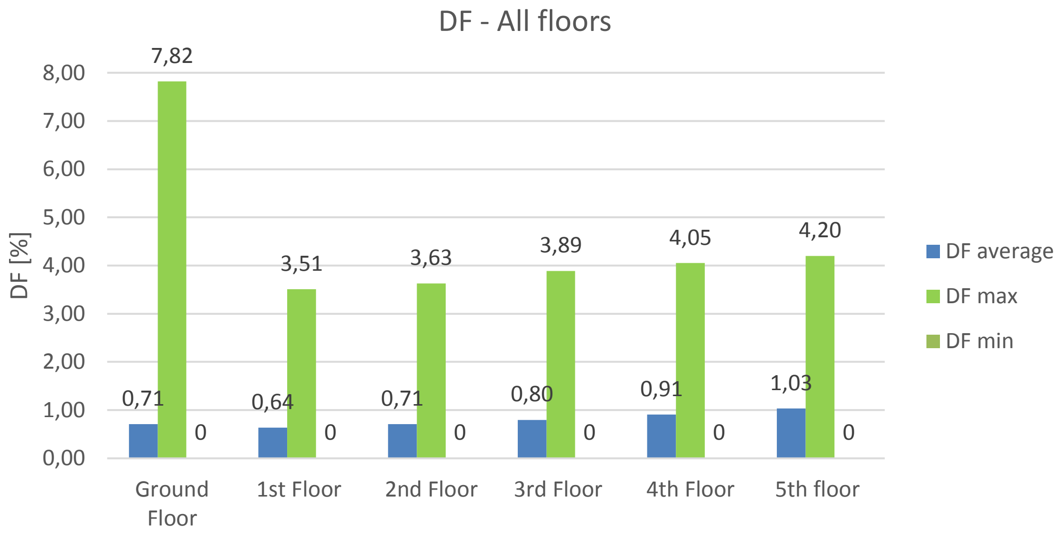
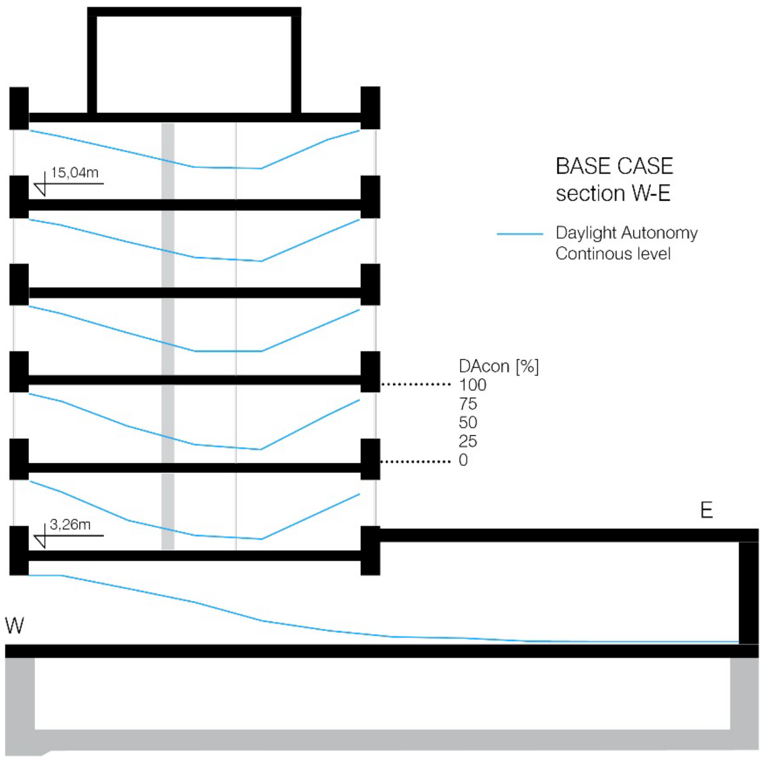


Figure 41: Average and maximal DF results for the Base Case, each floor.

Daylight availability



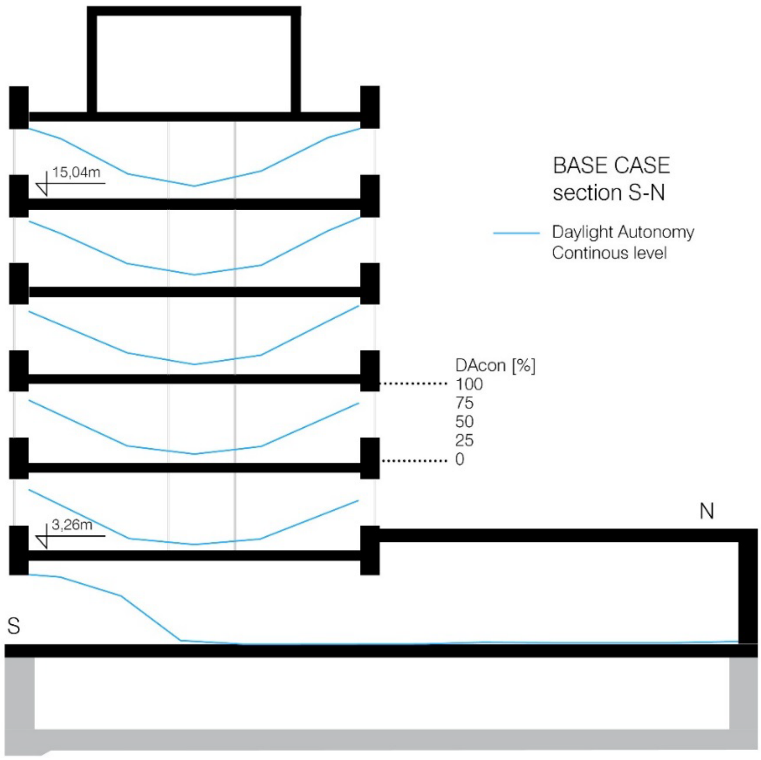


Figure 42, Continuous daylight autonomy across two sections, W-E and S-N accordingly, on each floor.

3.1.2 Energy Use

Steady-State calculations

Calculation the heat loss rate

The existing building has a value of $48{,}3W/m^2A_{temp}$, which is not within the restrictions for passive houses. See Appendix B **Base case FEBY 12** for the full hand calculation.

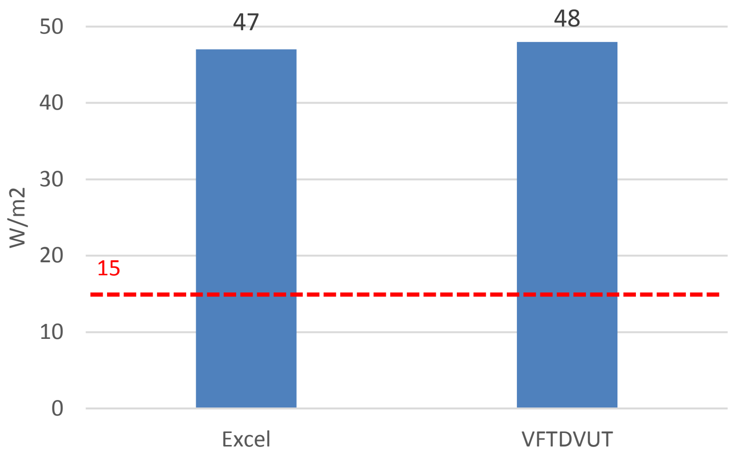


Figure 43 Heating load steady-state calculations, Base case

Calculation of the delivered yearly energy to the building

The existing building has a value of 65 $kWh/m^2 A_{temp,} year$, which is not within the requirements for passive houses according to FEBY 12. For the complete calculation see Appendix B Base case FEBY 12.

$$E_{delivered} = 65\ kWh/m^2 A_{temp,} year$$

"DesignBuilder"

Figure XX shows a comparison between Kaisa Flodberg's reference case and BRIO base case for the total energy use. The BRIO base case total-end energy resulted in 116 kWh/m2 year, compared to 139 kWh/m2 year for the other building. Excluding the user-related electricity and using the $E_{delivered}$ calculation, the base case results in specific energy use of 65 kWh/m2 year, which is above the requirements.

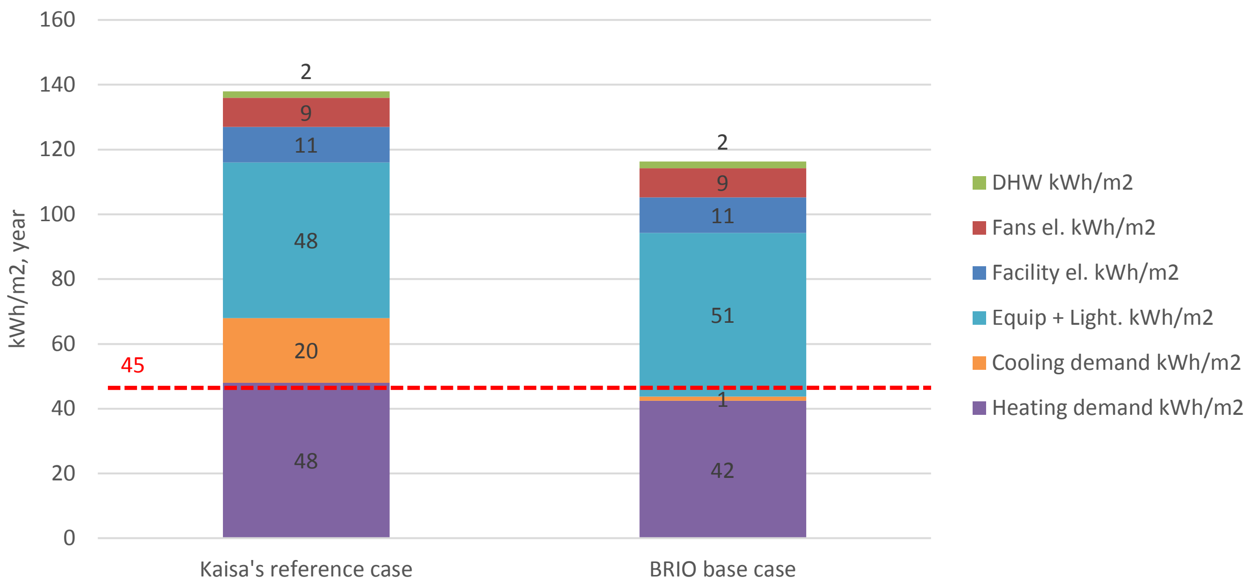


Figure 44 Total end-use energy, Base case

The following figure presents the peak power needed for heating and cooling of the buildings. Both buildings exceeded the VFT_{DVUT} requirement with approximately 2,5 times.

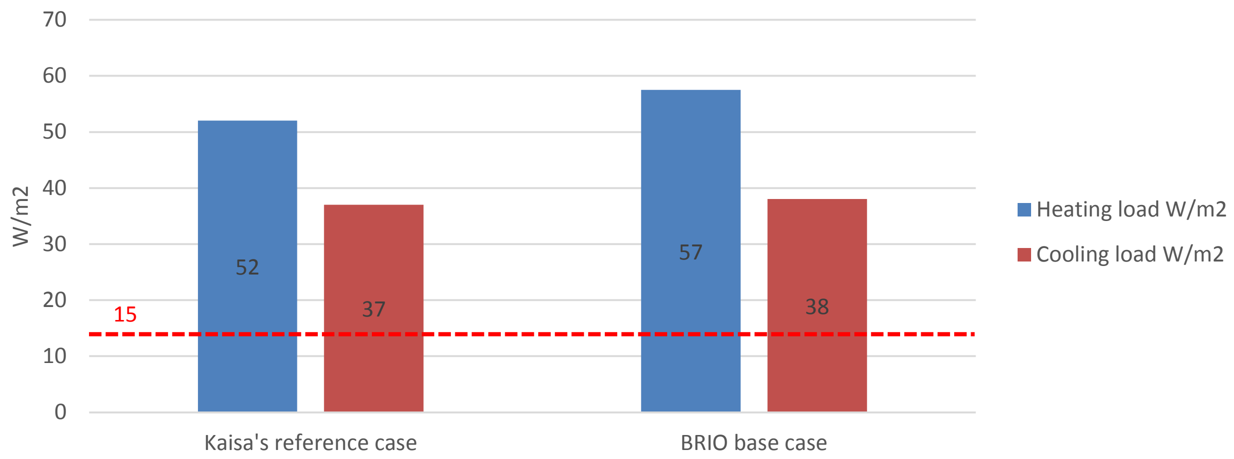


Figure 45 Peak loads, Base case

The annual operative temperature distribution for three of the floors in the building, is shown on the figures below. The higher temperature frequency raised with the height, however the most frequent indoor temperature was 20°C, which is under the demanded by FEBY 12.

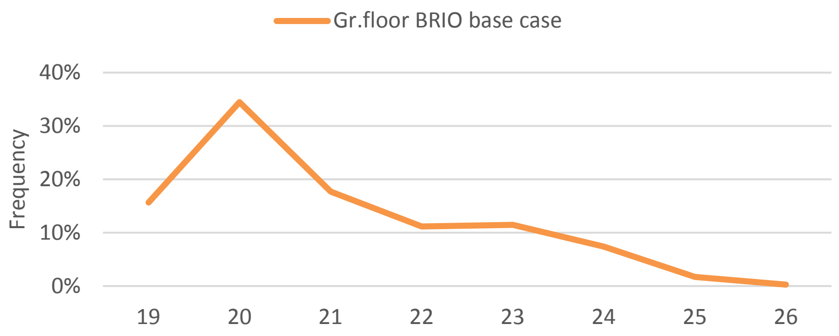


Figure 46 Annual temperature distribution, Ground floor, Base case

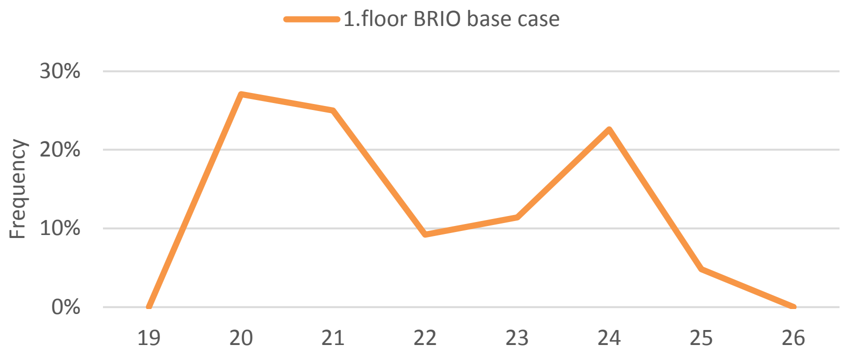


Figure 47 Annual temperature distribution, First floor, Base case

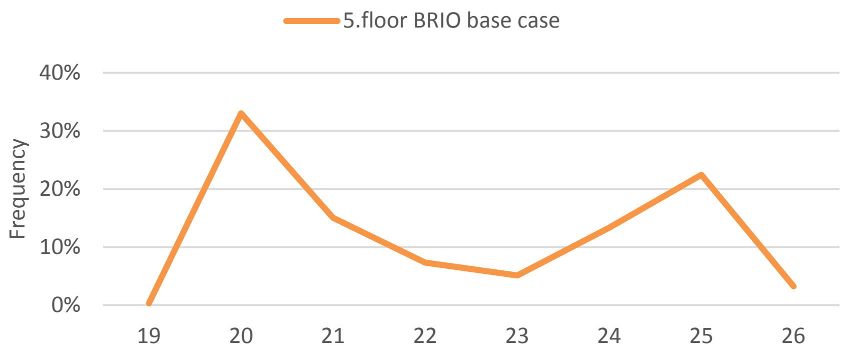


Figure 48 Annual temperature distribution, Fifth floor, Base case

The following figures present the temperature distribution of BRIO base case building, for the period between 01. April - 30. September. During that period the temperatures on the ground and first floor fulfilled the BELOK P25 requirement, whereas the fifth floor achieved P26, due to temperature frequency of 45% at 25°C.

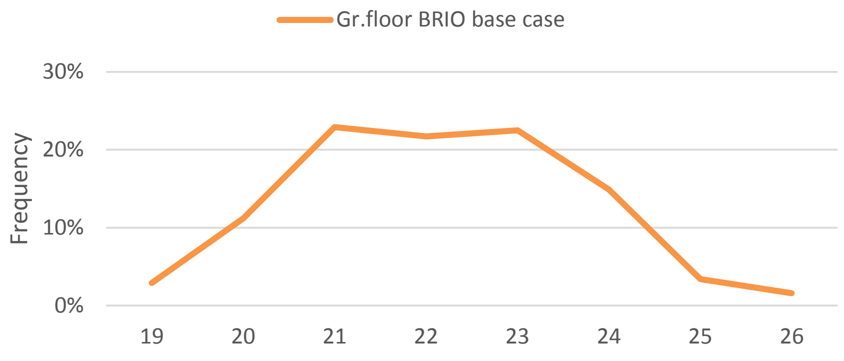


Figure 49 BELOK thermal comfort, Ground floor, Base case

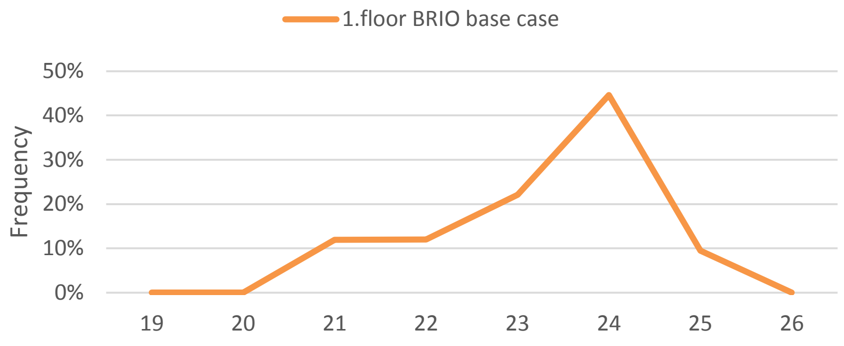


Figure 50 BELOK thermal comfort, First floor, Base case

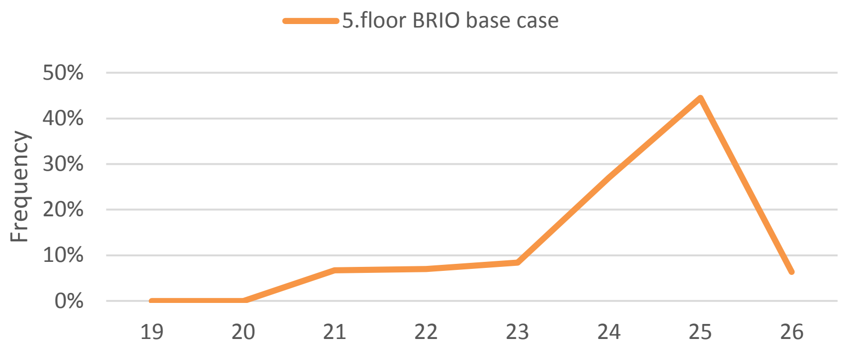


Figure 51 BELOK thermal comfort, Fifth floor, Base case

3.1.3 Parametric study

3.1.4 Main design parametric study [Base Case vs. Atrium Case]

3.1.4.1 Daylight

Daylight factor

First study on atrium, shows a decrease in maximal DF values in the building, especially on the 5th floor, where the maximal DF value is already high. On the other hand, the average DF values do not decrease significantly, again especially on the 1st floor, where the average DF value is already low.

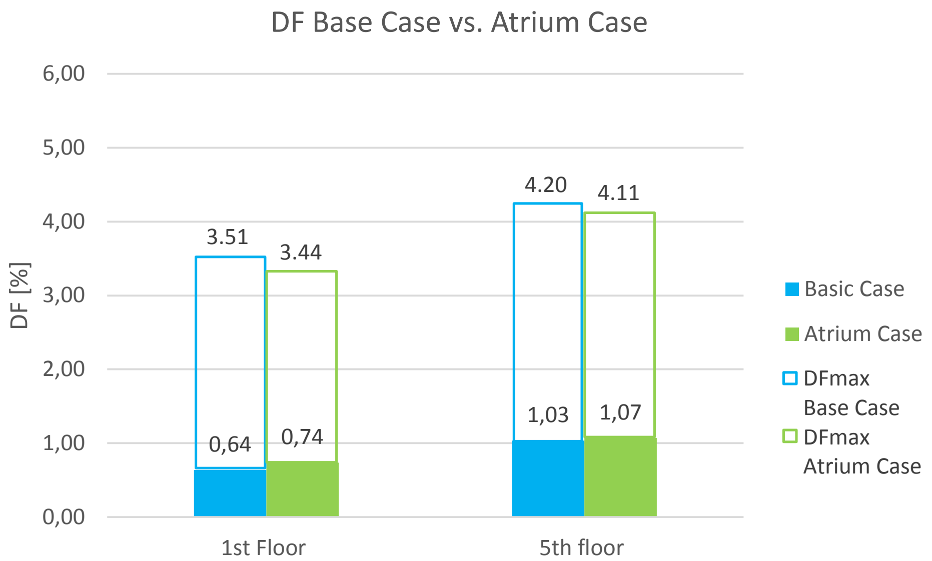


Figure 52: Average and maximal Daylight Factor comparison between Base Case and Atrium Case.

Daylight availability

DAcon study, for sections S-N and W-E, shows that the basic case with an atrium presents lower illuminance values in the area by the atrium windows [East or North], while the DAcon values in the middle of the sections increase slightly or stay the same.

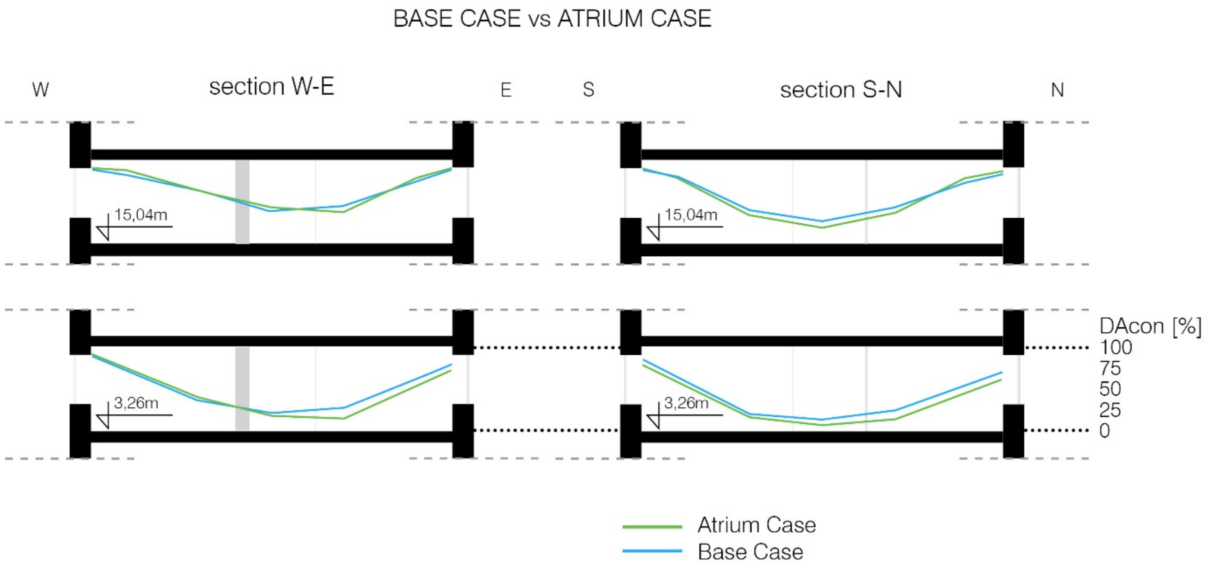


Figure 53, Dacon results comparison for Base Case and Atrium Case, on the 1st and 5th floor.

3.1.4.2 Energy use

Error! Reference source not found.54 compares the results for the total end-use energy of the Atrium case to the BRIO base case. The Atrium case registered 105 kWh/m2 year, which is a reduction of 11%. Without user related electricity, the result ended up at specific energy use of 61 kWh/m2 year, which does not fulfill the requirements. Reduction of respectively 10% and 13% was made in the heating and user related electricity demands.

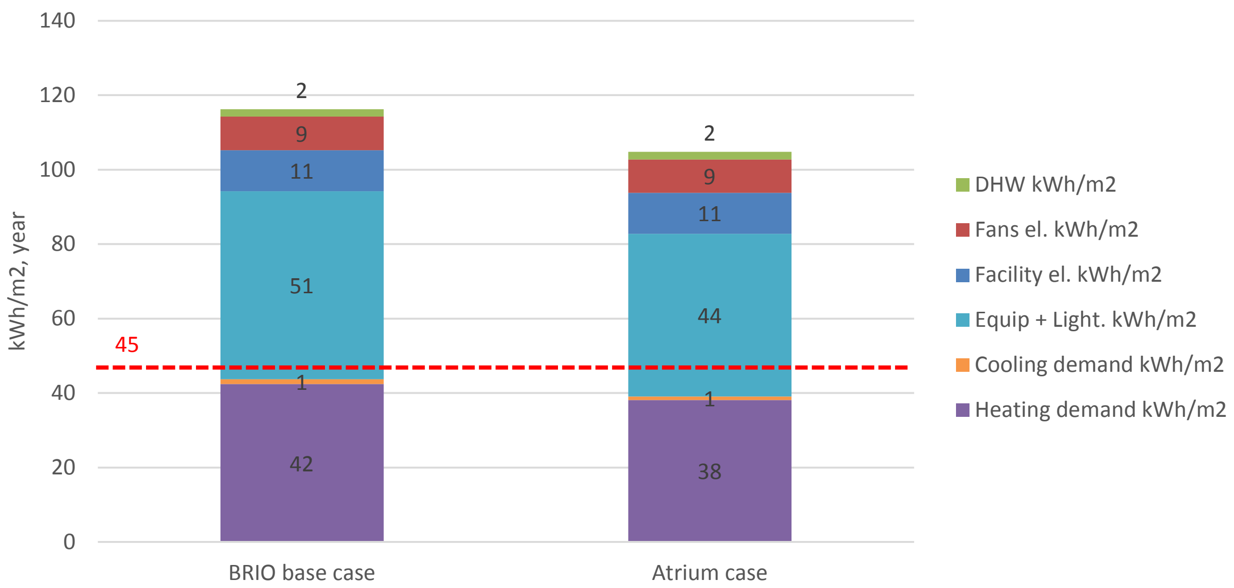


Figure 54 Total end-use energy, Atrium case

The following figure shows Atrium case's peak loads for heating and cooling, compared to the BRIO base case. The peak load remained high, even though a reduction of 35% and 16% was registered for the heating and cooling loads.

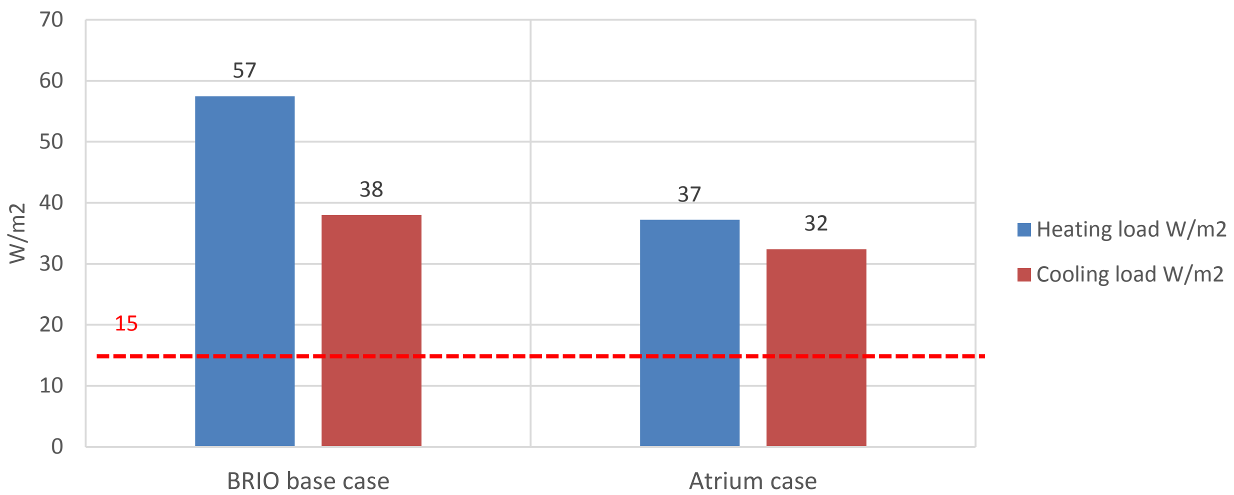


Figure 55 Peak loads, Atrium case

The following figures present the annual temperature distribution on four of floors. What can be noticed on 3 of the floors, present in the base case results, is that that the operative temperatures have slightly risen. Temperatures of 20-21°C were most often to occur. As for the sixth floor, the temperatures appeared to be lower and 19°C temperature can be noticed.

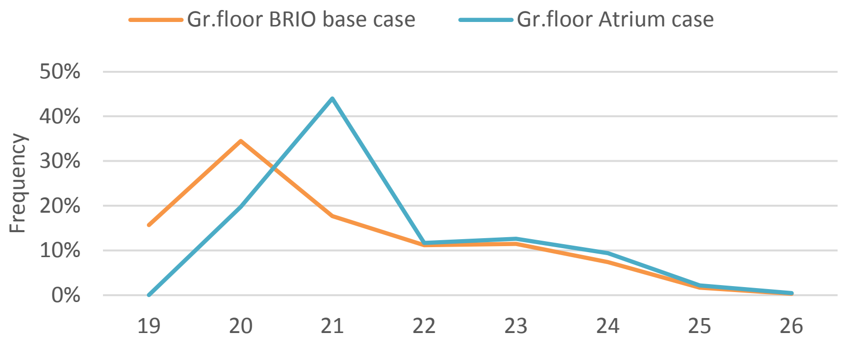


Figure 56 Annual temperature distribution, Ground floor, Atrium case

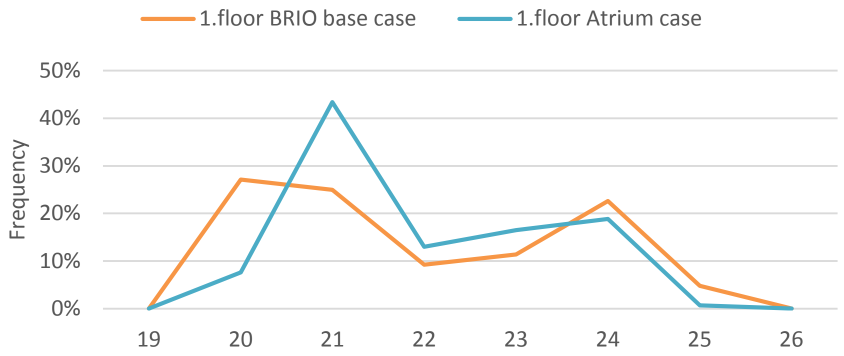


Figure 57 Annual temperature distribution, First floor, Atrium case

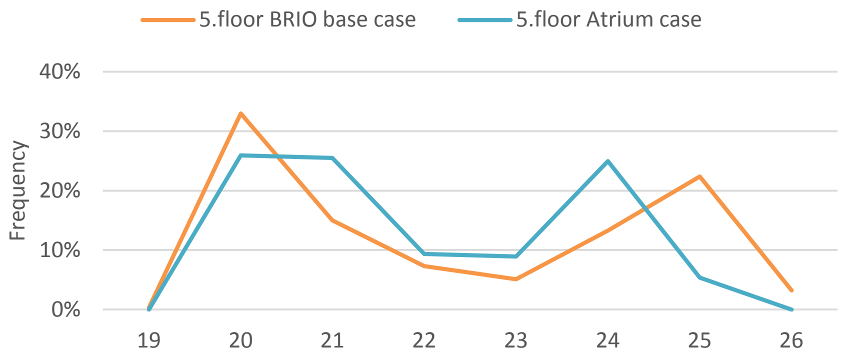


Figure 58 Annual temperature distribution, Fifth floor, Atrium case

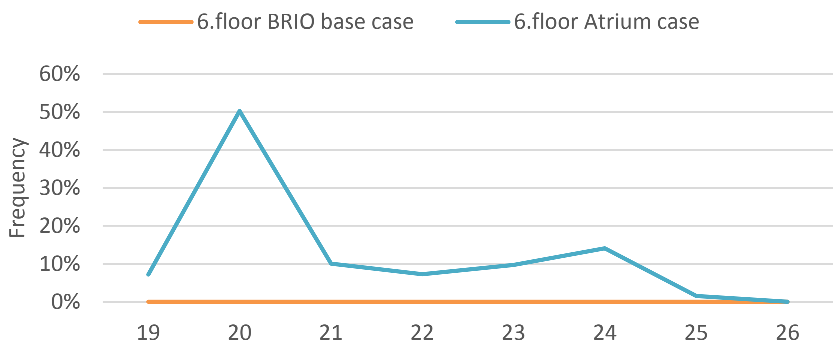


Figure 59 Annual temperature distribution, Sixth floor, Atrium case

A comparison between the temperature distribution of BRIO base case building and Atrium case, for the period between 01. April - 30. September, for representative floors is shown on the figures below. The temperatures in the Atrium case have slightly reduced, however all floors fulfilled the comfort criterion of P25, where the temperature frequency does not exceed 10% of the hours.

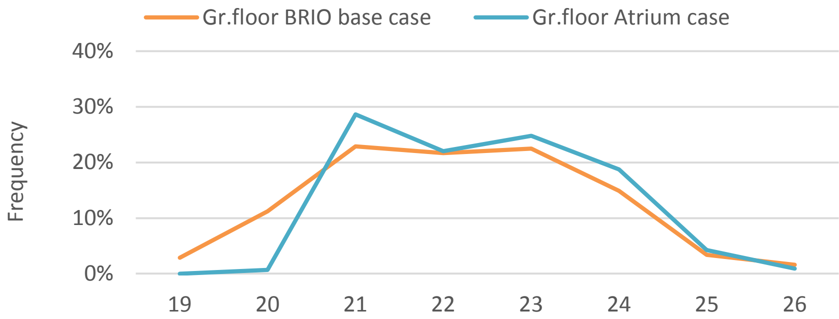


Figure 60 BELOK thermal comfort, Ground floor, Atrium case

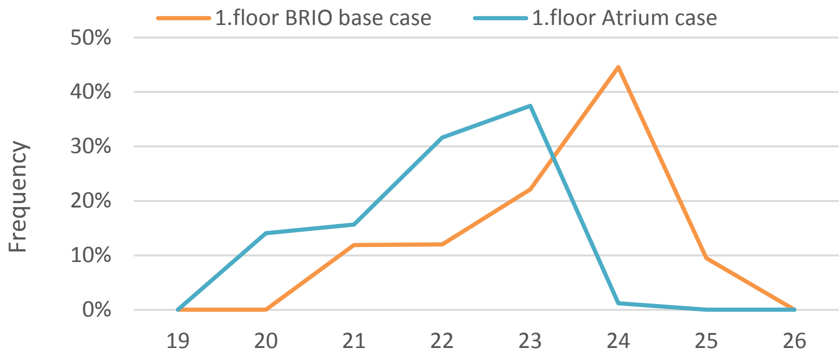


Figure 61 BELOK thermal comfort, First floor, Atrium case

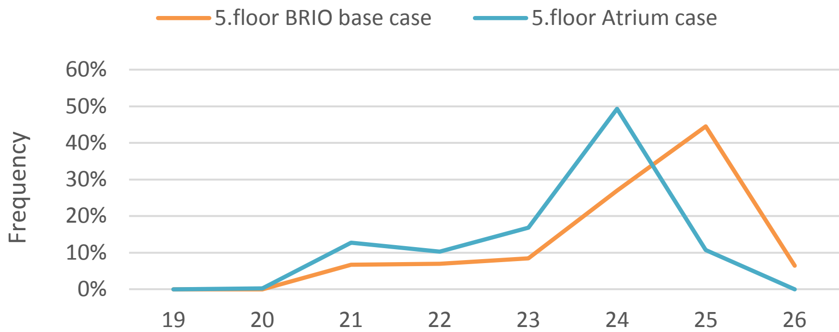


Figure 62 BELOK thermal comfort, Fifth floor, Atrium case

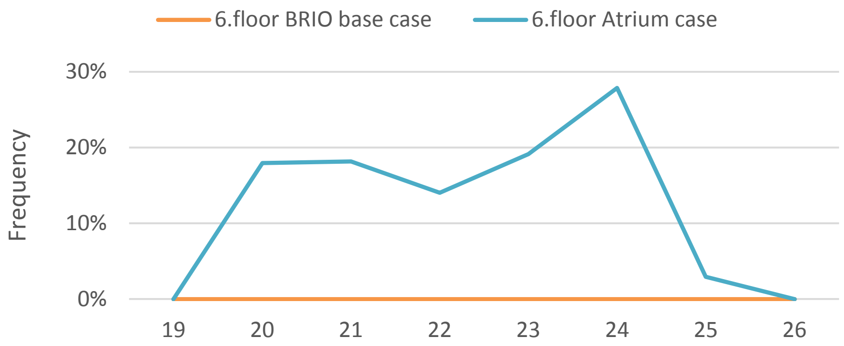
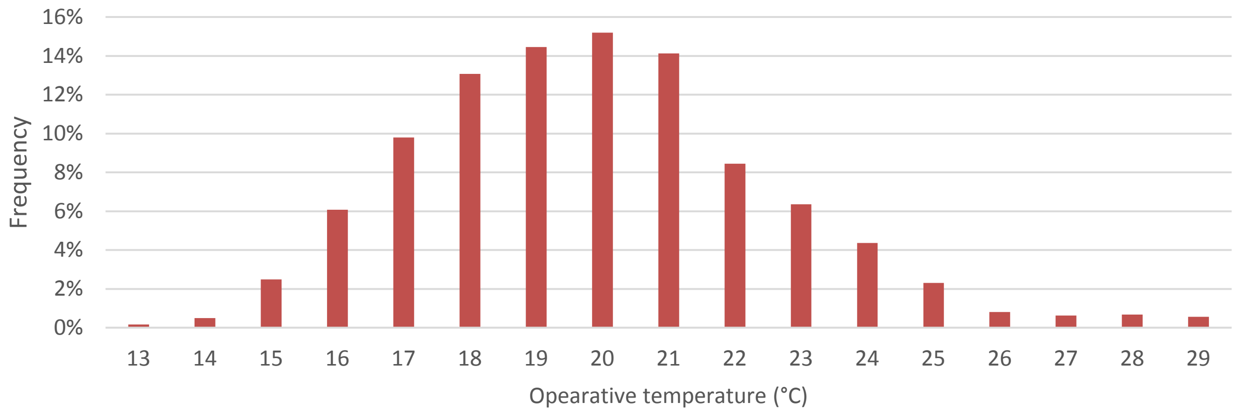


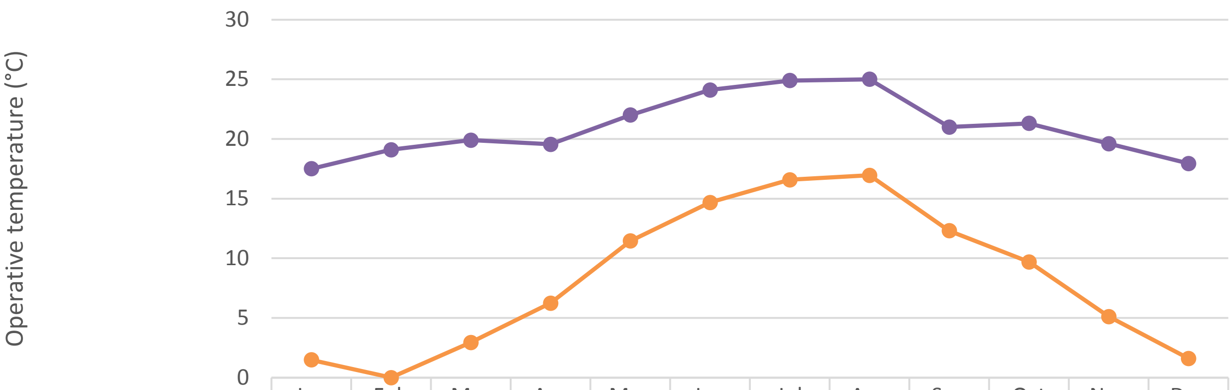
Figure 63 BELOK thermal comfort, Sixth floor, Atrium case

The lowest and the highest temperatures that occur in the atrium annually, range from 13°C to 29°C. However, the temperatures that are most frequently observed are between 17-21°C.



Figur 64Annual temperature distribution, Atrium

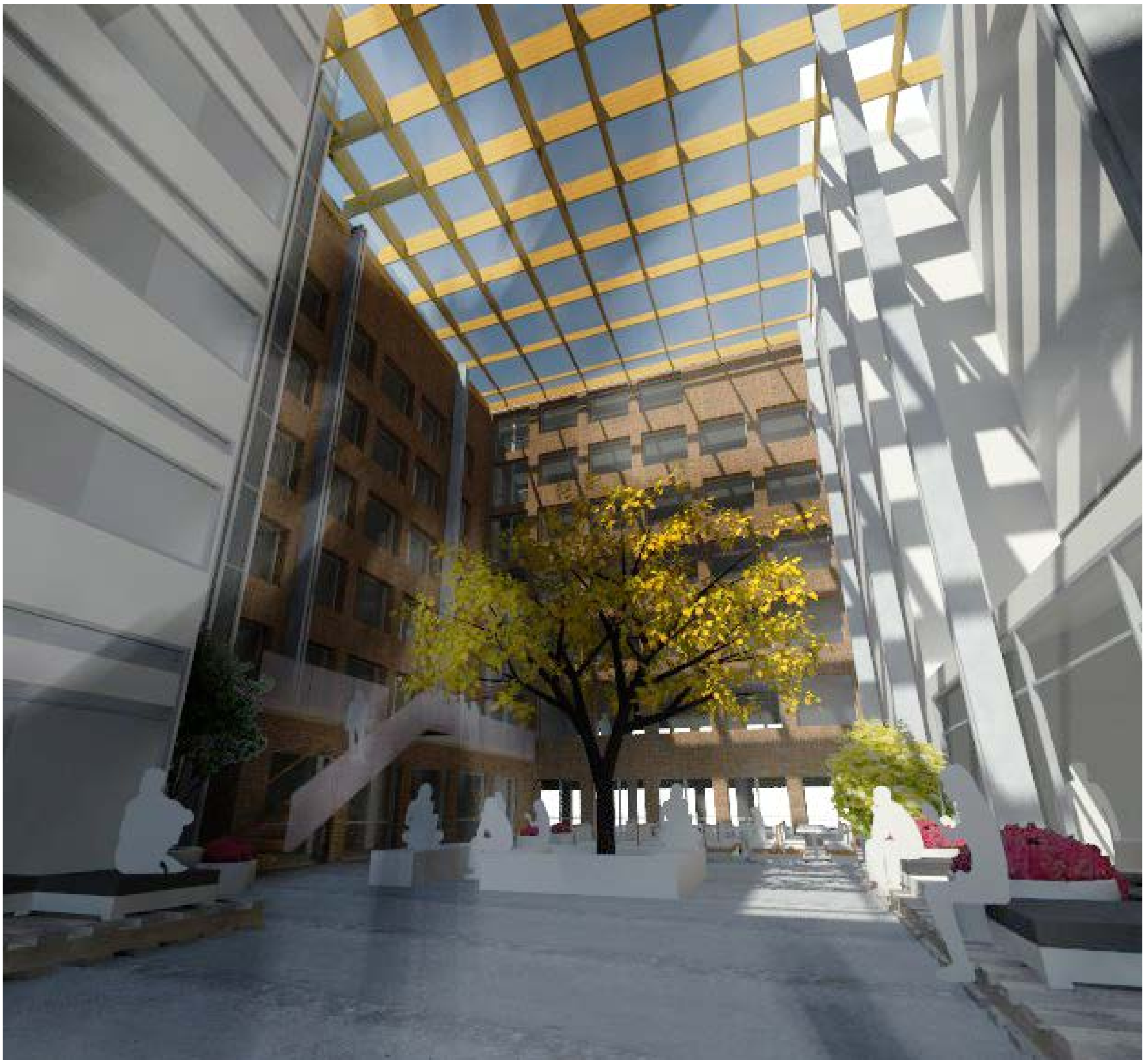
The following figure shows the monthly average temperatures in the atrium. Compared to the outdoor, the temperatures in the atrium resulted to be relatively stable, ranging from 17,5°C in January to 25°C in August.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Out. Dry-bulb temp	1,5	0,0	3,0	6,2	11,5	14,7	16,6	17,0	12,3	9,7	5,1	1,6
Atrium	17,5	19,1	19,9	19,6	22,0	24,1	24,9	25,0	21,0	21,3	19,6	18,0

Figure 65 Monthly average temperatures, Atrium

As a results of main design parametric study Atrium Case was chosen as an optimal solution in terms of daylighting and energy use. It has been also considered a solution which significantly increases quality of architecture and common spaces for BRIO office building and other buildings oriented to the atrium.



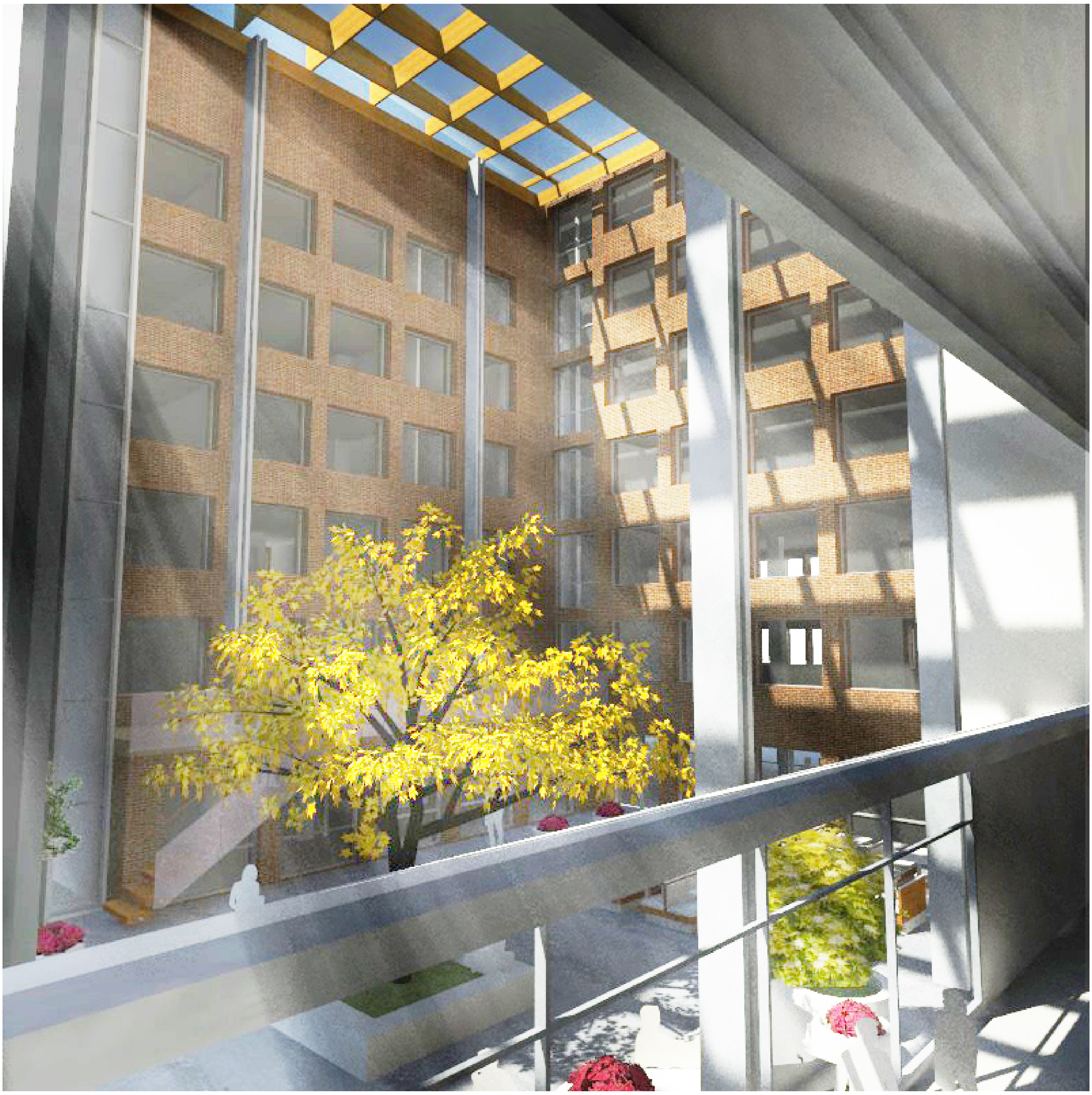


Figure 66, Perspective views of the atrium and BRIO northern and eastern facades.

Atrium Case was further analysed in detailed parametric study.

3.1.5 Detailed parametric study of the chosen design

3.1.5.1 Daylight

Functional Plan

Comparison of the DF results shows that an average DF value on each of analyzed floors is higher for the variation 1, where all office area is open. The changes in DF maximum values are very small and considered irrelevant, due to simulation error margin.

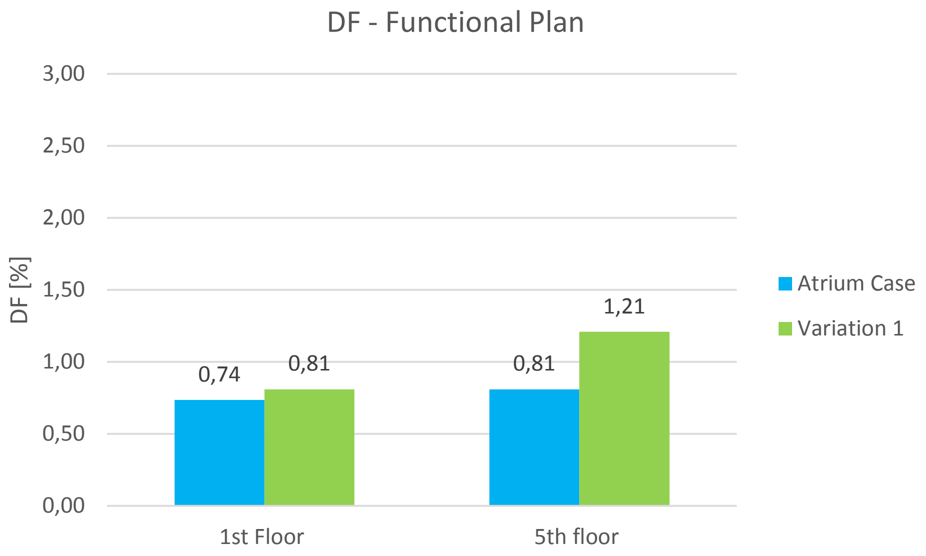


Figure 67, Average DF values for Variation 1 and Atrium Case

Continuous daylight autonomy study shows that open office functional plan does not have a significant effect on daylight availability on the first floor, however it increases the minimal DAcons values on the 5th floor from 20% up to 40% both in S-N and W-E section.

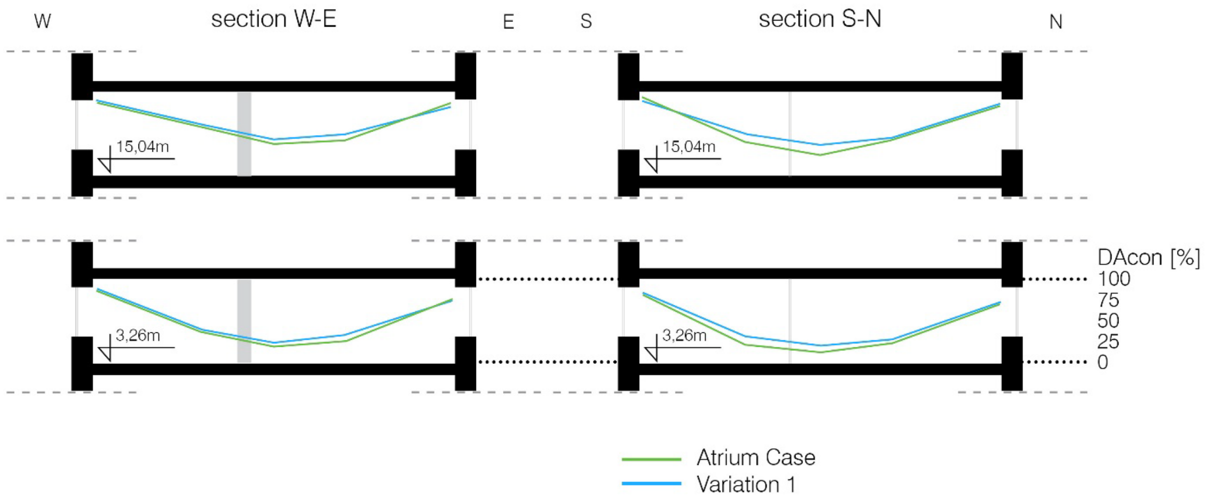


Figure 68, DAcon results comparison for Variation 1 and Atrium Case

Material properties

Both daylight factor and daylight availability results below, show that significant rise of the values for a case with high reflectances of interior surface materials, variation 1.

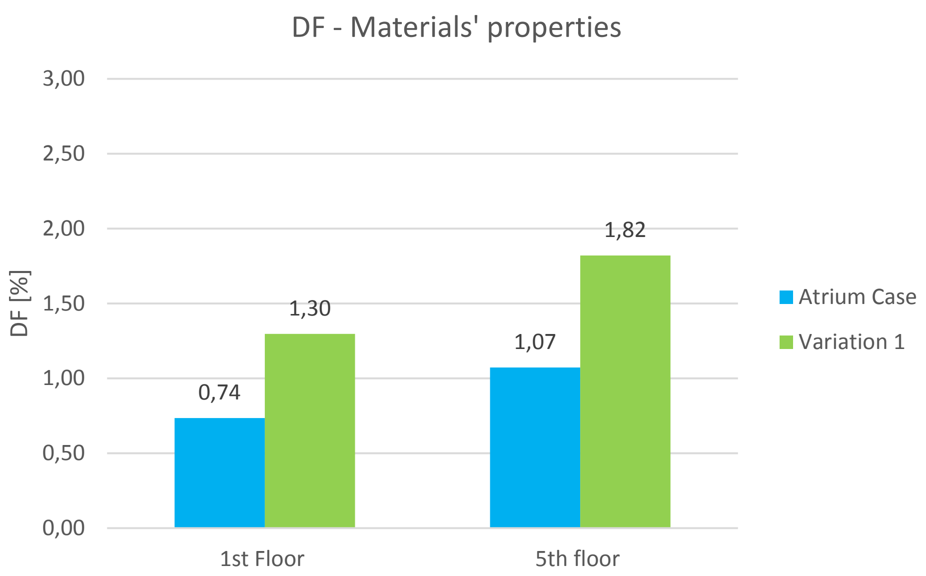


Figure 69, Average DF values for Variation 1 and Atrium Case

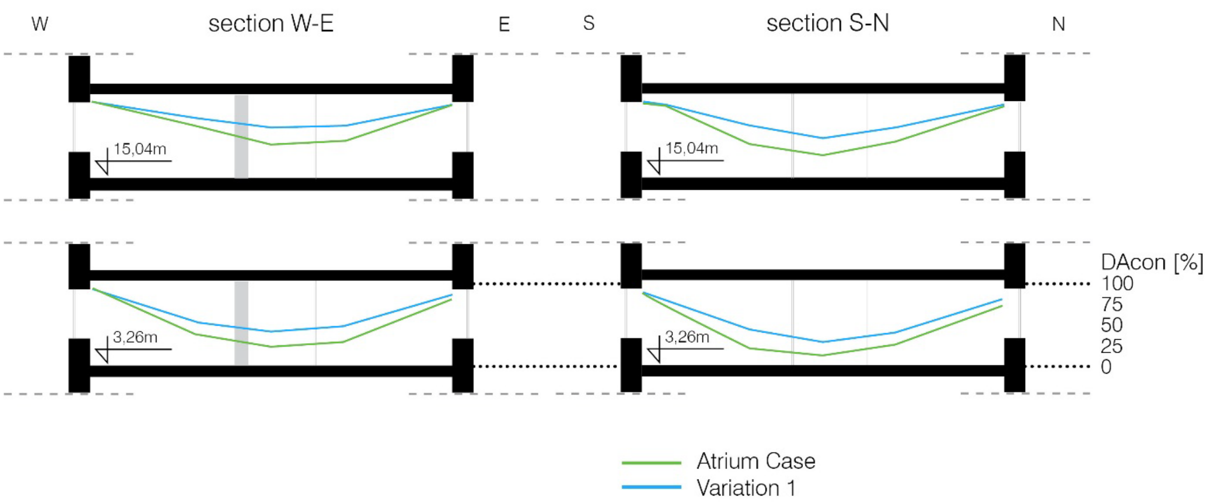


Figure 70, DAcon results comparison for Variation 1 and Atrium Case

Glazing

Both GWR and type of windows glazing show high importance while considering daylight factor and daylight autonomy in the building. Variation 1, increased GWR of 26%, show daylight factor average rise of 14% on the 1st floor and 17% on the 5th floor. While variation 2, triple clear window glazing, increased average DF by 66% on the 1st floor and 70% on the 5th floor, comparing with the basic case. DF and DAcon results are shown below:

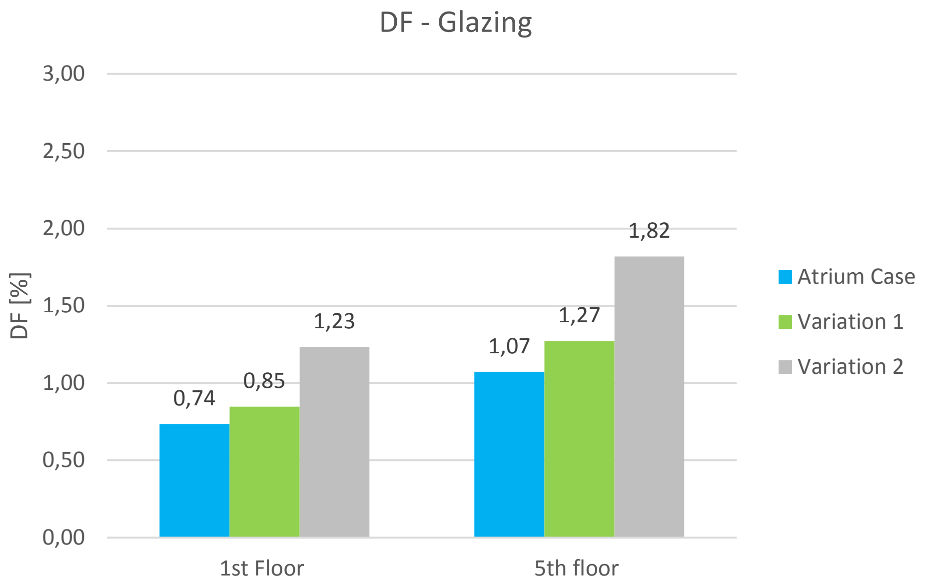


Figure 71, Average DF values for Variation 1 and Atrium Case

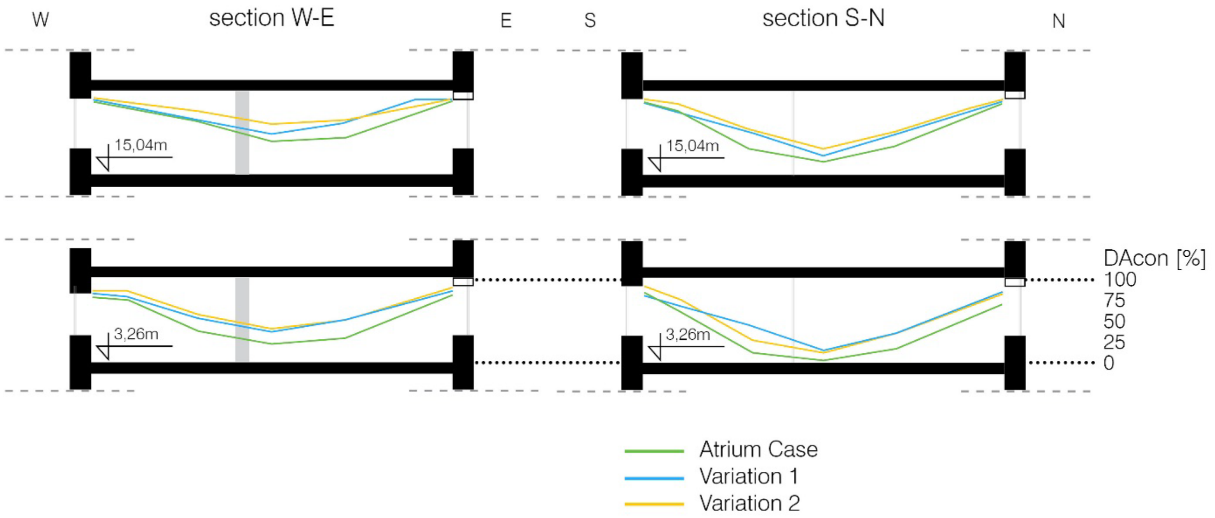


Figure 72, DAcons results comparison for Variation 1, Variation 2 and Atrium Case

Construction

Additional 10cm of insulation, as a result of envelope refurbishment, decreases insignificantly DF average values in the building. However as shown below, the DAcons values are visibly lower, especially in the area of northern and eastern façade.

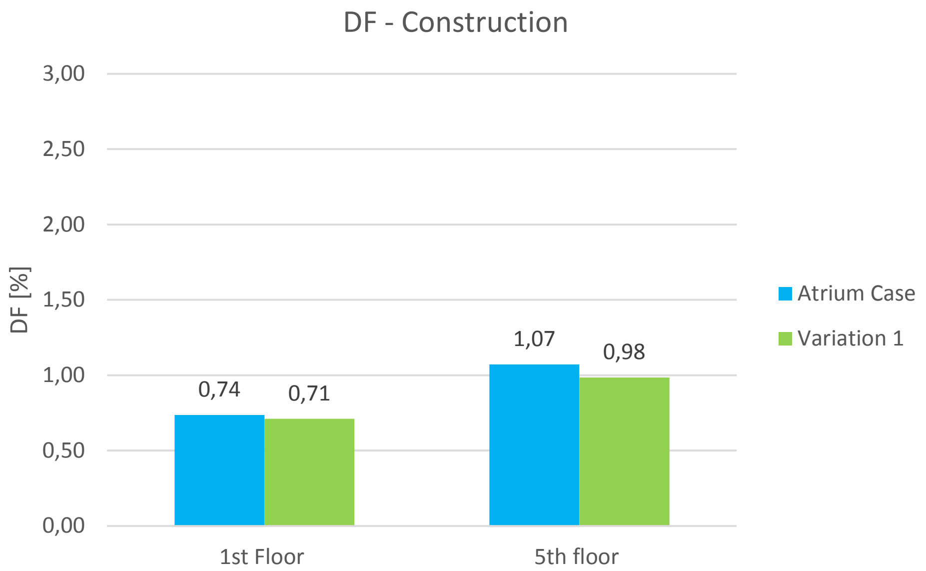


Figure 73, Average DF values for Variation 1 and Atrium Case

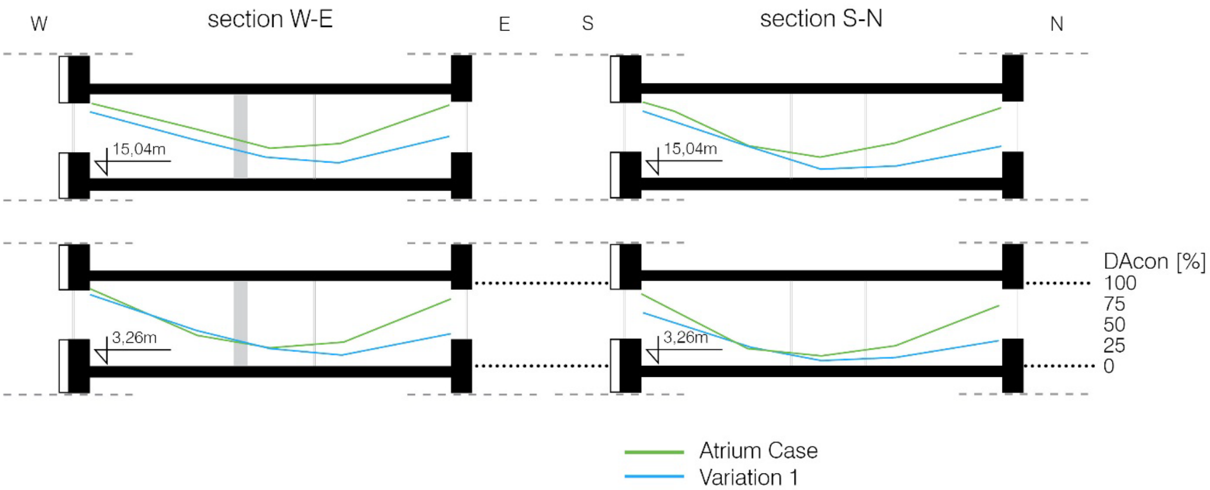


Figure 74, DAcons results comparison for Variation 1 and Atrium Case

Best case parametric study

As a result of parametric study the optimal design was achieved, which is called best parametric case. It resulted in 2,92% average DF on the first office floor, comparing to the 0,74% average DF in the base case. What is more, it resulted also in achieving the 65% of continuous daylight autonomy as the minimal value across the building section, already on the 1st floor.

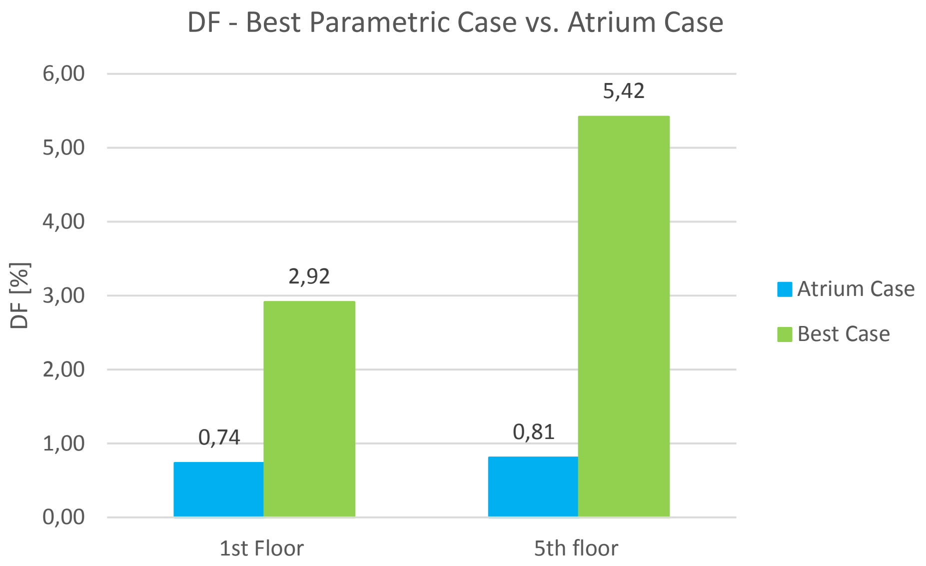


Figure 75, Average DF for the Best Parametric Case in comparison with the Atrium Case

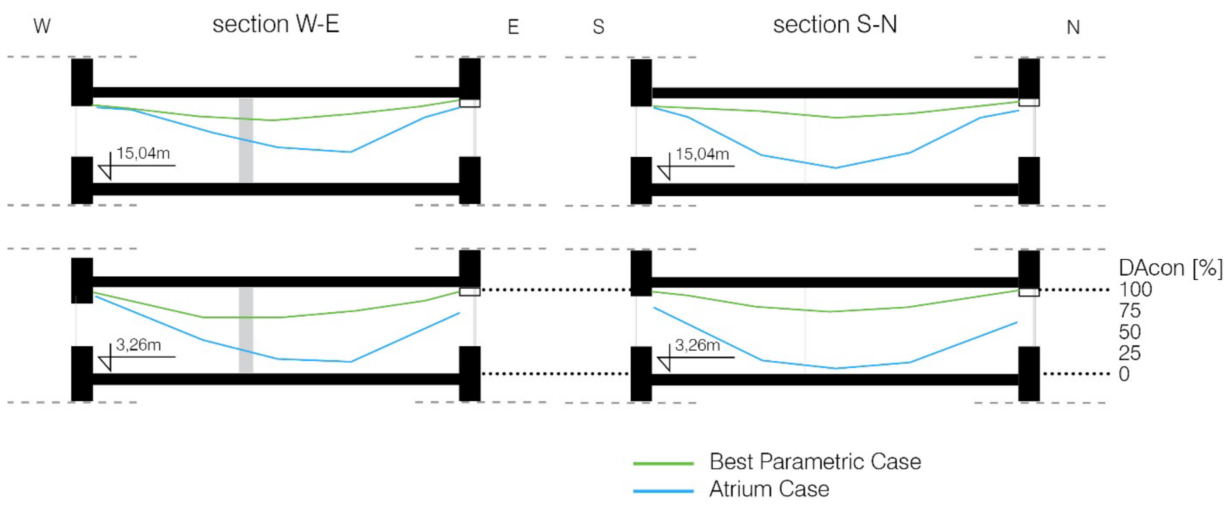


Figure 76, DAcons results comparing the Best Parametric Case with the Atrium Case

3.1.5.2 Energy Use

The parametric study demonstrated the effect of each studied parameter, where the airtightness showed the greatest reduction of 74% in heating demand. The temperature set point showed an improvement of 50%, as for the windows and the envelope, a reduction respectively of 21% and 24% was achieved.

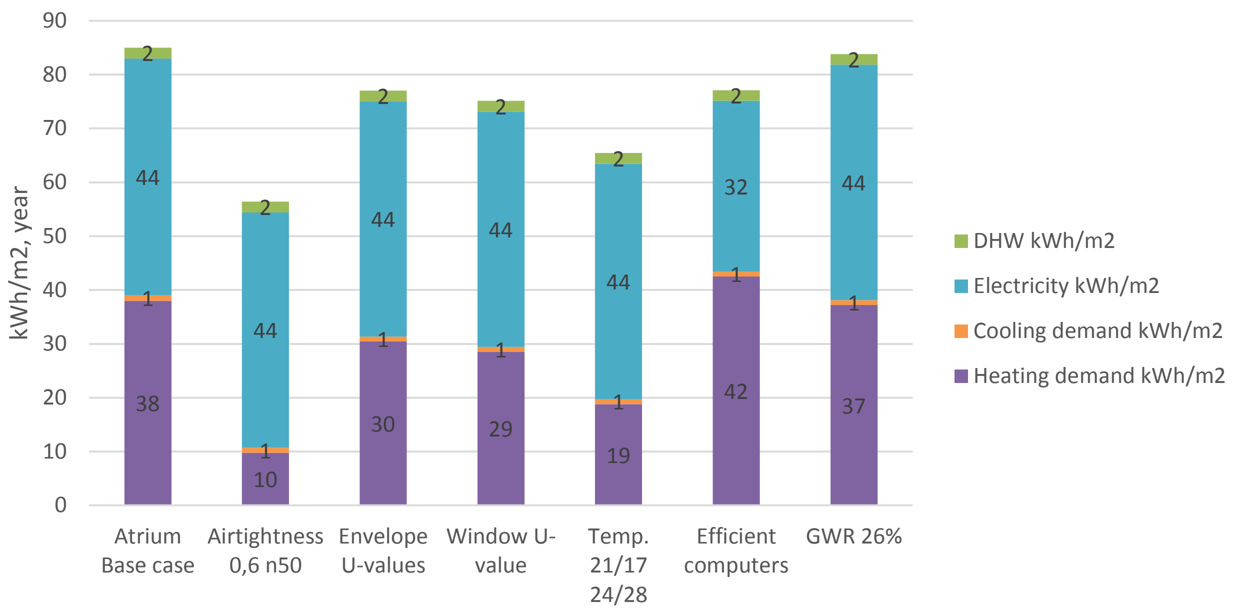


Figure 77 Parametric study results

Best case parametric study

The following figure presents the total energy compares the Atrium case and the Best parametric study case. The Best parametric study case resulted in 71 kWh/m2,year compared to the 105 kWh/m2,year for the Atrium case. This represents a 32% reduction, out of which the heating demand reduced with 61% and the user related electricity with 25%. If the specific energy use is calculated at this stage the end value is 51 kWh/m2, year, which is above than the required 45 kWh/m2, year.

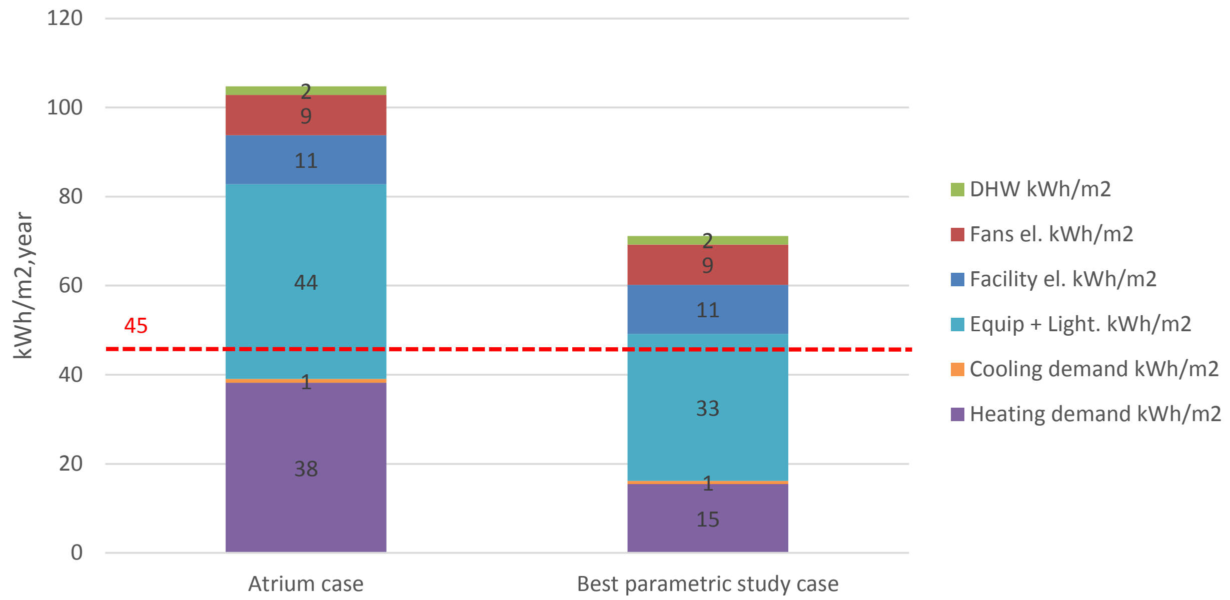


Figure 78 Total end-use energy, Best parametric study case

The peak loads for heating resulted in drastic reduction of 79% and fulfils the VFT_{DVUT} requirement, as for the cooling load it increased with 9% and remains high.

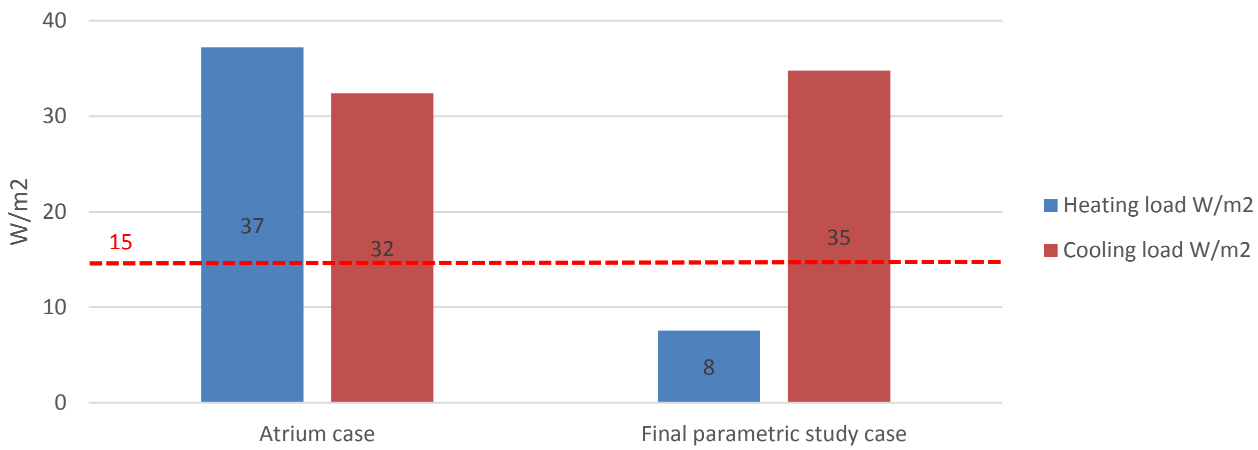


Figure 79 Peak loads, Best parametric study case

3.1.5.3 Lighting

Illuminance level results for the lighting design on the typical office floor are shown below:

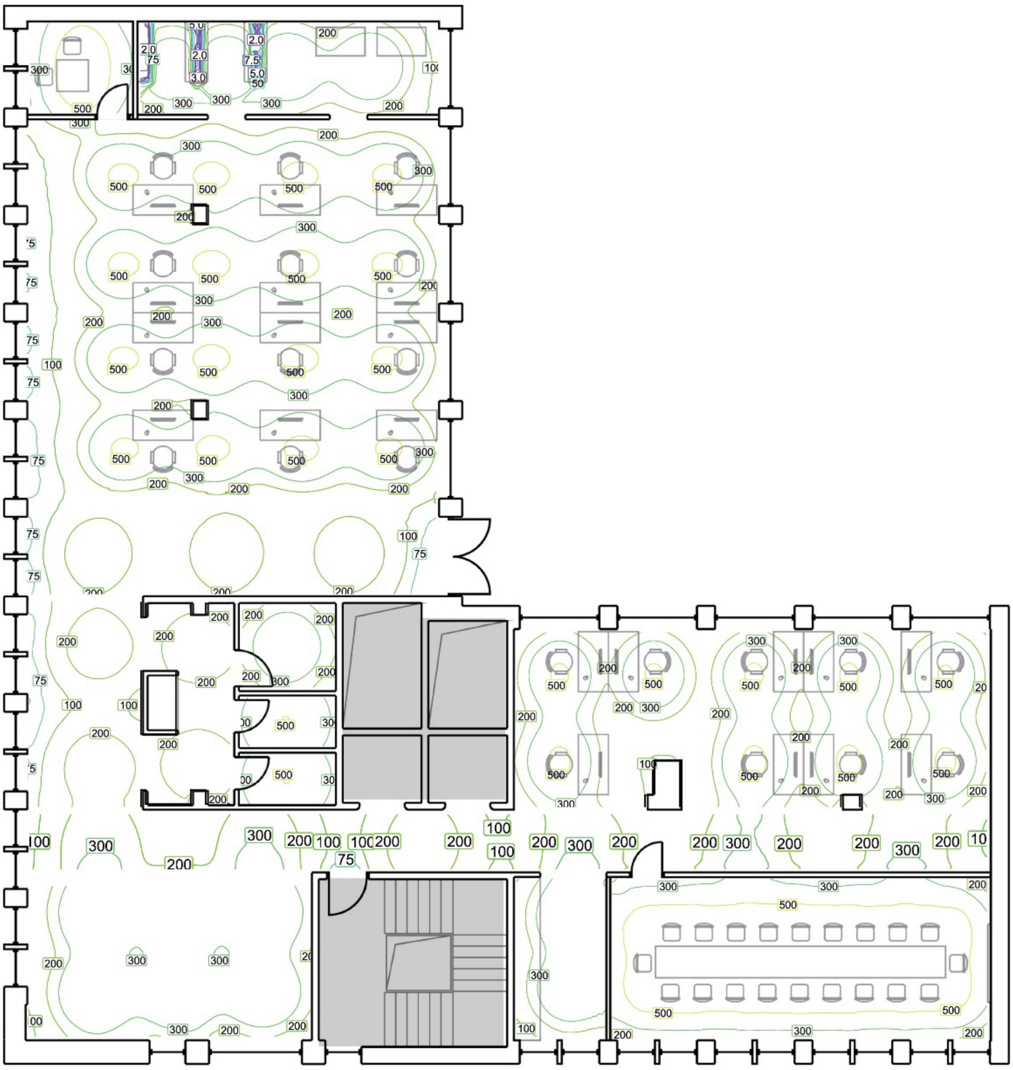


Figure 80: Illuminance level on the typical office floor, DIALux

The number of luminaires used across the analyzed floor area are:

- 41 x Philips BPS640 W21L125 1xLED24/840
- 13 x Sharp DL18D8310W70S4 YUNA LED Downlight - 18 W / 1,000 lm
- 15 x Sharp DL28S8417W70S4 YUNA LED Downlight - 28 W / 1,700 lm

Energy load for ambient lighting are calculated by "DIALux" to be 1536 W and the luminous flux - 111688 lm. Energy load for additional 21 task lighting in the open office area are calculated to be 210W. The total sum of 1746W corresponds to 3.87 W/m2. The energy load of each floors is therefore assumed to be as low as 4W/m2.

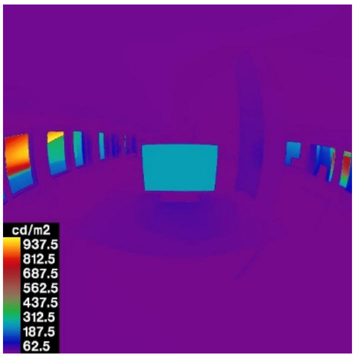
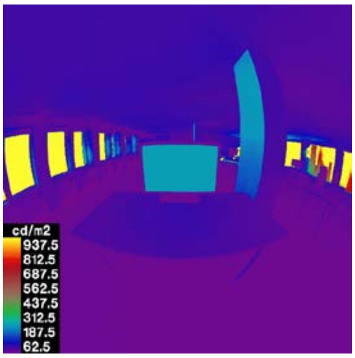
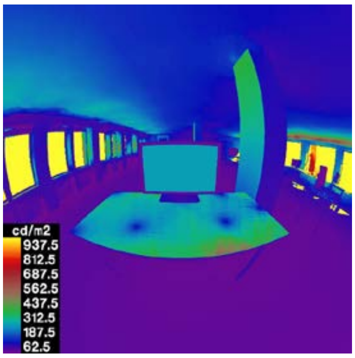
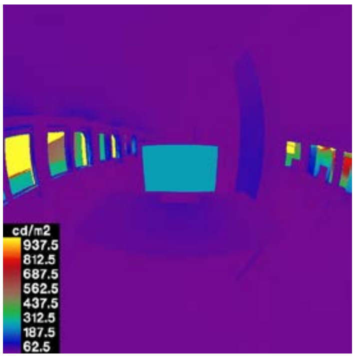
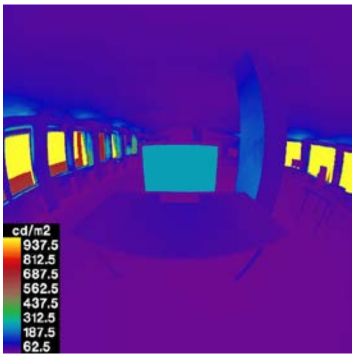
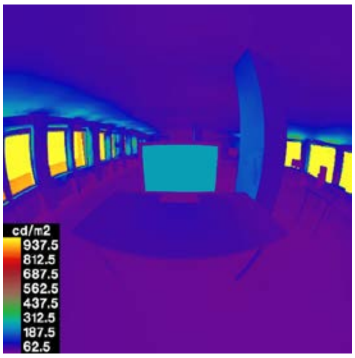
3.1.5.4 Shading

Glare analysis

Open office to the West

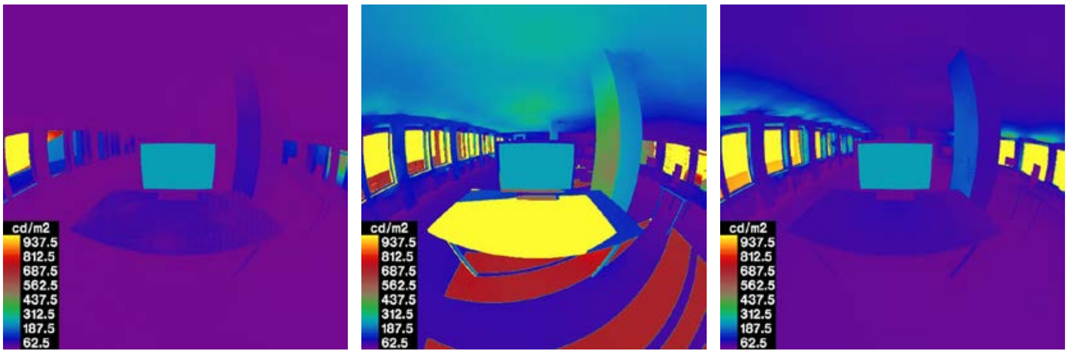
Point in time glare simulations below shows that the glare comfort is very high in the western part of open office. On the other hand, the luminance ratio for the analyzed computer work station exceed the acceptable level of 1:3:10 in the late spring afternoon during spring and autumn, when no electric lighting is considered. It is thought important to notice, that electric lighting was not considered in the simulations, which increases the ratio.

Table 19: Illuminance ratio simulations in the western part of open office, 5th floor, oriented to the West-East, for 4 seasons of the year.

Day time	Winter solstice	Spring / Autumn equinox	Summer solstice
0900			
1200			

1600

*1500
winter



The point in time glare results for most critical situation in spring / autumn equinox at 16:00 are shown on the figure below.

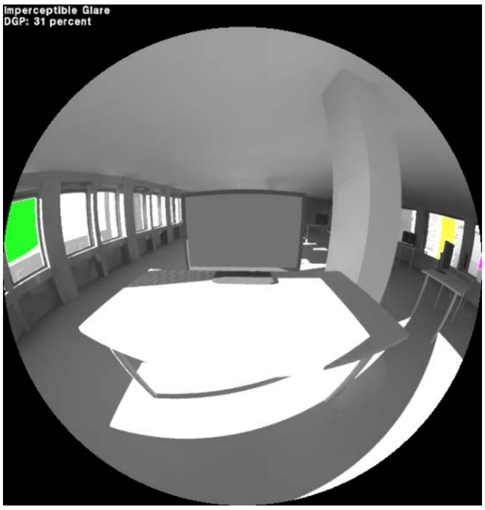


Figure 81: Point in time glare view at 16:00 in spring / autumn equinox

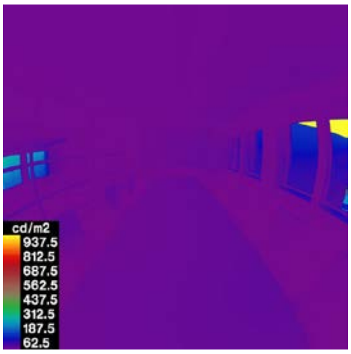
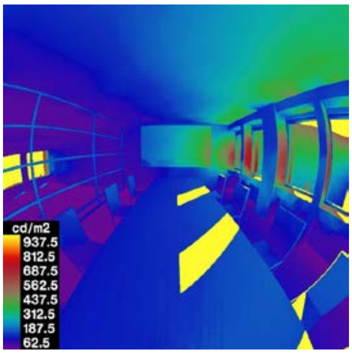
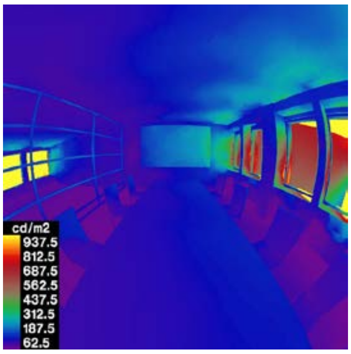
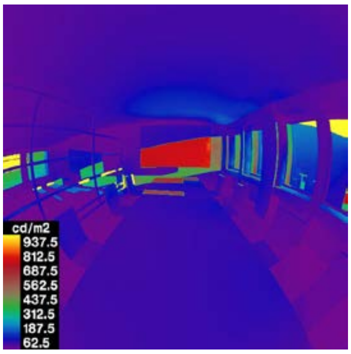
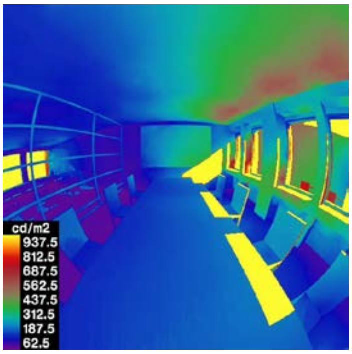
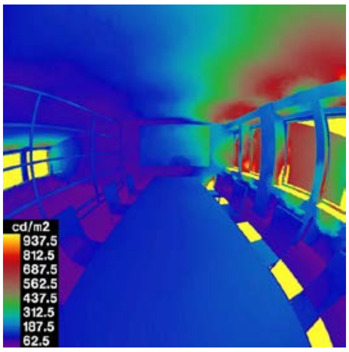
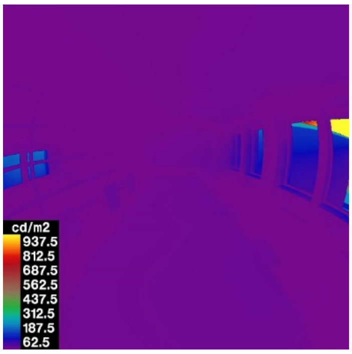
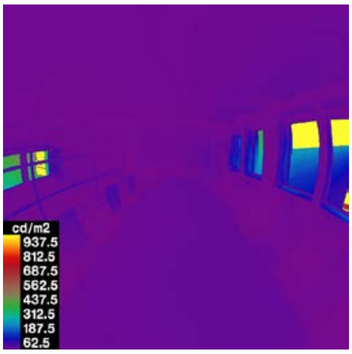
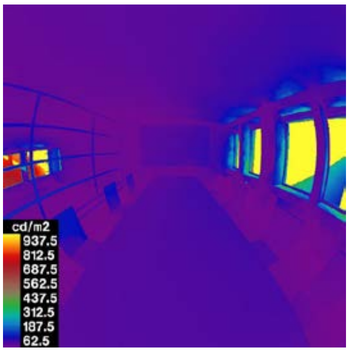
Finally, the annual glare analysis performed for the computer screen within the same computer working base, shows in the diagram below, that daylight glare probability DGP is below the required 0,35 for more than 95% of office time. In other words the actual simulated model of the office achieves the best class A in terms of daylight comfort.

Figure 82, Annual glare schedule for the computer screen in the Western open office, 5th floor.

Conference room to the South

Similarly, the illuminance ratio exceeds the acceptable level of 1:3:10 in spring / autumn morning and at noon. Again, the electric lighting should be considered in the simulations.

Table 20: Illuminance ratio simulations in the conference room, 5th floor, oriented to the South, for 4 seasons of the year.

Day time	Winter solstice	Spring / Autumn equinox	Summer solstice
0900			
1200			
1600 *1500 winter			

The point in time glare results for most critical situation in spring / autumn equinox at 9:00 and in winter solstice at 12:00 are shown below:

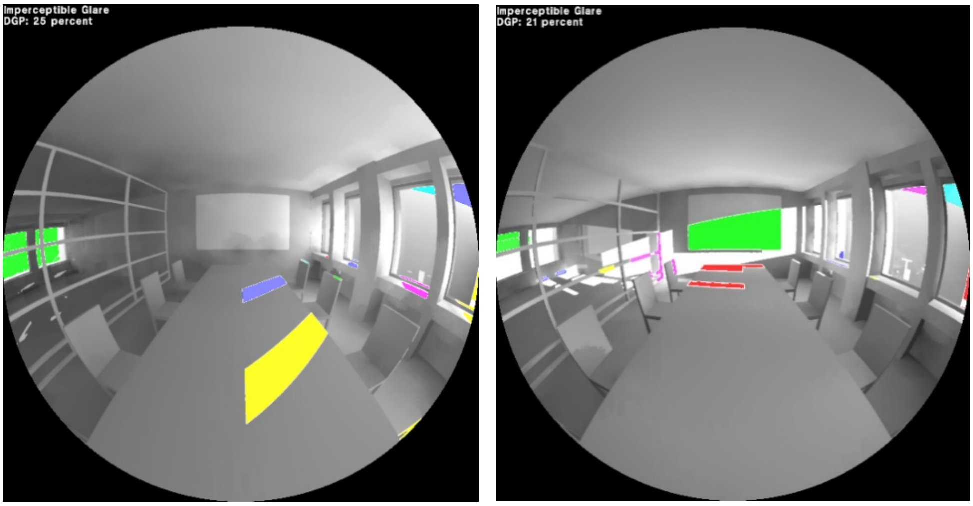


Figure 83, Point in time glare analysis for the critical seasons, 0900 in spring / autumn equinox and 1200 in winter solstice.

As before, the annual glare analysis of the same computer screen, shows daylight glare probability DGP below the required 0,35 for more than 95% of office time. Western open office achieves the best class A in terms of daylight comfort, as well.

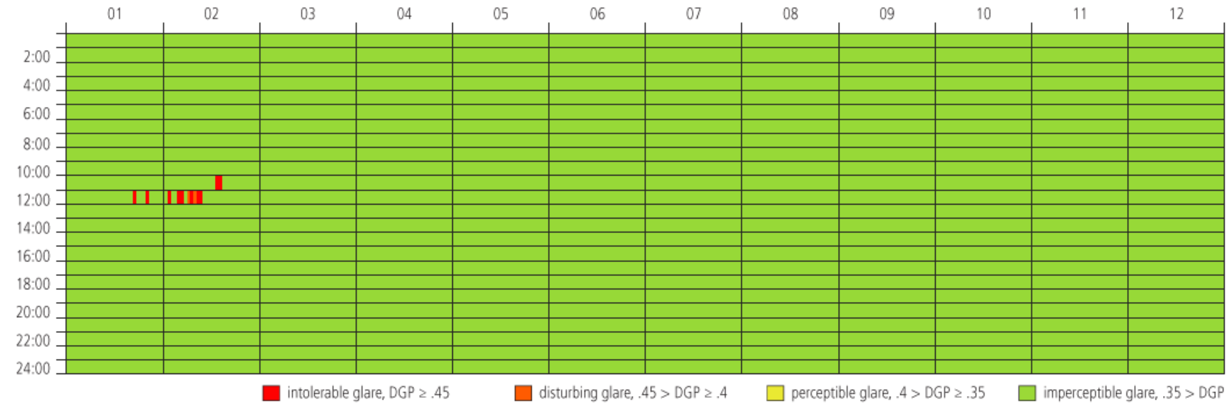


Figure 84, Annual glare analysis for the presentation screen in conference room, 5th floor.

Interior Shading

“Daysim” Simulation Report gained for Conceptual Dynamic Shading shows that the dynamic simple blinds are considered open for 72% of occupied hours. Detailed results of the dynamic simple system blinds controlled by two sensors in the open office to the West, and the conference room to the South, are shown below:

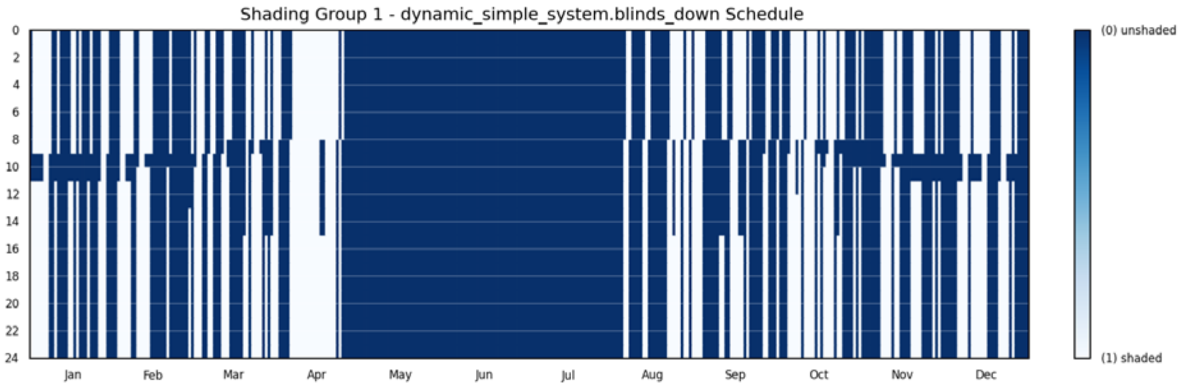


Figure 85: Dynamic system blinds annual schedule for the typical floor, DIVA

Exterior Shading

Preliminary "TeknoSIM" calculations proved that full exterior shading devices is needed on the South and West façade in order to achieve satisfying 20% of PPD results. Rolled screens made of exceptionally transparent ETFE Foil, have been proposed. The reference use of ETFE foil is shown on the reference below:

Figure 86, Reference use of ETFE foil.

A single layer of ETFE has light transmission of 85%, which is not much reduced when adding more layers. ETFE foil g- value varies from 0,35 - 0.45 depending on the number of layers (Architen, 2014). The design of rolled screens is shown below:

Figure 87, Exterior shading design.

3.2 Final case

Final Case in an ultimate design which combine both the concept of an atrium, the best parametric study case and finally, the lighting and shading design.

3.2.1 Daylighting

Average DF and DAcons results for the final show a very high potential for increasing the daylight levels in the building on all the floors comparing with the Base Case. Results prove also that it is possible to achieve high daylight levels not only on the 5th or 6th floor, but also on the ground floor and 1st floor.

Daylight Factor

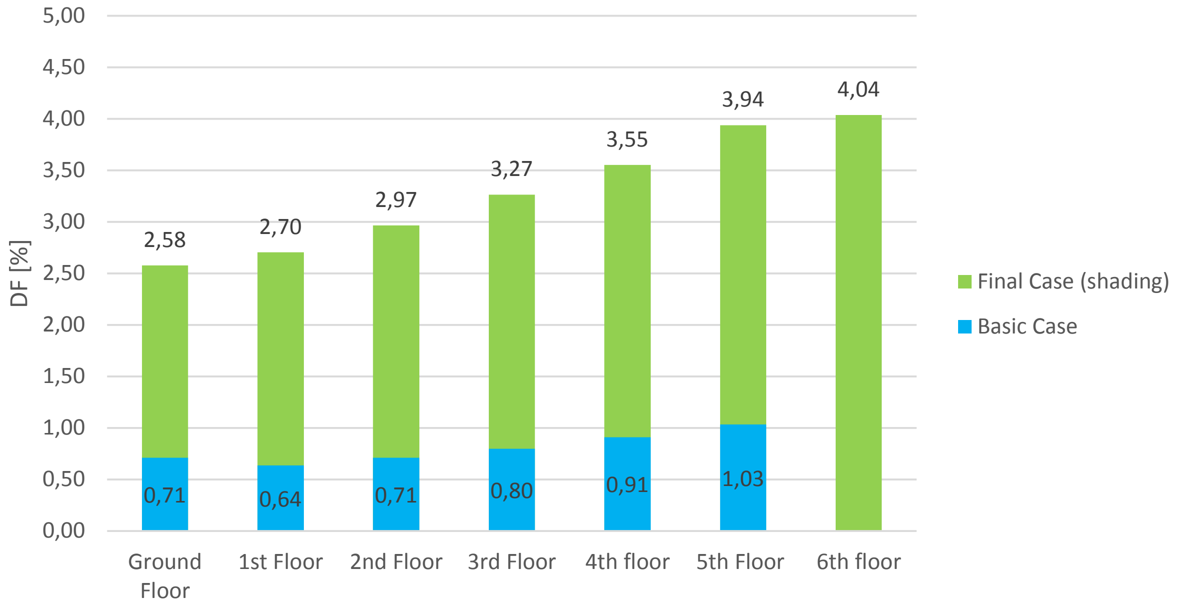


Figure 88, Average DF values for the Final Case

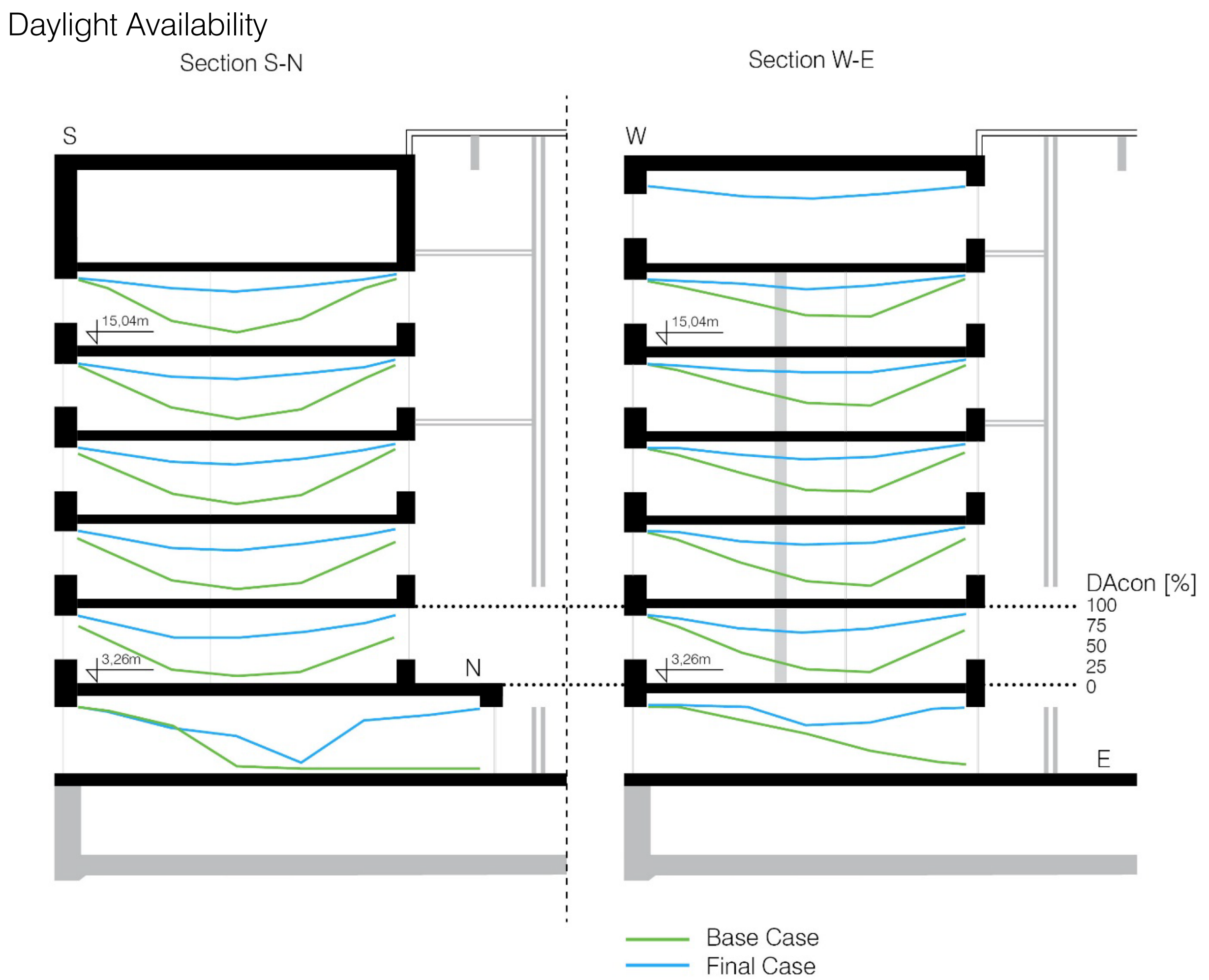


Figure 89, DAcons results for the Final Case.

BREEAM evaluation

As shown on the results of BREEAM evaluation of the first office floor below, new design of BRIO building reaches the exemplary levels of daylight. What is more, the daylight factor plan of the first floor shows the exceptionally even distribution of daylight across the lettable area.

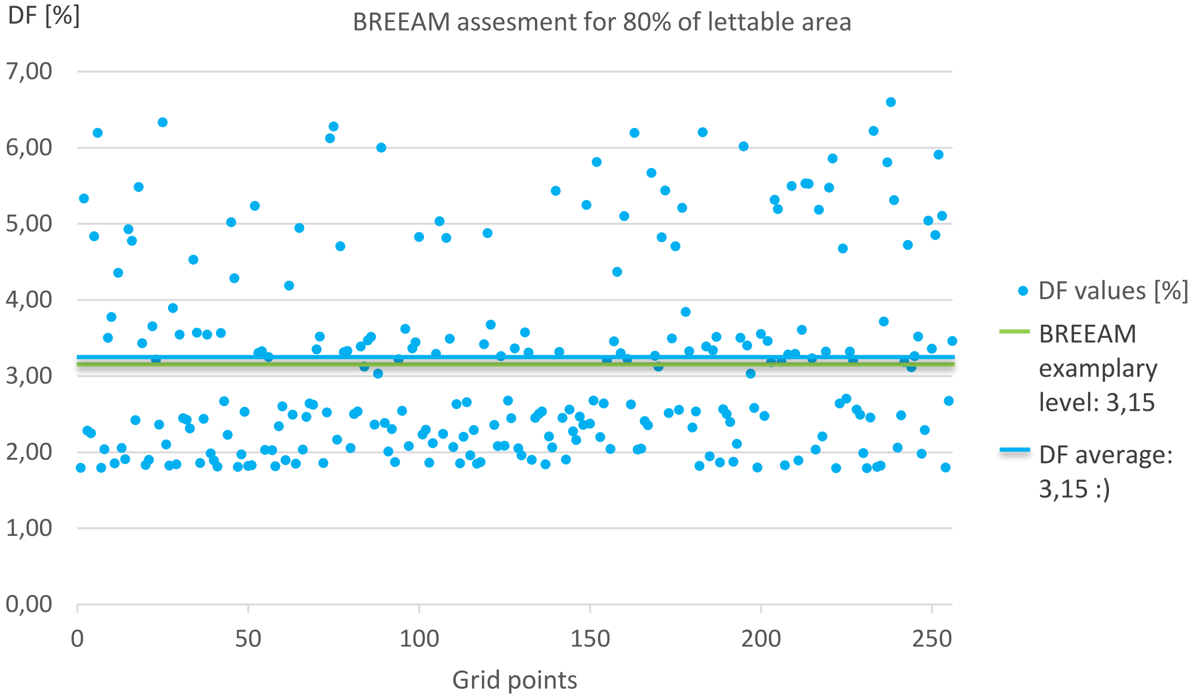


Figure 90, BREEAM exemplary evaluation of 80% of lettable area, measure points.

Figure 91, Average DF distribution on the 1st floor.

3.2.2 Energy use

Steady-state calculation

Calculation the heat loss rate

The refurbished building has a value of $11{,}4\ W/m^2A_{temp}$, which is within the restrictions for passive houses. See Appendix B Final case FEBY 12 for the full hand calculation.

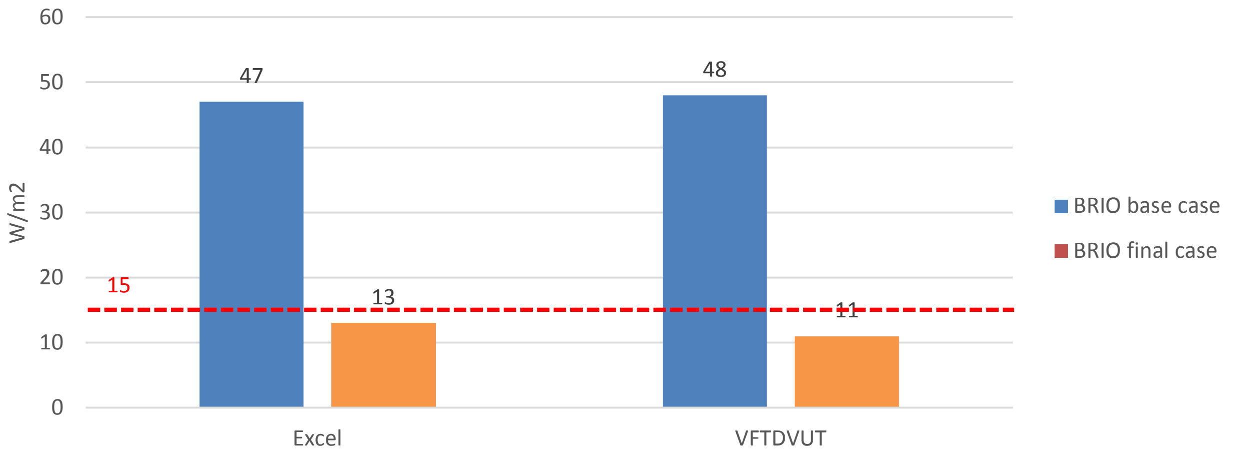


Figure 92 Steady-state calculations, Base case to Final case

Calculation of the delivered yearly energy to the building

The refurbished building has a value of $32\ kWh/m^2A_{temp,}year$, which is within the requirements for passive houses according to FEBY 12. See Appendix B Final case FEBY 12 for the full hand calculation.

$$E_{delivered} = 32\ kWh/m^2A_{temp,}year$$

“DesignBuilder”

The following figure shows the result obtained by adding lighting, shading and heat recovery to reach the Final case result. The reduction in lighting increases the heating demand by 22%, but reduces the user related electricity by 30%.

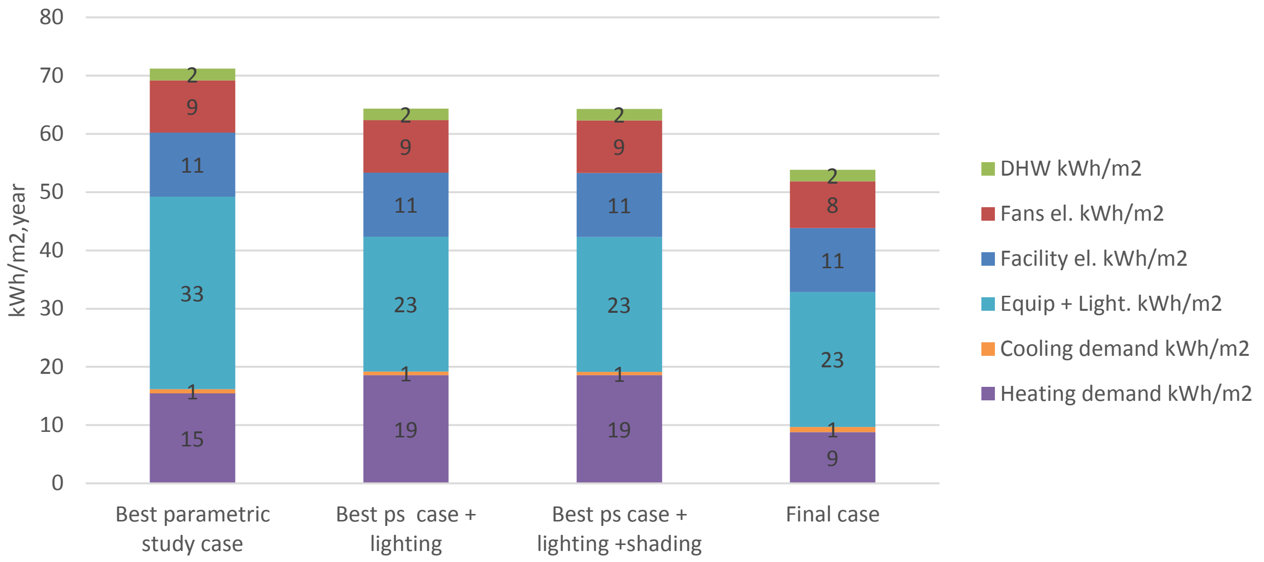


Figure 93 Total end-use energy, Additional parameters

The following diagram shows the Final case of the improved building. The total end-use energy resulted in 54 kWh/m2 year, which is a 53% improvement to the BRIO base case. If the user related electricity is excluded, the specific energy use for the Final case would result in 32 kWh/m2 year, which fulfills the requirements set by FEBY 12 for a Passive house.

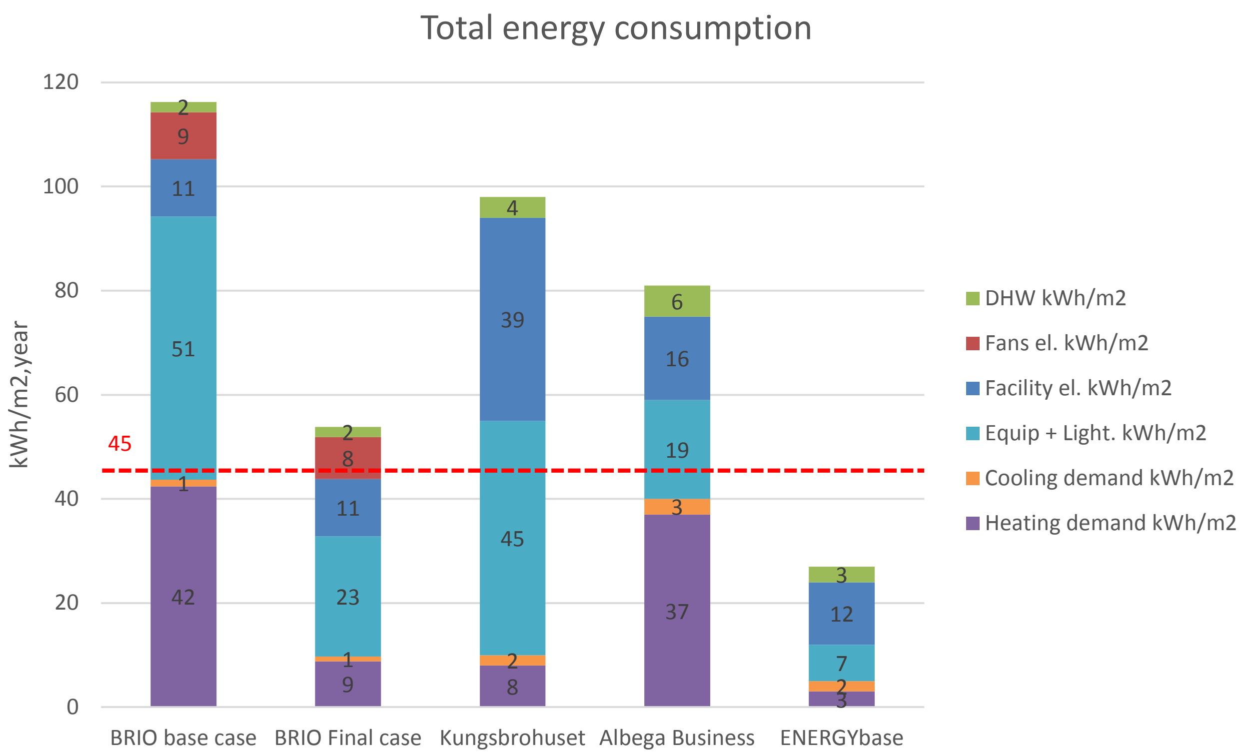


Figure 94 Total end-use energy, Final case

The heating load was improved by 86% compared to the BRIO base case. The heating load of 8 W/m2 achieves the VFT_{DVUT} requirement from FEBY 12 of 15 W/m2. On the other hand, cooling load regardless of its reduction of 24%, remained high.

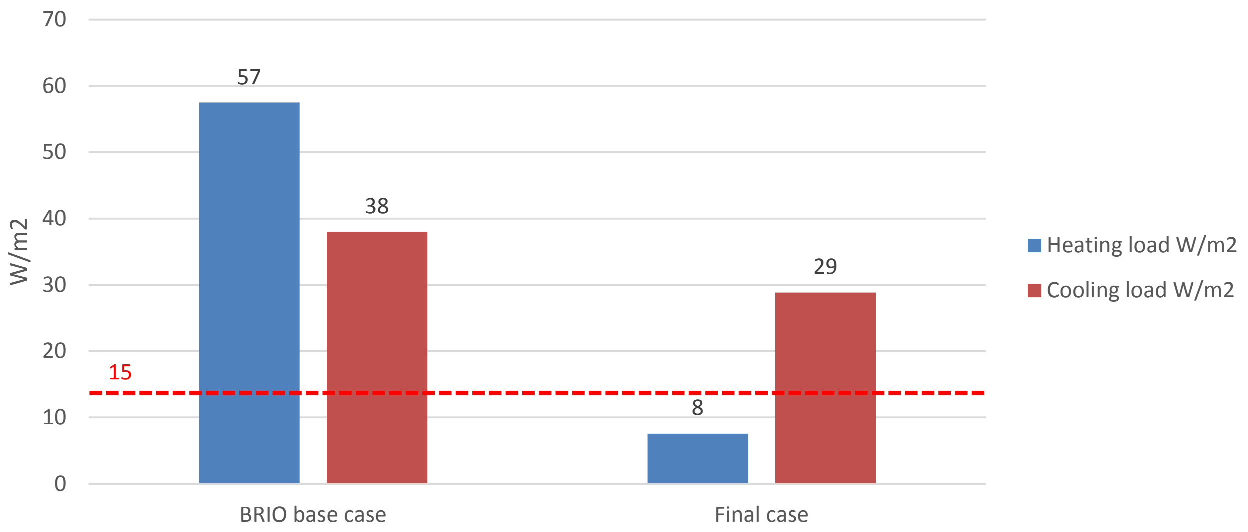


Figure 95 Peak loads, Final case

The following figures show the annual temperature distribution in the Final case. The temperatures rarely reached values under 21°C on all floors. The temperatures are within the range 21-25°C, and no under heating nor overheating were registered.

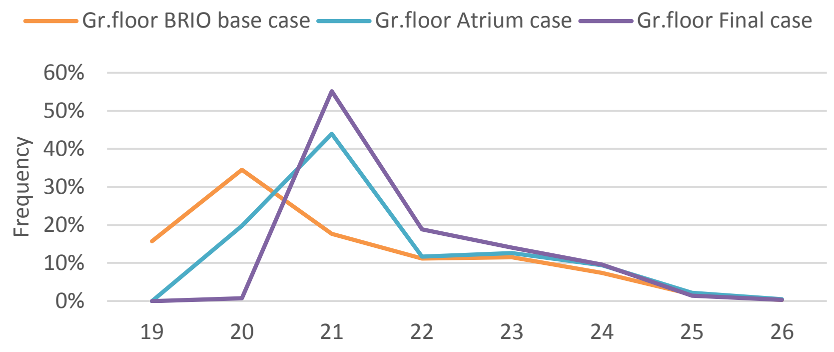


Figure 96 Annual temperature distribution, Ground floor, Final case

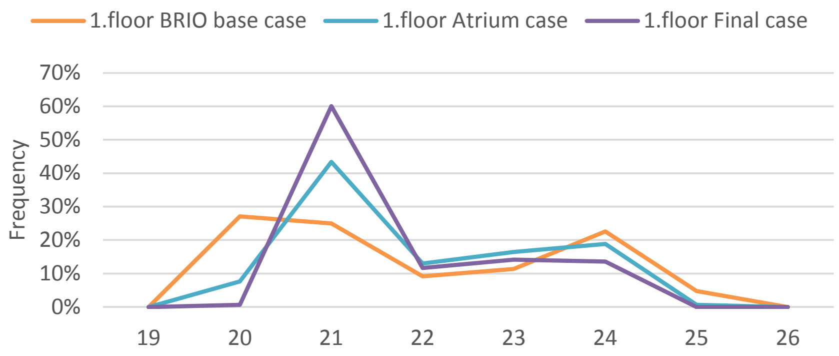


Figure 97 Annual temperature distribution, First floor, Final case

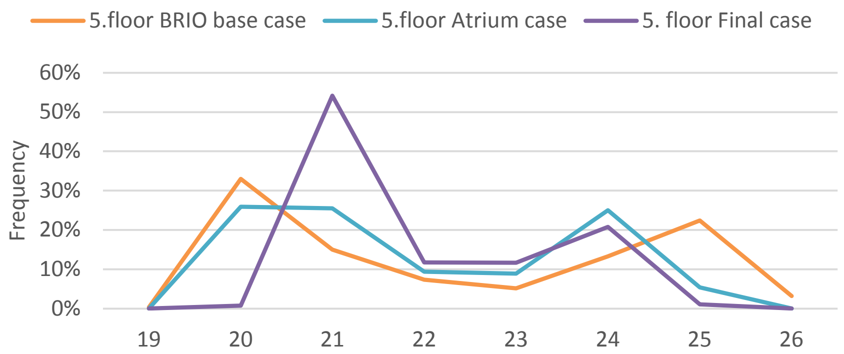


Figure 98 Annual temperature distribution, Fifth floor, Final case

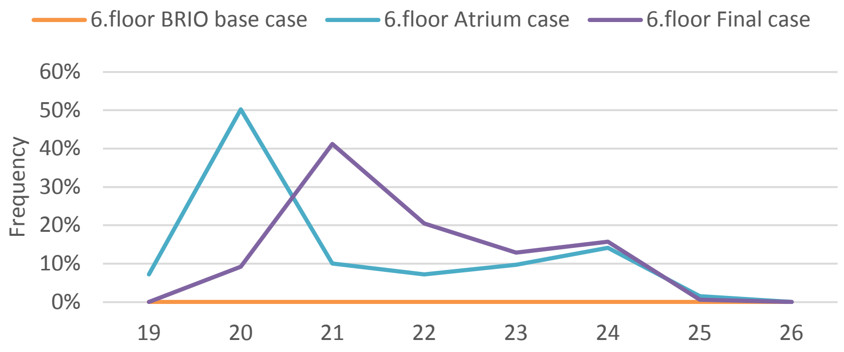


Figure 99 Annual temperature distribution, Fifth floor, Final case

The following figure presents the temperature distribution in the period April – September. All floors registered temperature frequency below 10% of the hours at 25°C, therefore BELOK P25 is fulfilled.

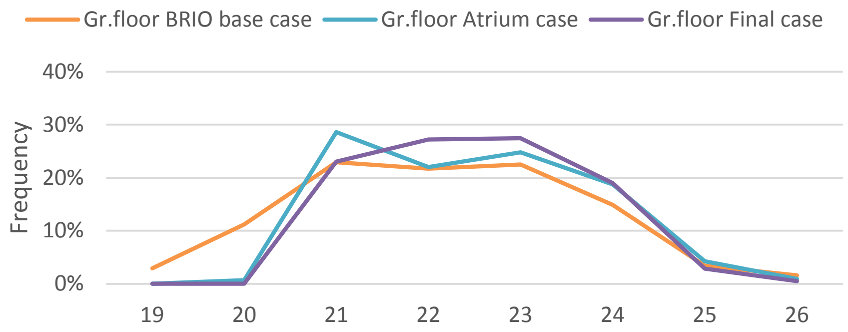


Figure 100 BELOK thermal comfort, Ground floor, Final case

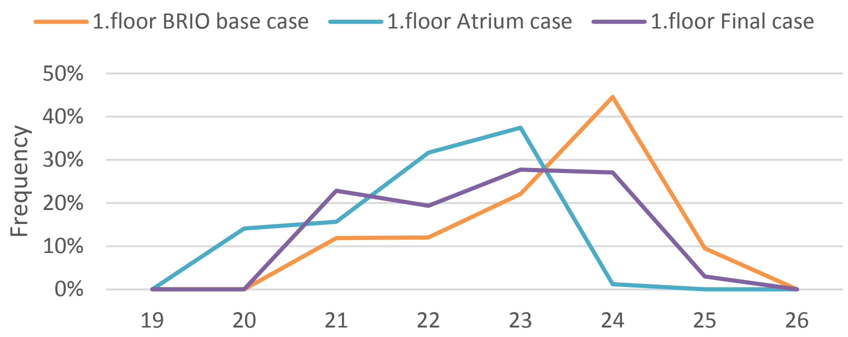


Figure 101 BELOK thermal comfort, First floor, Final case

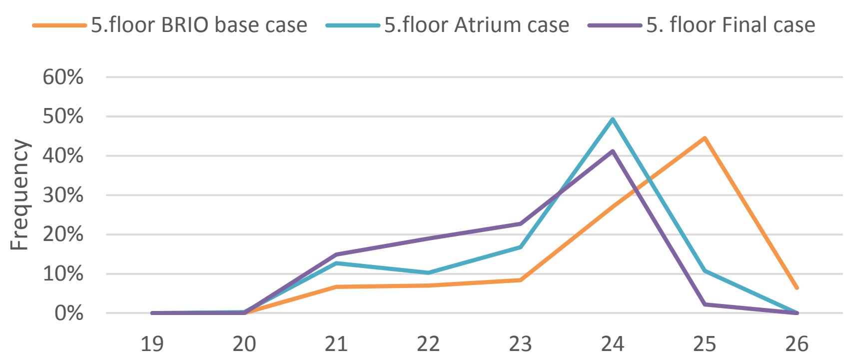


Figure 102 BELOK thermal comfort, Fifth floor, Final case

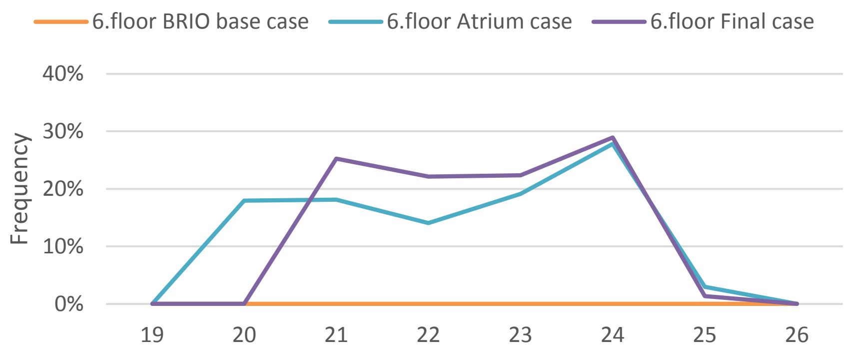
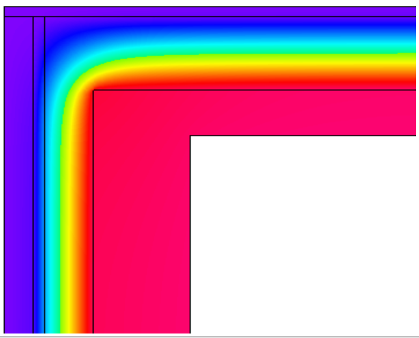


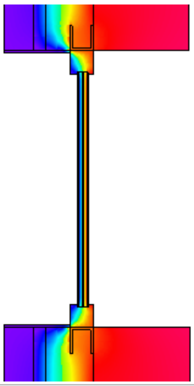
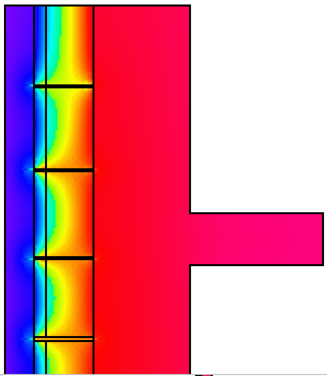
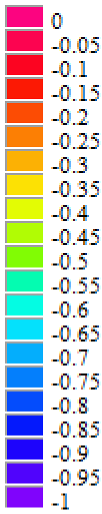
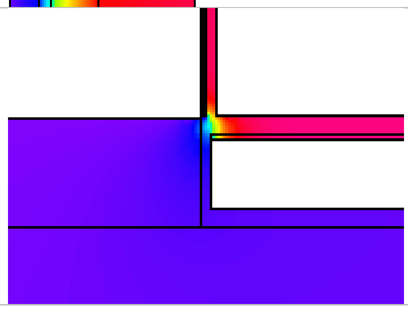
Figure 103 BELOK thermal comfort, Sixth floor, Final case

Analysis of thermal properties for critical construction details

The atrium has a fully glazed roof and due to its complex structure moisture problems has to be avoided. The glazing will have metal framing this structure will lower the risk of moisture problems such as rot. On the other hand the metal construction is not optimal for the thermal properties, therefore the area that is in direct contact with the office building should be as small as possible.

Table1: Results from analysis in HEAT

Construction Part	Coldest temperature, outside [°C]		Coldest temperature inside [°C]	[W/m]	Temp. scale [°C]
Roof – Wall	-13,0		19,7	0,33	

Window – Wall	-13,0		10,8	1,78	
Floor Slab-Wall	-13,0		19,2	0,85	
Ground Slab - Wall	-13,0		10,2	2,31	

3.2.3 Moisture analysis and moisture safety

The analyzed parts of the constructions are the roof and the exterior walls for the new construction.

Exterior wall

It is assumed that the brick will absorb less moisture than in the case of a newly produced brick and what is shown in the analysis. The exterior walls were analyzed for two different cases. One case were the bearing part of the construction, the concrete columns are included and one analysis where the columns are excluded. This is done to represent different parts of the construction. The result of the analysis is presented in the following diagrams.

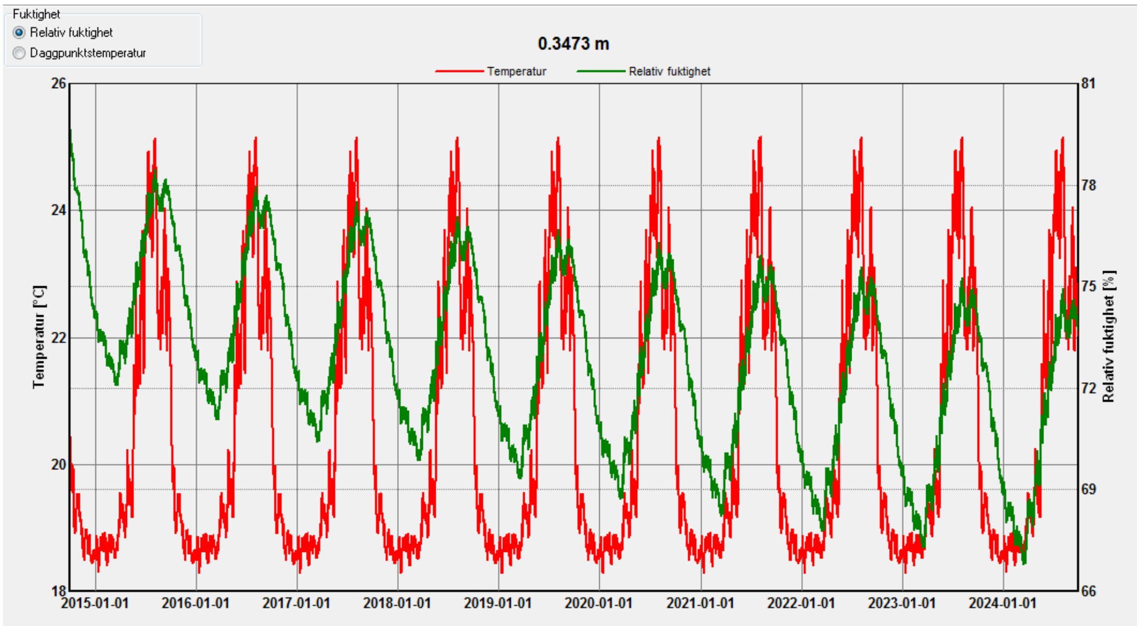


Figure 104: WUFI analysis of exterior wall, with concrete columns of the middle part of cellular plastic

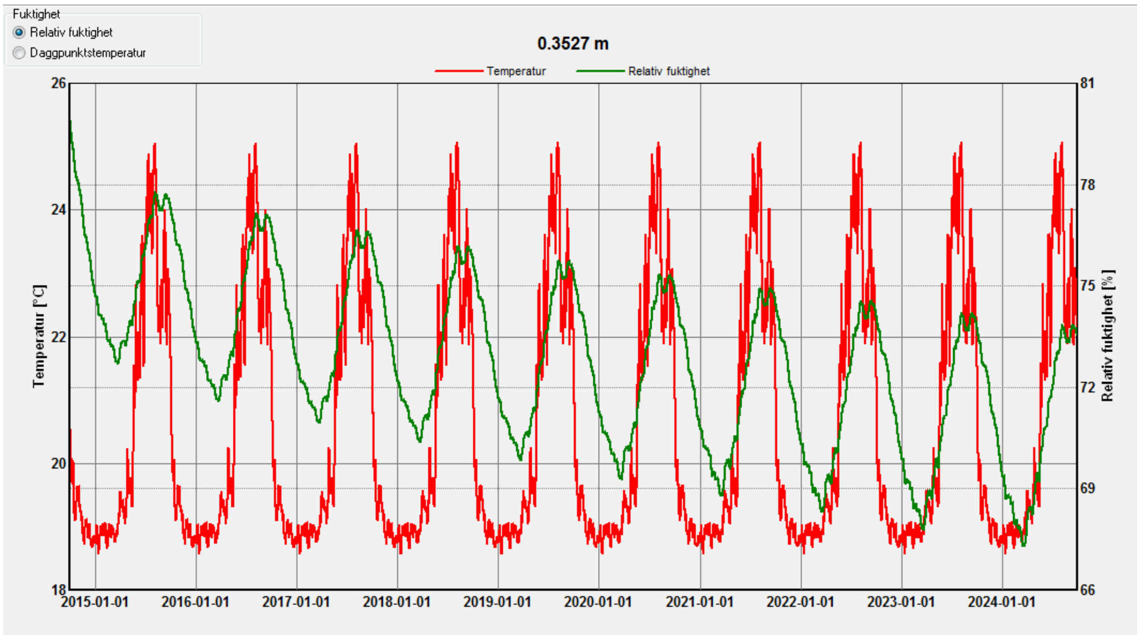


Figure 105: WUFI analysis of exterior wall, with concrete columns in the inner cellular plastic

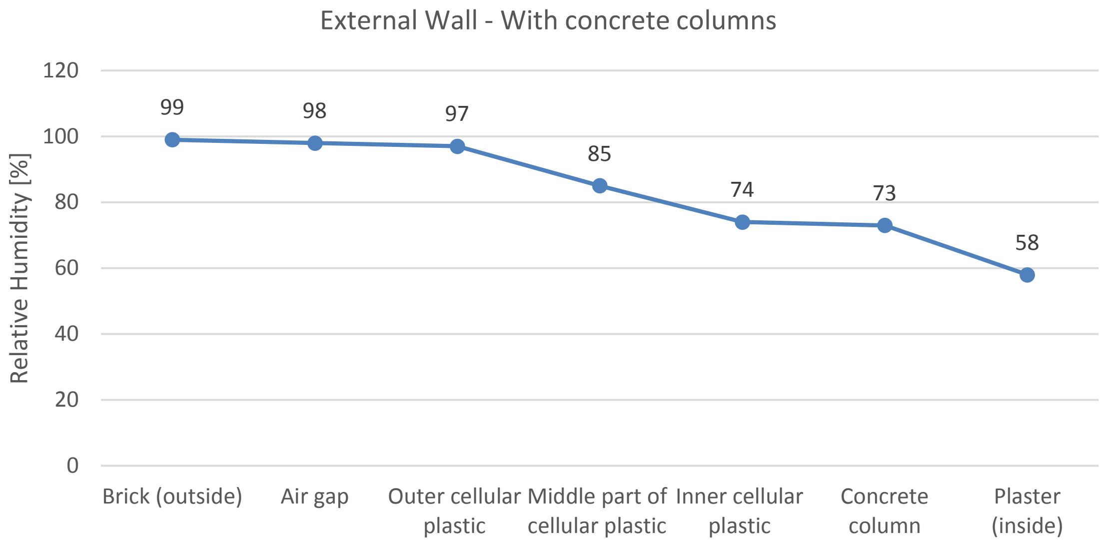


Figure 106: WUFI analysis of exterior wall with concrete columns

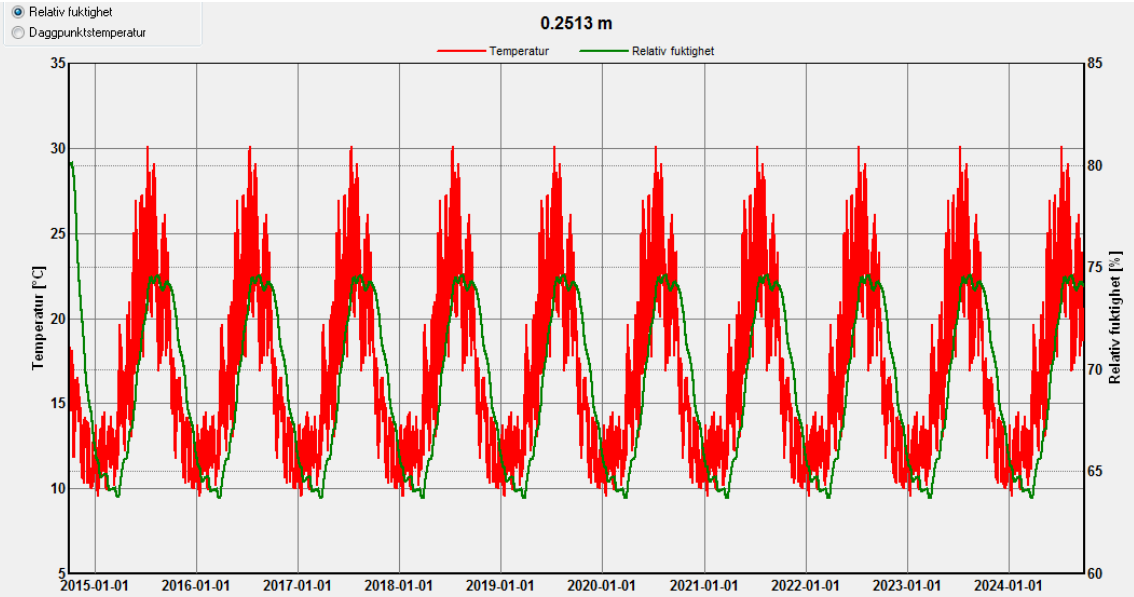


Figure 107: WUFI analysis of exterior wall, without concrete columns of the middle part of cellular plastic

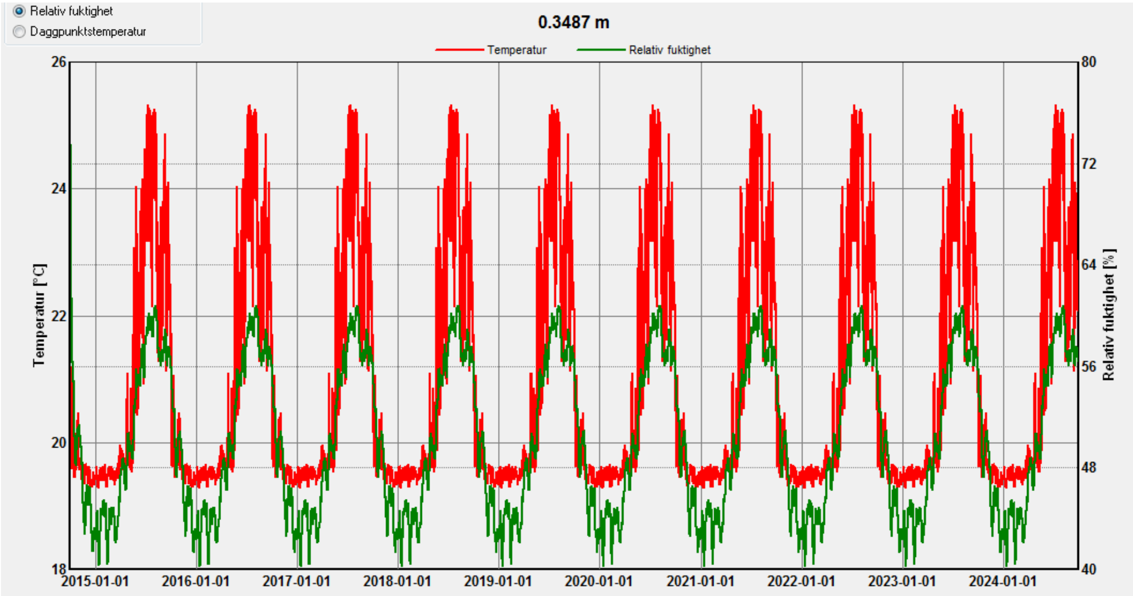


Figure 108: WUFI analysis of exterior wall, without concrete columns in the inner cellular plastic

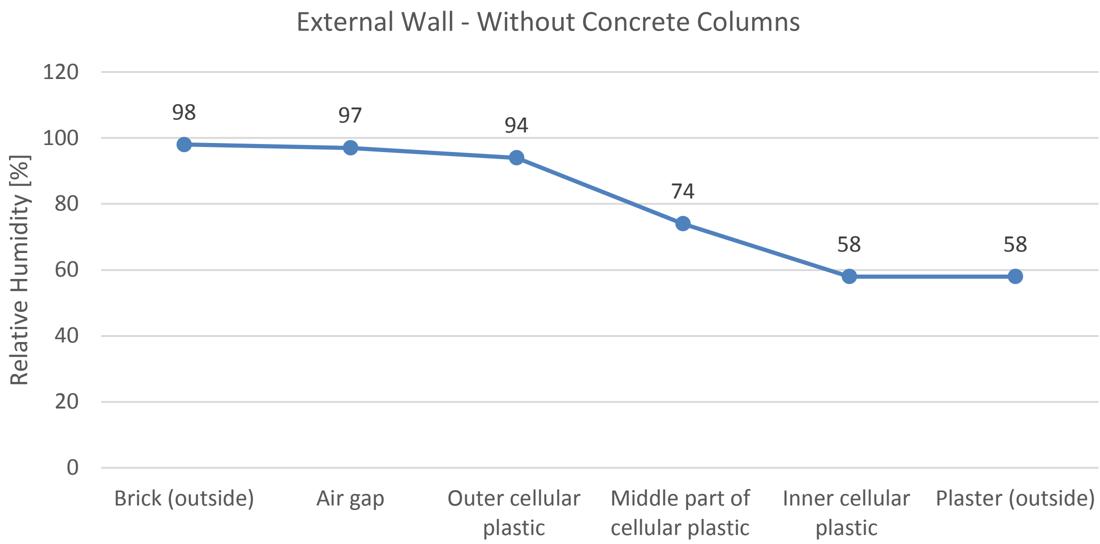


Figure 109: WUFI analysis of exterior wall without concrete columns

If the construction is built with wooden studs, then there will be moisture problems according to the simulation.

Roof

The diagrams from the simulations are shown below, these are done for the in the middle of the insulation and between the insulation layer and the concrete layer.

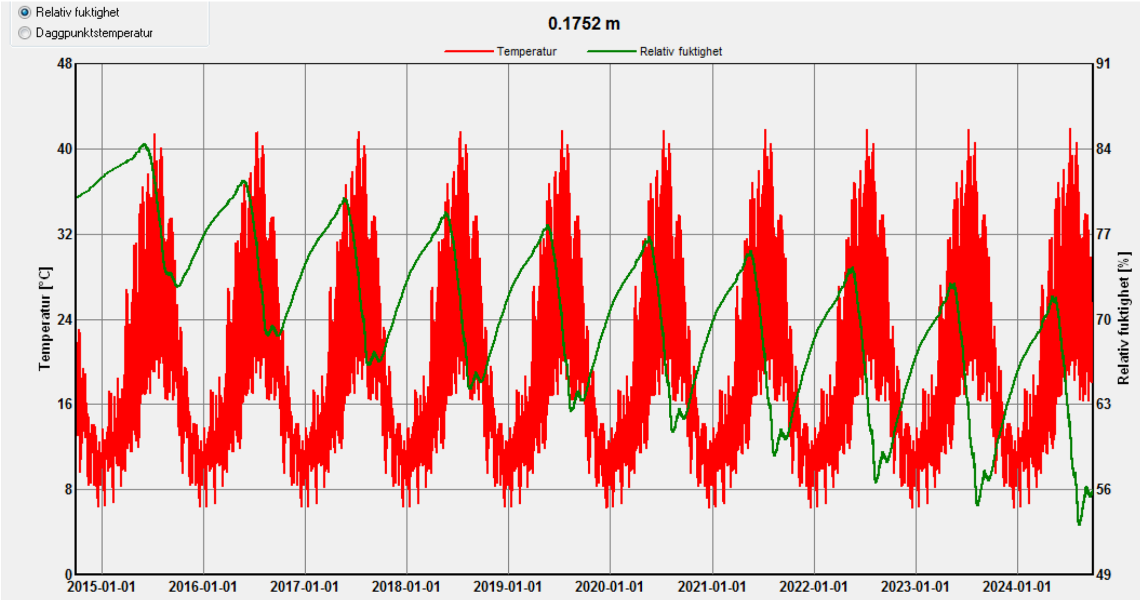


Figure 110: WUFI analysis of the middle layer of the insulation layer

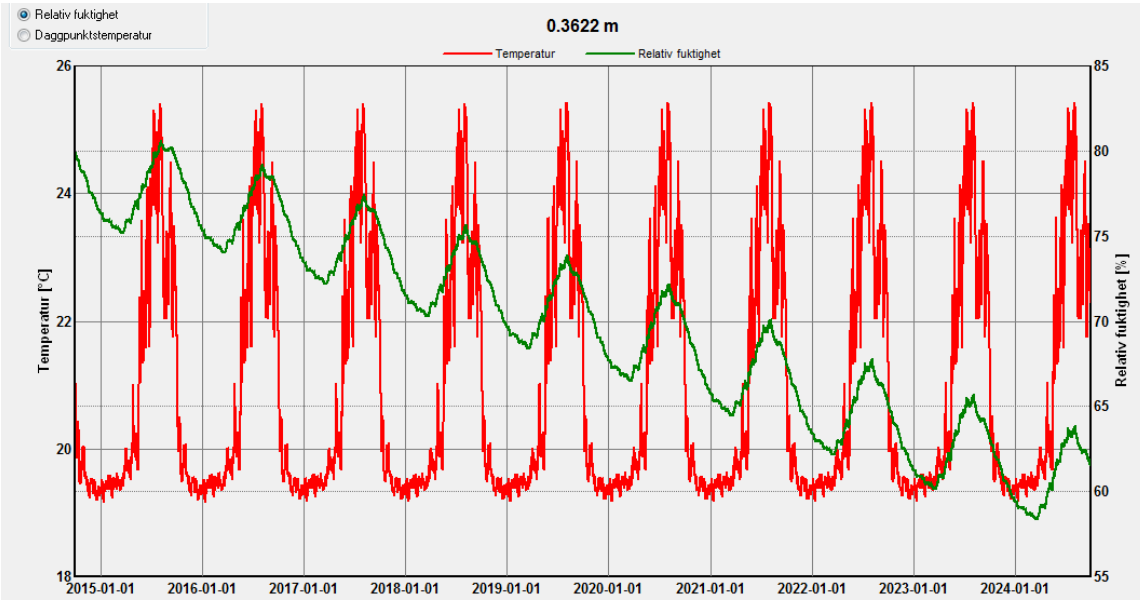


Figure 111: WUFI analysis in-between the middle of the insulation layer

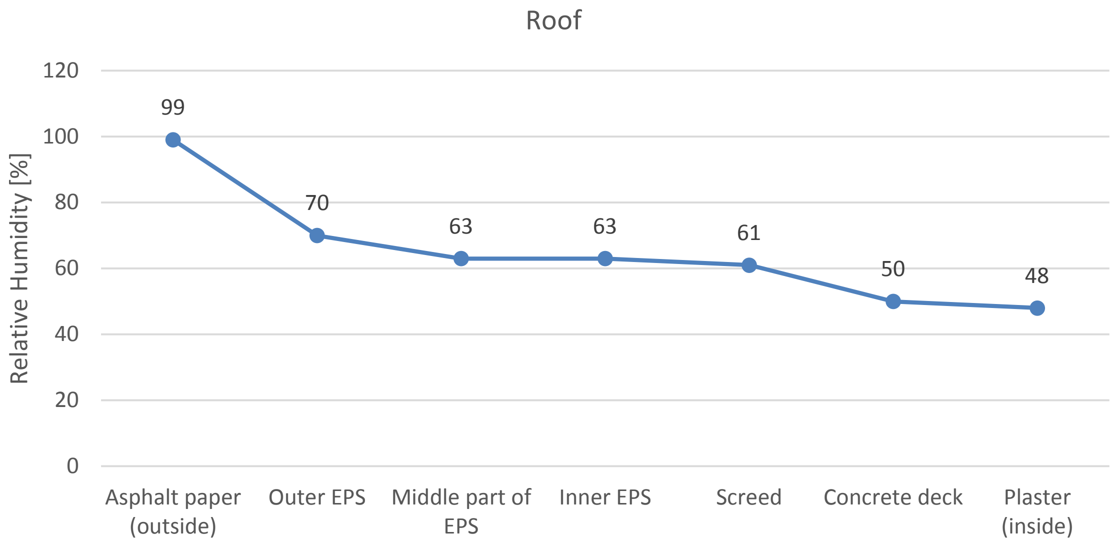


Figure 112: WUFI analysis of the roof

From the simulation of the roof shows that the construction will not have any problems when it comes to the moisture content in the construction.

Risk assessment

In the following text the main points from the risk assessment will be explained. For the complete risk assessment, see Appendix D.

The refurbishment of the buildings

To lower the risk of moisture inside the building, a tent that covers the parts that are sensitive to moisture should be used. Since the refurbished external wall is constructed without any moisture sensitive materials there should not be any risk of moisture problems. The construction should, however, prevent moisture storage and therefore there should be a drainage plate in the connections with other components.

When the brick is mounted to the building, extra precaution should be taken so that the mortar will not fall down in the air gap. It is also important that the building damp from the mortar can dry out from the building. In that case there should be no coverage like wall paper or other wall cover should be put on the wall.

Process for how to refurbish brick wall

This is one of the most critical phases during the refurbishment because of the risk of moisture problems. During this phase the brick with its supporting structure and insulation beneath will be taken down, which will expose the whole building. The process for this will be done by a step by step approach, where every step has to be carried out with extra precaution. The strategy will be to take down the brick as carefully as possible so that it could be reused for the improved wall. To be able to do this, the bricks has to be cleaned from the mortar and then stored in the meantime, this has to be done in a moisture safe storage. The advantage of this is that since the brick already has been used once, there will be less moisture absorption in the brick. The new construction are out of steel studs, which will make the wall moisture safe and also the insulation will be changed to one with better properties that will retain less moisture.

Gutters

One of the main critical areas in the construction is how the rainwater is going to be taken care of. The building has a complex roof construction, where the atrium is connected to the main building. To be able to fit the downpipe on the inside of the atrium and to lower the risk of thermal bridging, the building will have a gap between the atrium and the office building. This will also allow the gutters to go in a straight line which will reduce the risk of leakages in the piping. To secure that there will not be any moisture problems there has to be gutters along the whole roof-base. The connection between the bituminous paper has to be attached to the gutters so that no water or moisture can infiltrate from this connection. See appendix C for construction details of the roof.

3.3 HVAC

3.3.1 Mechanical ventilation system division

The air-conditioned system was divided into three separate working system. AHU1 takes up all the room required cooling treatment in standard floor plus the reception area on the ground floor, and AHU2 takes charge of conference room and its lobby on the top floor. AHU3 (not included in the design because of lack of information on internal heat gains etc.) takes care of the restaurant on ground floor. Systematic section for the two designed system with air flow rate and the main duct dimension is shown in Figure 43.

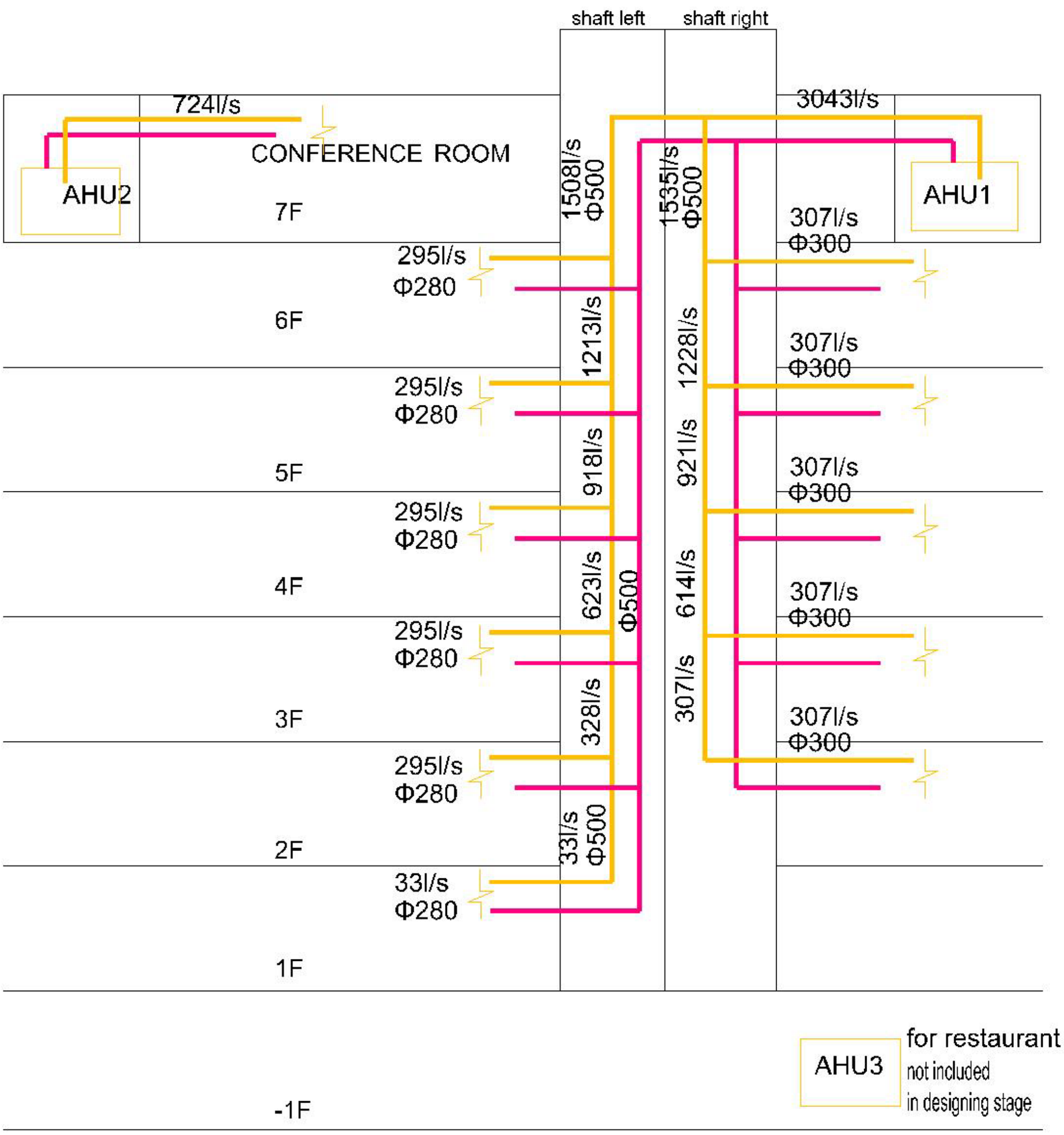


Figure 113 Systematic section for ventilation system

3.3.2 Air Flows

Preliminary study shows the room require lesser supply air with automatically controlled screen on. So screen are implemented in the new BRIO building as shading device. Comparisons among three shading devices are shown in Table below.

Table 21 shading device comparisons

	Screen		Window awning		Projections over the window	
	Operative temperature ℃	dissatisfied percentage %	Operative temperature ℃	dissatisfied percentage %	Operative temperature ℃	dissatisfied percentage %
Opening office	25.8	0	26	0.8	28.1	7.8
Conference room	27.4	5.4	28.3	12.4	29.8	22.8

Table 22 Required airflow rate

		Supply Airflow (l/s)	Minimum supply flow (l/s)	Maximum operative temperature(℃)	Dissatisfied percentage (%)
Ground floor	lobby	33	33	26.7	2.8
Standard floor (from 2rd to 6th)	Western office	135	135	25.8	0
	Copying room	7	7	27.5	9.6
	Rest room / office	18	18	26.7	0.6
	Flexible area (West)	135	108	27.2	9.8
	Northern office	94	94	24.9	0
	Southern conference	195	158	27.4	5.4
	Rest room / conference	18	18	25.7	3.1
Total Air flow for standard floor		602			
Top floor	Conference room	584	466	26.9	8.3
	lobby	140	99	26.9	6.2
Supply air floor for AHU 1		= airflow for standard floor+ lobby on ground floor =5*602+33= 3043 l/s			
Supply air floor for AHU 2		= supply air flow for top floor = 724 l/s			

In order to achieve positive pressure in air-conditioned area, the ratio of supply to exhaust air flow for each room was 1.2.

3.3.3 Selection of diffusers

The diffuser selection for West-facade opening office on standard floor and conference room on top floor were explained below to show the method.

For the West-faced opening office

Supply device type Eagle Ca 125-400-4v+ALSd 100-125, 8 of which were placed uniformly under ceiling. Exhaust device were chosen from Eagle Fc 160-F, 4 all together. The pressure drop through the supply diffuser is 12/32/82Pa, fully opened, half opened and almost closed respectively.

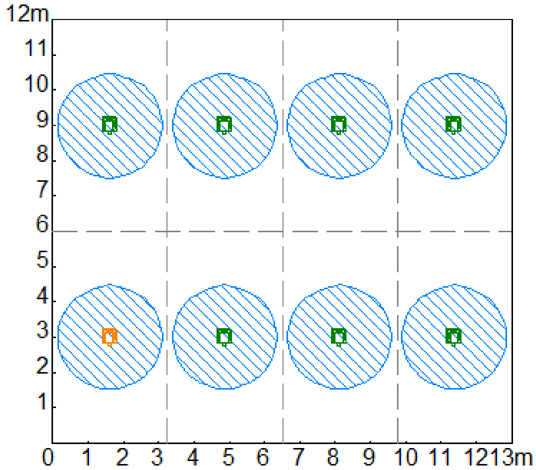


Figure 114 Plan view of throw, summer case

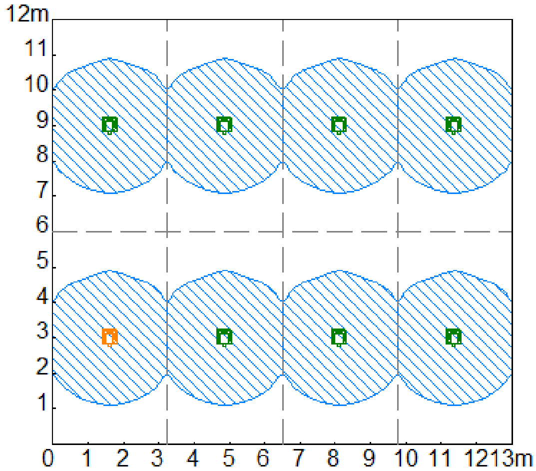


Figure 115 Plan view of throw, winter case

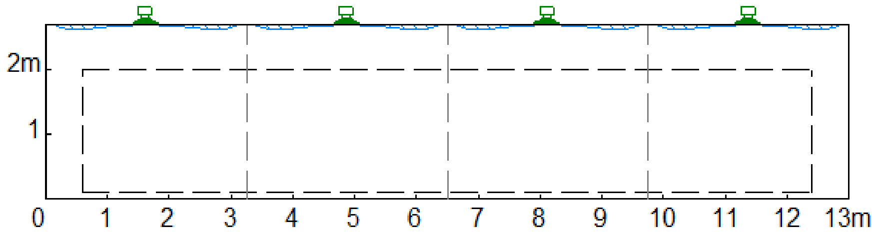


Figure 116 Section view of throw, summer case

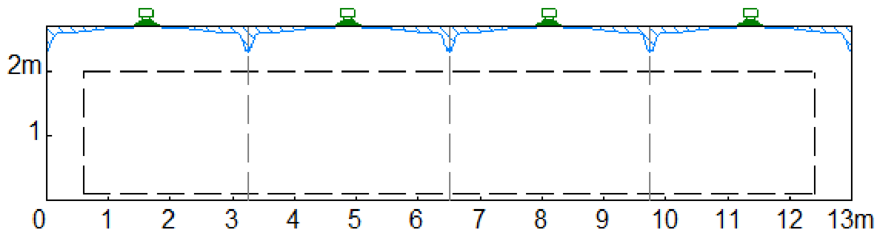


Figure 117 Section view of throw, winter case

For conference room on top floor

Supply device type Eagle Ca L-250-600-RO+ALSd L-200-250, 9 of which were laid uniformly in ceiling. Exhaust device were chosen from ALGc 500-200-F+TRGc 500-200-315-B, 3 all together mounted in the upper height of side wall. The pressure drop through the supply diffuser is 8/20/60Pa, at state of fully open, half opening and almost closed respectively. Plan and section view for the air throw were shown for both summer and winter case in below.

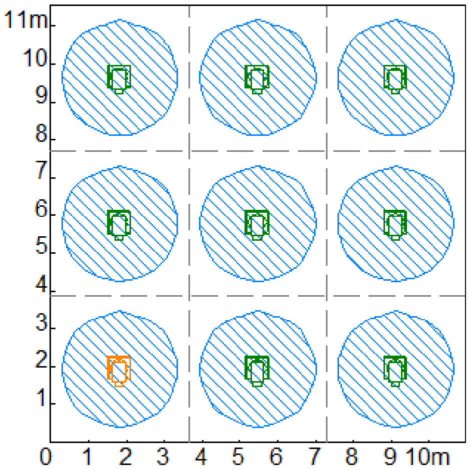


Figure 118 Plan view of throw, summer case

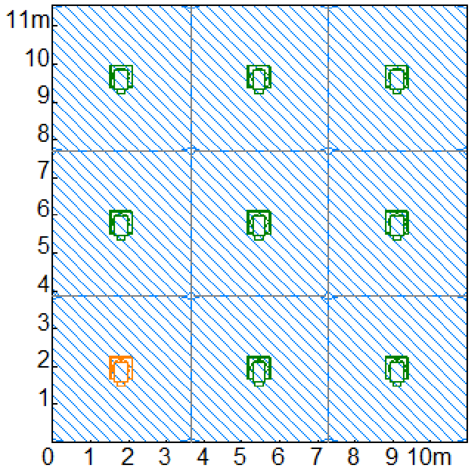


Figure 119Plan view of throw, winter case

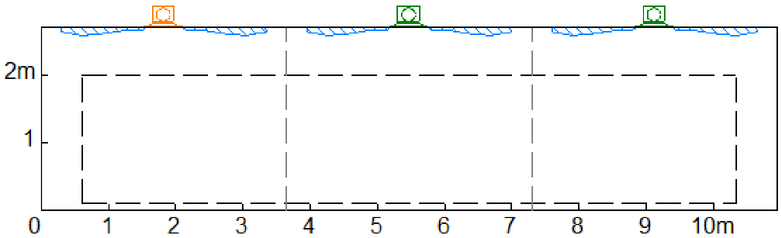


Figure 120 Section view of throw, summer case

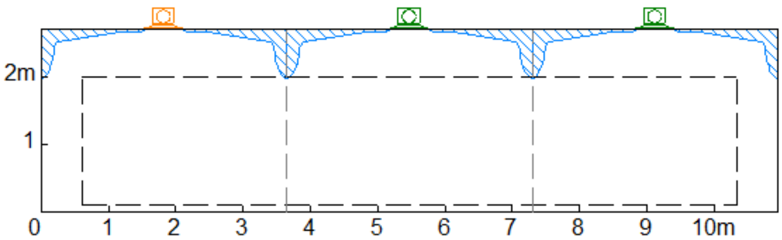


Figure 121 Section view of throw, winter case

All the supply and exhaust devices and its number selected for the air-conditioned room and its selected commissioning airflow are listed in appendix H. Exhaust devices located in opening offices extract air from opening office as well as its adjacent sepearte room.

3.3.4 Layouts and sizing of ductworks

Ductworks layouts with airflow rate for standard floor and top floor are relatively shown in below.

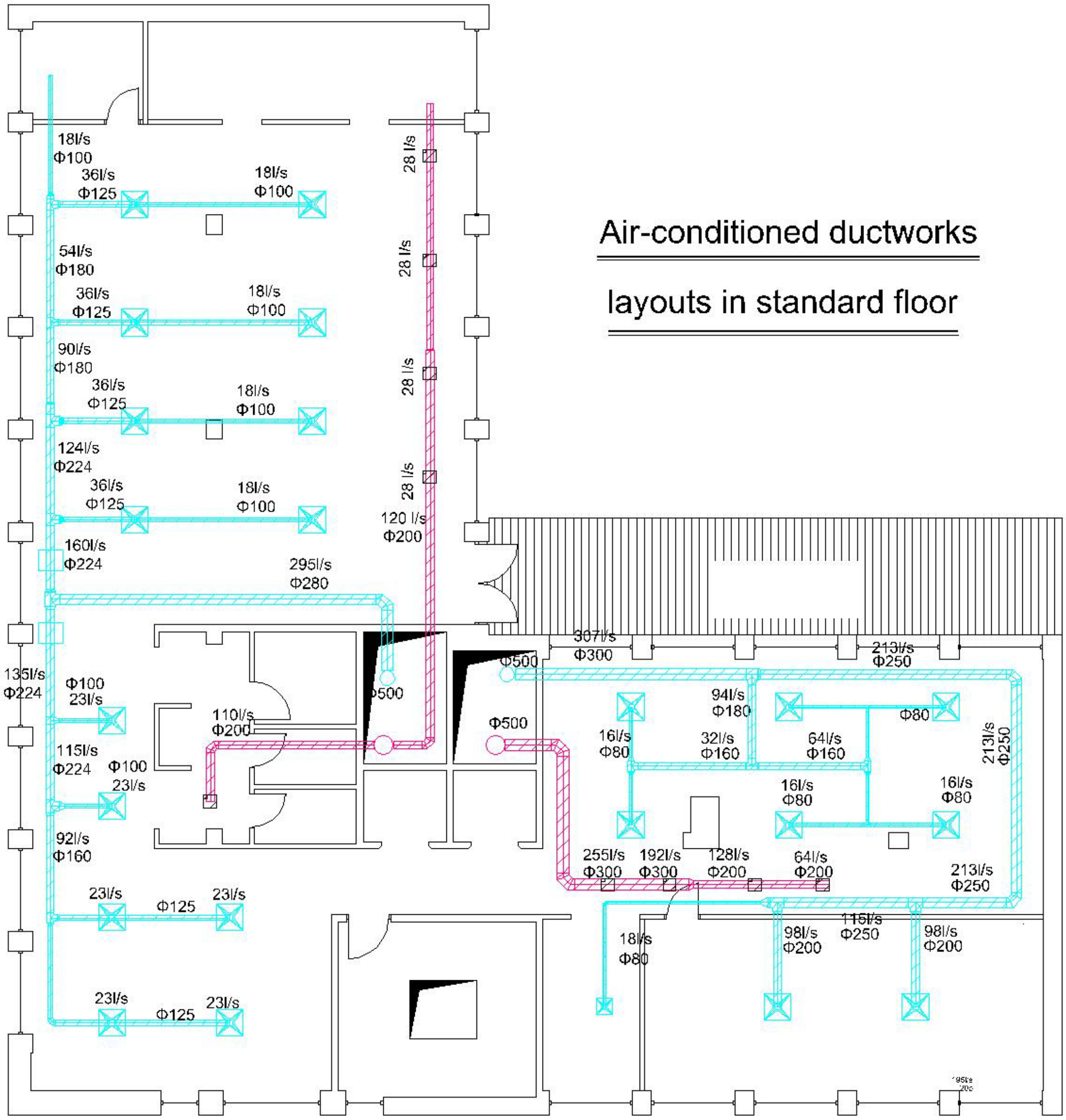


Figure 122 ductwork layout, standard floor

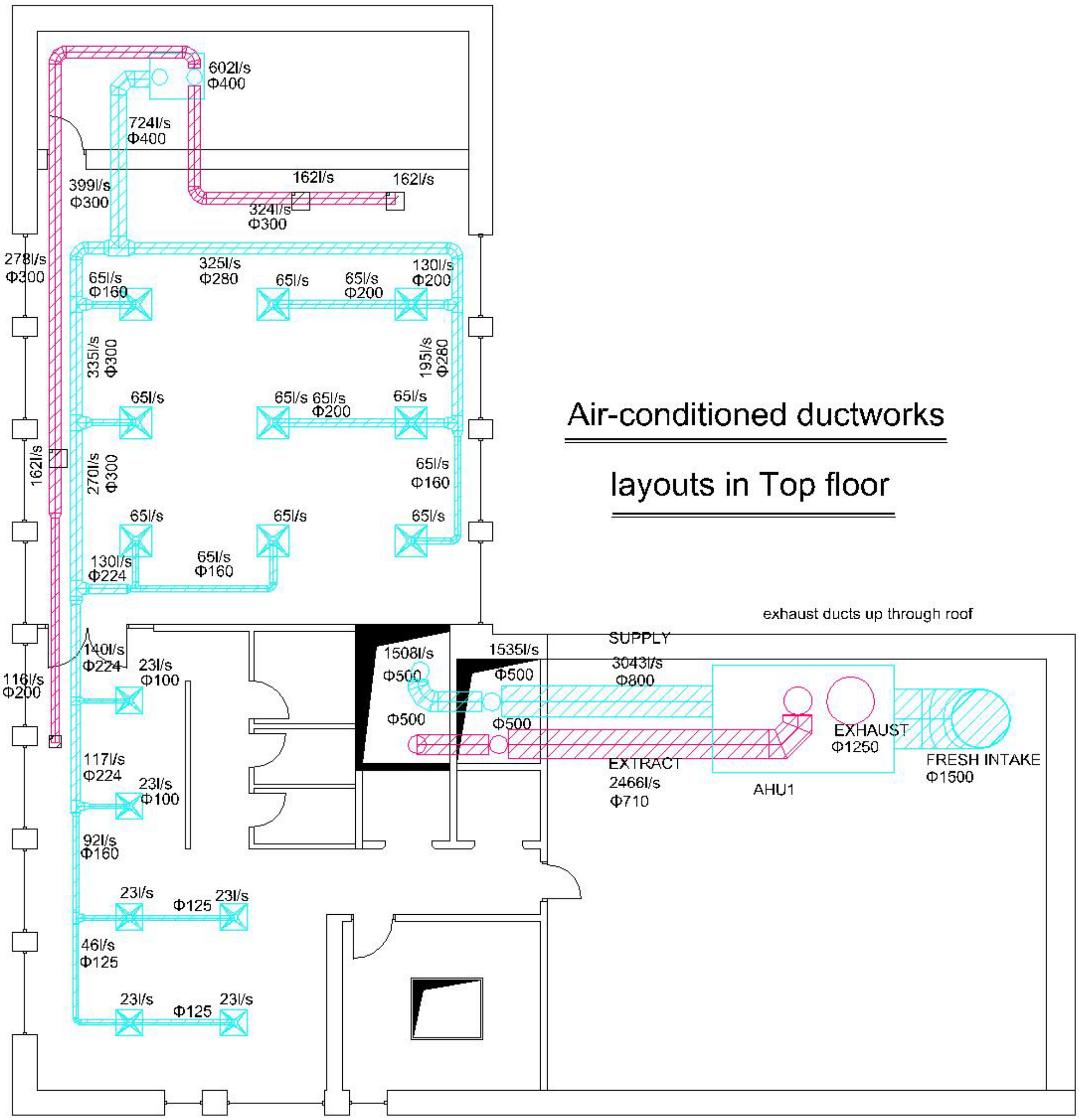


Figure 123 ductworks layouts, top floor

Ductworks AHU1

The duct size were summarized together with pressure drops calculation in Appendix I.

The ducts are designed to be mounted exposed. The usable height of the room is, at the lowest position, 2.3m, with a margin for mounting and maintenance of 0.1m.

3.3.5 Intake/exit air

The layouts of intake and exit air ducts and devices were shown in below.

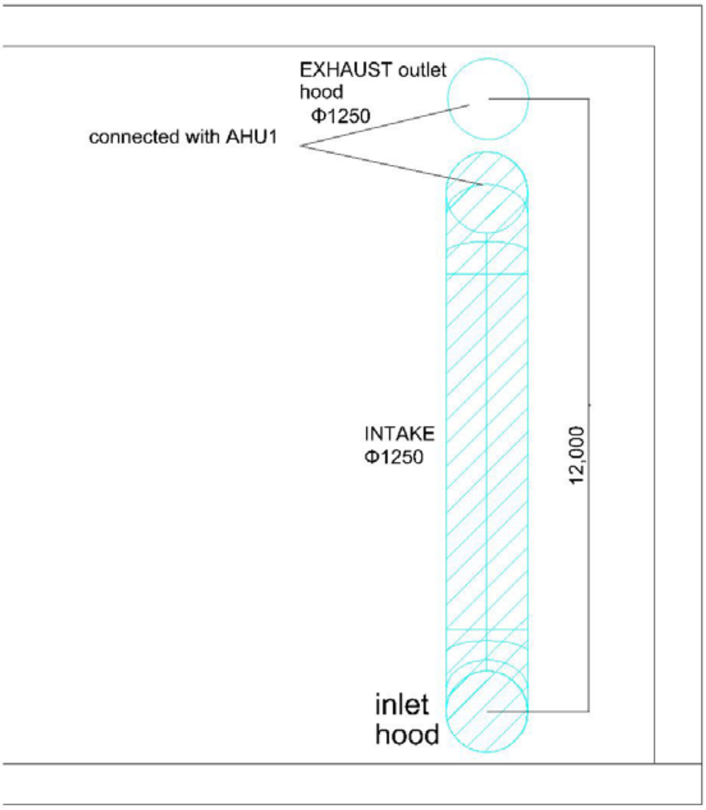


Figure 124 inlet and outlet location for AHU1

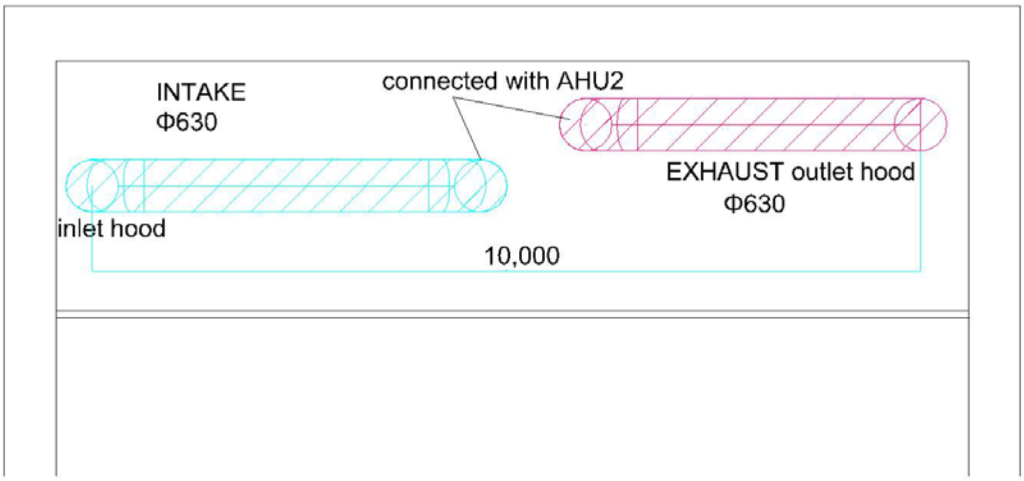


Figure 125 inlet and outlet location for AHU2

The outlet air and air inlet is located on the roof, with a safety distance away from each other for over 10m. The velocity in inlet and outlet ducts is less than 2m/s.

3.3.6 Total pressure drop

Pressure drop calculation are shown in appendix I. For the ducts part, in systerm1 (supplied by AHU1), the critical branch are the east branch (in right shaft) with a pressure drop of 89Pa for supply and 49Pa for exhaust. For system2, the critical branch has a supply drop of 57pa and exhaust drop of 32pa.The pressure drop at diffuser counted in the calculation is the lowest value at its fully open state. VAV box has a pressure drop of 5Pa, assumed by looking up relative brochure from website.

According to the results, for AHU1,

The total supply pressure drop include inlet ducts, is 89Pa+1.1Pa= 90.1Pa

The total exhaust pressure drop include outlet ducts, is 49.79Pa+ 1Pa= 50.79Pa.

For AHU2,

The total supply pressure drop is 59.9Pa

The total exhaust pressure drop is 34.11Pa

3.3.7 AHU unit selection and SFP-factor

Simultaneous usage factor should be considered during the system operation since that not all the designed air-conditioned room would have a worst case cooling demand at the same time. The simultaneous usage factor is set as 0.7.

The supply airflow rate used for selecting AHU:

$$AHU1: 3043 \cdot 0{,}7 = 2130\ l/s$$

$$AHU2: 724 \cdot 0{,}7 = 2130\ l/s$$

3.3.7.1 Manual method for AHU selection and SFP calculation

According to “Swegon” brochure “GOLD RX”,

For AHU1, size 25 was chosen which has a heat recovery of 84%.

For AHU2, size 05 was chosen which has a heat recovery of 85%. The selection diagram is shown in below.

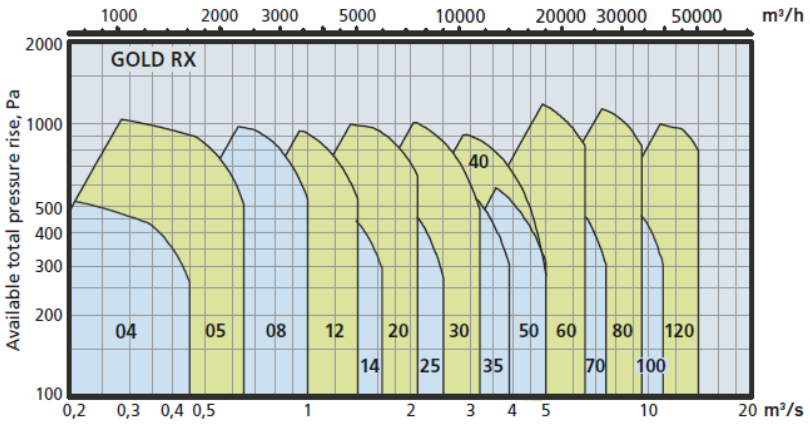


Figure 126 *AHU selection chart*

According to the two selected AHU and the calculated pressure drop in chapter 3.3.6. The detail calculation process are shown in Appendix J.

For AHU1, SFP AHU,1 = 1.155 kW/(m3/s)

For AHU2: SFP AHU,2 = 1.092 kW/(m3/s)

Efficiency for both supply and exhaust fan is taken 65%.

The AHU selected from each system are size 25 and size 05, which have a maximum air flow of 2.5 m^3/s and 0.65 m^3/s respectively.

3.3.7.2 Heating and cooling coil design

Cooling capacity

AHU1: $Q_{cooler} =$ 33 kW,

AHU2: $Q_{cooler} =$ 8.58 kW

Heating capacity

AHU1: $Q_{heater} =$ 18 kW,

AHU2: $Q_{cooler} =$ 4.68 kW

Detail equation and calculation process are shown in appendix K, process in mollier chart are shown in below.

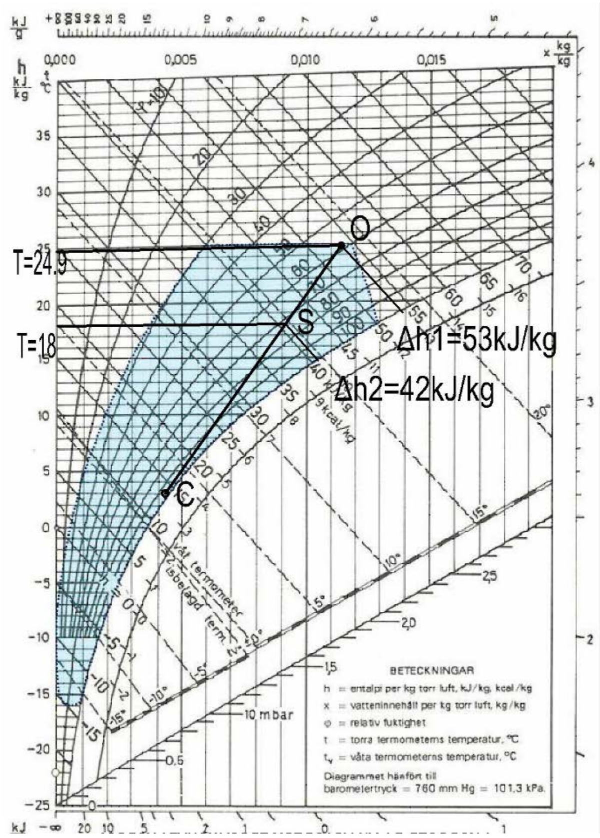


Figure 127 Mollier diagram, summer case

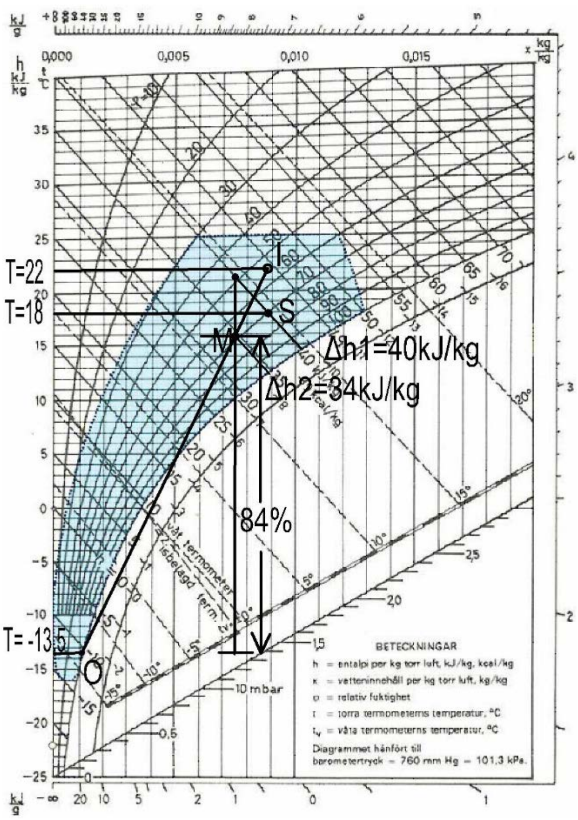


Figure 128 Mollier diagram, winter case

3.3.8 Space heating system

The velocity of the pipes were calculated to: $q = 0{,}5\ l/s$

Pressure drop in pipe system was calculated to be: $\Delta p = 74{,}8\ kPa$

Selection of circulation pump:
To be able to choose pump the service for pump selection on Grundfos webpage (Anon., u.d.) was used. When the input data, $q = 0{,}5\ l/s$ and $\Delta p = 74{,}8\ kPa$ was inserted the pump “MAGNA/UPE serie 2000” was recommended. See figure below.

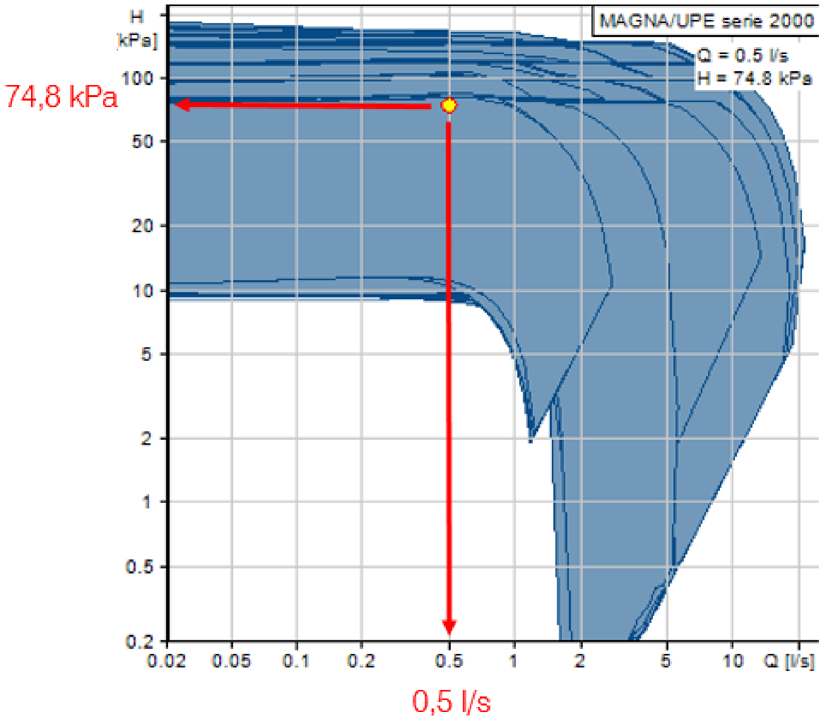


Figure 127: Diagram for MAGNA/UPE serie 2000

3.4 Construction details

For all construction details, see appendix C.

3.4.1 Construction Atrium

As bearing support for the atrium construction wooden beams will be used, this construction will both be architectural and usage satisfying. The wooden beams will work as a sunshades because of their height, that has to be quite high since they have to be load bearing. Due to that wood is quite sensitive when it comes to moisture, there has to be some precaution in the wood to metal connection is created. Therefore it should only be in contact where it is absolutely necessary and in these parts a sealant should be used.
As loadbearing for the roof construction concrete columns will be used. These will mostly be put to the outer parts to create more open spaced in the middle of the atrium.

4 Conclusions

The complex design of the office refurbishment project with both high architectural and energy efficiency ambitions has evoked multidisciplinary challenges. A number of dynamic simulations and analyses were carried out to understand the influence of an atrium design on thermal and energy performance of the building. Many of them have not been included in this study. At the same time the potential for improvements in terms of daylighting, energy use, moisture safety and HVAC have been continuously checked with the use of the parametric study.

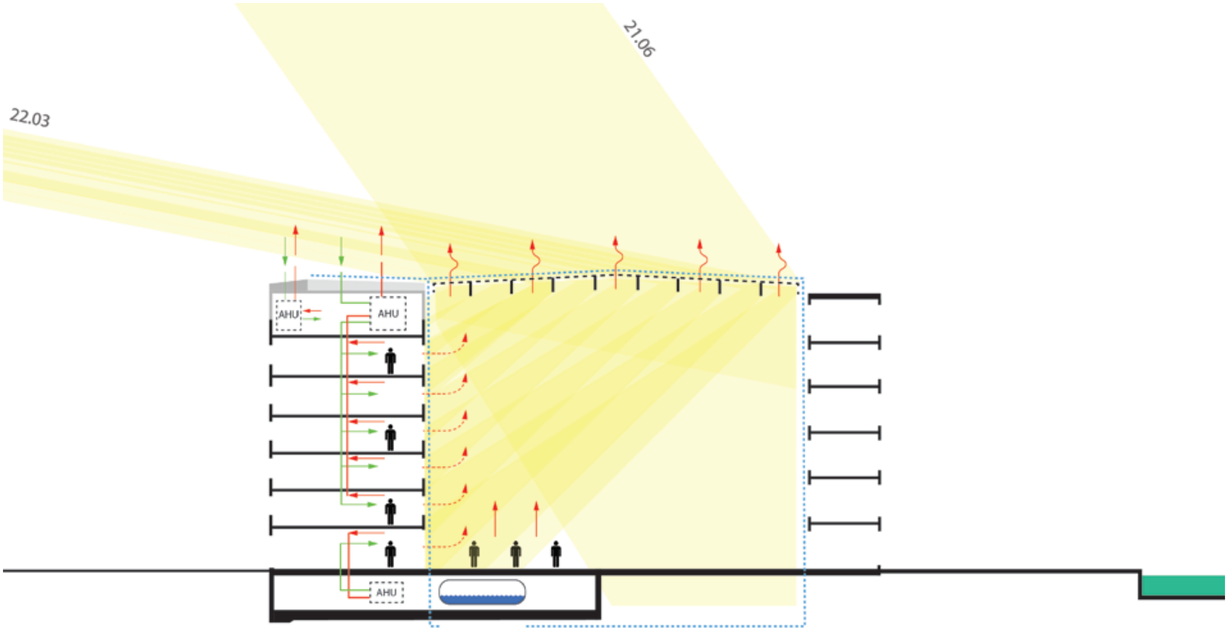


Figure 128, Conceptual section of the main design solutions implemented in the building.

In the initial phase, the simulations demonstrated that an integrated design through space utilization for a courtyard, converted to an atrium, increased not only the architectural quality of the building, but had a positive effect on daylighting, energy use and thermal comfort in the existing building.

In terms of daylighting, the atrium helped to improve the uniformity of daylight distribution across the office spaces, oriented both to the South-North and West-East. Initial assumptions about functional plan orientation minimizing the risk of glare proved to be correct. However in order to realized the actual improvements, comparison to the existing situation should be performed. By improving the functional layout and visual transmissivity of the windows, BREEAM's exemplary level of 3,15 DF over 80% of the lettable office area was possible. However, exterior shadings proved to be necessary to achieve balanced heat gains through the windows, which means that lower g-values should be considered in the future.

The simulation of DAcons levels showed a high potential for electrical lighting savings. However, difficulties in practical use of these results in lighting energy loads calculations, encouraged the authors to perform a new electrical lighting studies in "DIALux", which clearly proved 50% decrease in energy loads. The relation between the DAcons simulations and practical lighting calculation stays uncertain, what as a consequence diminish the merit of DAcons simulations in the process of energy efficient lighting design.

The simulations for energy use resulted in a very low energy office building with a total end-use electricity of 55 kWh/m2, year for heating, cooling, DHW, facility electricity, fans and user related electricity. This shows that 53% energy can be saved compared to the base situation by the implementation of energy saving strategies. Excluding the user related electricity the building achieved a value of 32 kWh/m2, year, which fulfills the FEBY 12 requirement of 45 kWh/m2, year. Achieving a Passive house standard airtightness can be highlighted as the most crucial strategy for reduction of the heat losses. Moreover, the atrium ensured for less surfaces exposed to the outside conditions, which reduced the heating demand and the heating load, respectively by 10% and 35%. This way, the walls to the atrium, did not need to be improved, because of the small temperature difference between BRIO and the atrium, leading to a smaller heat transfer.

Simulations using “HEAT” confirmed adopting an external insulation of the envelope reduced the thermal bridges in the building. However, the window detail and the connection between ground floor and basement need improvement. The lower inner surface temperature is an indicator of a thermal bridge, which could lead to discomfort and condensation. Therefore, placing insulation in front of the window frame, as well as insulation of the exterior walls of the basement should be considered.

Due to the improvements in the envelope and the implementation of an atrium as a thermal buffer zone, the comfort temperatures were within the required 21°C. Minimizing the internal heat sources, adopting efficient shading devices and sufficient ventilation lead to achieving BELOK P25 for the period April – September.

In terms of moisture safety design, the external wall was the most crucial construction, due to very high moisture content. In order to eliminate that steel studs were considered, which left out any organic material in the cavity.

The ventilation system were designed and sized for the worst situation not considering natural ventilation effects in the atrium. But which can be assured from case study is that natural ventilation could result in reducing the annual operating hours of mechanical system. One risky liability of the atrium is that if the glazing roof were not controlled advanced, overheating problem will cause higher cooling demand in the office zone, which will increase the burden on AHUs.

The layouts of ductworks influence greatly in the duct pressure drop. When calculating the duct pressure losses, a lowest pressure drop for the diffuser was counted in the process. The system pressure drop and SFP factor will be higher if taking the 50% open state for the diffuser.
In the AHU selection, result from manual method was adopted. That is because with “ProUnit” tool from “Swegon”, size 35 and size05 were chosen respectively for AHU1 and 2 in order to reach a SFP of below 1 kW/ (m3/s). The choice is not economical since the maximum air flow rate for the units are almost twice than the required airflow.

Limitations

This increased the temperature due to solar gains, heat gains from the surrounding buildings and if not ventilated correctly, overheating issues could occur and increase
Finally, one of the most interesting aspect of the project, which is considered to be a potential of natural ventilation to decrease the energy used in the mechanical one, could not be quantified. Constant difficulties in controlling the natural airflow while simulating the model in “DesignBuilder” together with uncertainty about correctness of the flow sizing made it impossible to obtain reliable results. Additionally, a CFD analysis must be performed in order obtain information whether the air flow in the atrium is sufficient, as well as to assess the operative temperatures not only on the ground floor, but at different heights.

References

[1], 2014. *Swedish Meteorological and Hydrological Institute.* [Online]
Available at: http://www.smhi.se/
2, 2011. *Ecotect, Weather Tools,* s.l.: s.n.
3, 2013. *http://www.ipcc.ch/.* [Online].
A/S, V., 2014. *Velfac.dk.* [Online]
Available at: http://velfac.dk/
[Accessed 27 05 2014].
Anon., 2011. [Online]
Available at: http://www.purmo.com/docs/_TP_Dimensioneringsbroschyr_SE_1110.pdf
[Accessed 20 5 2014].
Anon., 2012-09-27. *Specification of requirements for zero-energy-, passive- and minienergi houses - Commercial buildings,* s.l.: Swedish Centre for zero-energy.
Anon., 2013. *Fraunhofer IBP.* [Online]
Available at: http://www.wufi.de/index_e.html
[Accessed 8 5 2014].
Anon., 2014. *DesignBuilder Help.* [Online]
Available at: http://www.designbuilder.co.uk/helpv3.4/
[Accessed 24 05 2014].
Anon., n.d. [Online]
Available at:
http://net.grundfos.com/Appl/WebCAPS/custom?userid=GMAinternal&lang=ENU&appl=HEATING&familycode=TPFAM&flow=0,5&flowunit=UC_l/s&head=74,8%20&headunit=kPa
[Accessed 20 5 2014].
Anon., n.d. [Online]
Available at:
HTTP://NET.GRUNDFOS.COM/APPL/WEBCAPS/DETAILS?ID=GSV&PRODUCTNUMBER=98346576&CPN=&FREQ=50&LANG=SVE&UNITS=UC_DEFAULT_UNITS
[Accessed 20 5 2014].
Catarina Warfvinge, M. D., 2010. *Projektering av VVS-installationer.* Lund: Studentlitteratur.
Flodberg, K., 2012. *Very Low Energy Office Buildings in Sweden - Simulations with low internal heat gains,* Lund: Faculty of Engineering LTH,.
Reppen Laila, B. C. K. P., n.d. *Så byggdes husen 1880-2000. Arkitektur, konstruktion och material i våra flerbostadhus under 120 år.* s.l.:Svensk Byggtjänst.