MEP REPORT

23 June 2024

2 students

TEAM 6 | 41936 Advanced Building Design

TABLES OF CONTENT

1 BUILDING 313

Building 313 is a new high-rise building on DTU Campus. The building is 69.1 meters heigh with 16 floors and 2 floors of basement. The building is divided into different zones: Office floors, a student floor, ground floor with café and auditorium, technical floors, a skybar and bike parking. Figure 1 shows the zone sections.

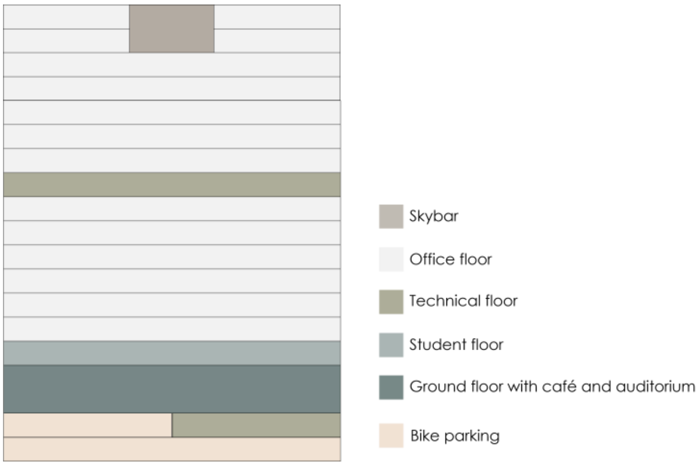


Figure 1: Visualization of building floor breakdown

The building is constructed around two structural cores, where stairs and elevators are located. At each floor, two technical rooms, each containing a dry and a wet area, are found. A generic office floor plan is shown at Figure 2. Rooms are given room numbers, which are used throughout the report. The building has 13 office floors with a total of 1620 permanent workstations. At each office floor, a large meeting room is placed in the center.

Figure 2: Office floor plan including zones and room numbering

At the office plan, load bearing walls are only placed around the core, creating the opportunity of flexibility in future office plan designs. The technical installations are designed with a capacity according to the current floor plan, as this is considered to be the most compact solution. For future use, small offices can be transformed to single offices at each floor. Furthermore, partitions can be removed to create open spaces. Walls around the technical shaft are not load bearing. Therefore, there is a possibility of expanding the technical shaft, if the occupancy load should increase with future tenants. However, this is not recommended since office floors are already designed with large occupancy.

Mechanical, energy and plumbing (MEP) aim to ensure that Building 313 has a low energy consumption together with an acceptable indoor climate as well as daylight conditions. This subject report will go through descriptions and calculations of the technical installations, daylight- and thermal comfort simulations as well as the energy frame calculation.

1.1 DESIGN CRITERIA AND DGNB

Building 313 is designed to fulfill requirements in accordance with the Danish Building Regulation (BR18) and DS/EN 16798. The defined design criteria are:

DAYLIGHT	300 lux at 50% of the area in 50% of the time
THERMAL COMFORT	Less than 100 hours with temperature above 26°C and 25 hours above 27°C
AIR QUALITY	CO_2-concentration less than 1200 ppm
ENERGY FRAME	Energy consumption of maximum 41 kWh/m^2 per year

Furthermore, the building is designed to achieve DGNB Gold in accordance with the DGNB Lite manual. MEP has an influence on the qualities: Environmental (ENV), Social (SOC) and Technical (TEC). In addition, amounts of material used for pipes and technical components, and the energy performance are included in the LCA and LCC influencing the score of ENV1.1 and ECO1.1. Table 1: MEP related DGNB criteria shows indicators directly related to MEP, where points are fulfilled.

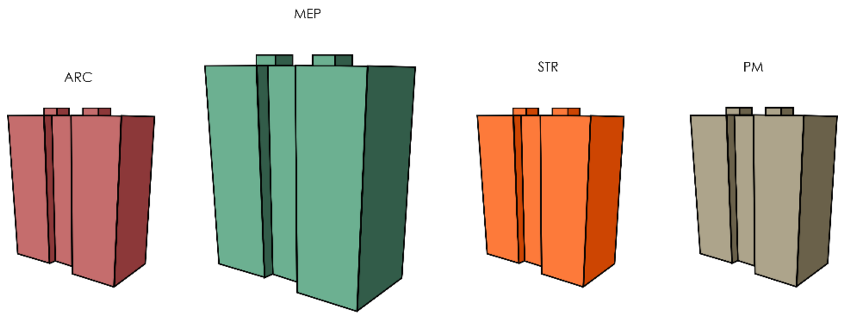
Table 1: MEP related DGNB criteria

CRITERIA/INDICATOR		**POINTS**
SOC3.2.3	**Air change rate and daylight availability**	
	Air exchange rate at workplace meets EN 16798 Category II	+50
	300 lux > 50% daylight hours > 50% reference plan	+18
SOC3.2.5	**Visual contact**	
	View out >100% space = High	+30
SOC3.2.7	**Acoustic concepts formulated during the planning process**	
	Consider acoustic comfort in the design	+90
TEC4.4	**Quality of the building envelope**	
	Average U-value of exterior wall < - 30% of min. Building Regulation requirement	+50

TEC5.7	**Use and integration of building**	
	Arrangement and compactness of the building structure, proportion of windows area	+5
	Use of daylight	+5
	Solar radiation protection	+5
	Storage mass and insulation	+5

1.2 INTEGRTION

Building 313 is designed and developed by an interdisciplinary team consisting of; project managers, architects, structure- and MEP specialists. Throughout the development of the building design, cooperation and compromises have been necessary. In the following, the coordination between MEP and the other subject teams is described.



CONSULTING WITH PROJECT MANAGERS

MEP's have been consulting with projects managers on constructions layers, material choices and quantities. This was important to get an accurate LCA. MEP's and PM's have been in close contact regarding the energy frame calculated for MEP's to get updated areas and PM's to get results of heat and electricity use for LCC and LCA. Time registration was coordinated between PM's and MEP's for the PM's to stay within the budget. Finally, there has been communication on how many points MEP's were responsible for to reach a gold DGNB lite certification.

CONSULTING WITH ARCHITECTS

To develop a functional design of the building, communication between architects and MEP's was important. A key communication point was placement and size of glazed area. Furthermore, the floorplan design was coordinated in collaboration to ensure sufficient daylight at permanent workstations. A great part of the communication with the architects was related to the placement and sizing of the technical shaft. For the MEP's the correct size and placement was highly relevant to ensure space for ducts and pipes as well as good routing from the shaft to each floorplan. It was important for architects to know the duct size to draw ceilings.

CONSULTING WITH STRUCTURE

With the structure team, placement and size of vertical ducts should be coordinated for the structure team to take into consideration holes in the slab all the way through the building. Furthermore, large beams that potentially collides with ducts and other technical installations in the ceiling was important to coordinate. The structure team needed weight estimates of technical installations and placement of technical floors.

2 BUILDING ENVELOPE

The thermal building envelope is designed to meet the requirements in BR18 and DGNB. The U-values of the envelope are calculated in accordance with DS 418 [1]. U-value calculations can be found in Appendix A. 70% is added to the calculated U-values to account for thermal bridges. Figure 3 gives an overview of the U-values and the façade system.

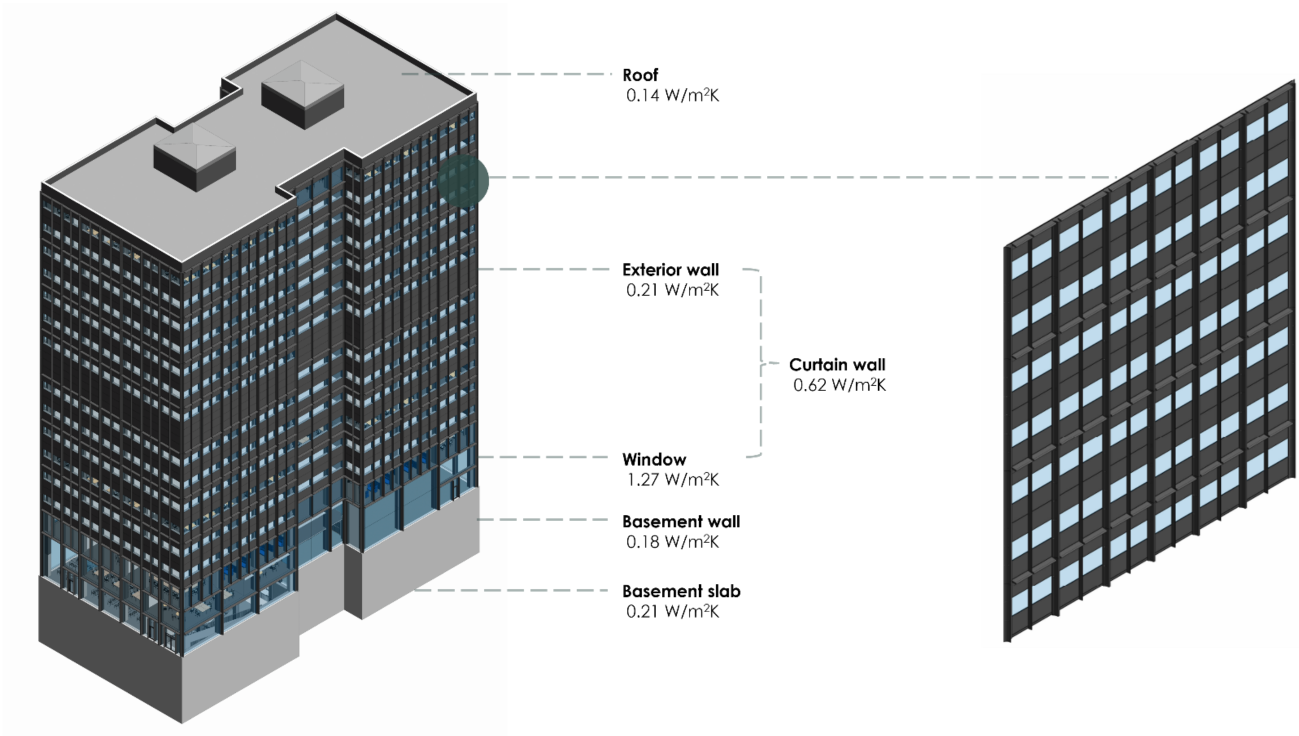


Figure 3: Building envelope

The facade is a curtain wall system with is attached to the load bearing structure. The façade system consists of an open and a close part. The open parts are windows with a U-value of 1.27 W/m²K, and the closed facades are insulated parts with a facing of fiber cement with a calculated U-value of 0.21 W/m²K. The wall to window ratio is 37%, which leads to a total U-value of the curtain wall of 0.62 W/m²K.

The façade elements are separated by the integrated fixed horizontal and vertical fins, also working as solar shading. The fins are made of terracotta and have a depth of 0.39 m, a horizontal distance of 3.5 m and a vertical distance of 7.6 m.

3 VENTILATION

The building is ventilated with balanced mechanical ventilation. The system is designed as diffuse ventilation due to less risk of draft and noise nuisance. The ventilation system is designed for air quality in accordance with Category II in DS/EN 16798 [2]. The ventilation principle is visualized at Figure 4.

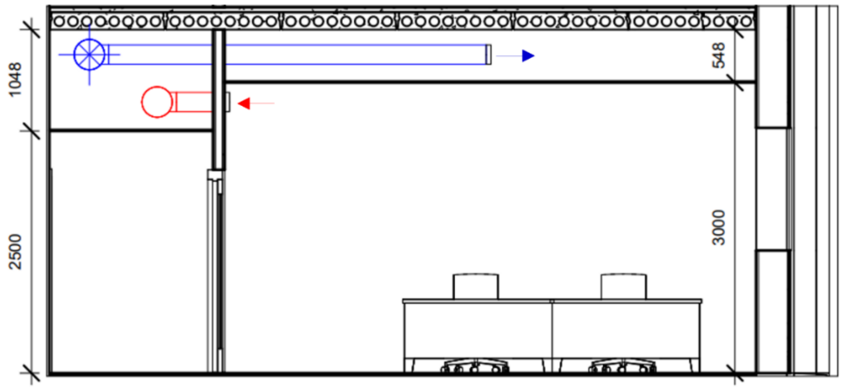


Figure 4: Ventilation system in office

Equations used for calculating the ventilation demand for different room types are shown in Table 2. It is assumed that the ventilation demand for toilets is 10 l/s.

Table 2: Ventilation demands according to Category II in EN 19798 [2].

ROOM TYPE	VENTILATION DEMAND
Offices, meeting rooms, auditorium, café, and skybar	7 l/s per person + 0.7 l/s/m²
Corridors, cores, and technical floors	0.7 l/s/m²
Toilets	10 l/s

Additionally, the ventilation system is dimensioned based on an assumed maximum peak of people of 80% during occupation hours in the offices, meeting rooms, café and skybar. A maximum peak of people of 60% is assumed at the student floor. Table 3 shows the total ventilation rates for specific floor types. Room specific ventilation rates can be found in Appendix B.

Table 3: Total calculated ventilation rates for specific floor types.

FLOOR TYPE	TOTAL VENTILATION RATE
Ground (incl. café)	919 l/s
Student (incl. auditorium)	2110 l/s
Office	1620 l/s
Skybar	538 l/s
Technical	882 l/s

3.1 DUCT DIMENSIONING

The dimension of the ducts is determined through material provided in course 41936 Advanced Building Design [2], which can be found in Appendix C. The design of the duct system is made with a focus on minimizing energy consumption. A maximum pressure gradient of 0.5 Pa/m is generally prioritized over smaller ducts, despite the extra use of materials, when having larger ducts. However, in some cases, 0.5 Pa/m is surpassed. Moreover, a focus has been on short pipe routes aimed at reducing pressure loss and material use both horizontal and vertical. Duct dimensions can be found in Appendix B. The design of the ventilation system for an office floor is visualized in Figure 5. Two critical crosses are highlighted at the floor plan and visualized at Figure 6, showing enough space over the suspended ceiling for the ducts not colliding with beams and the largest duct crossings.

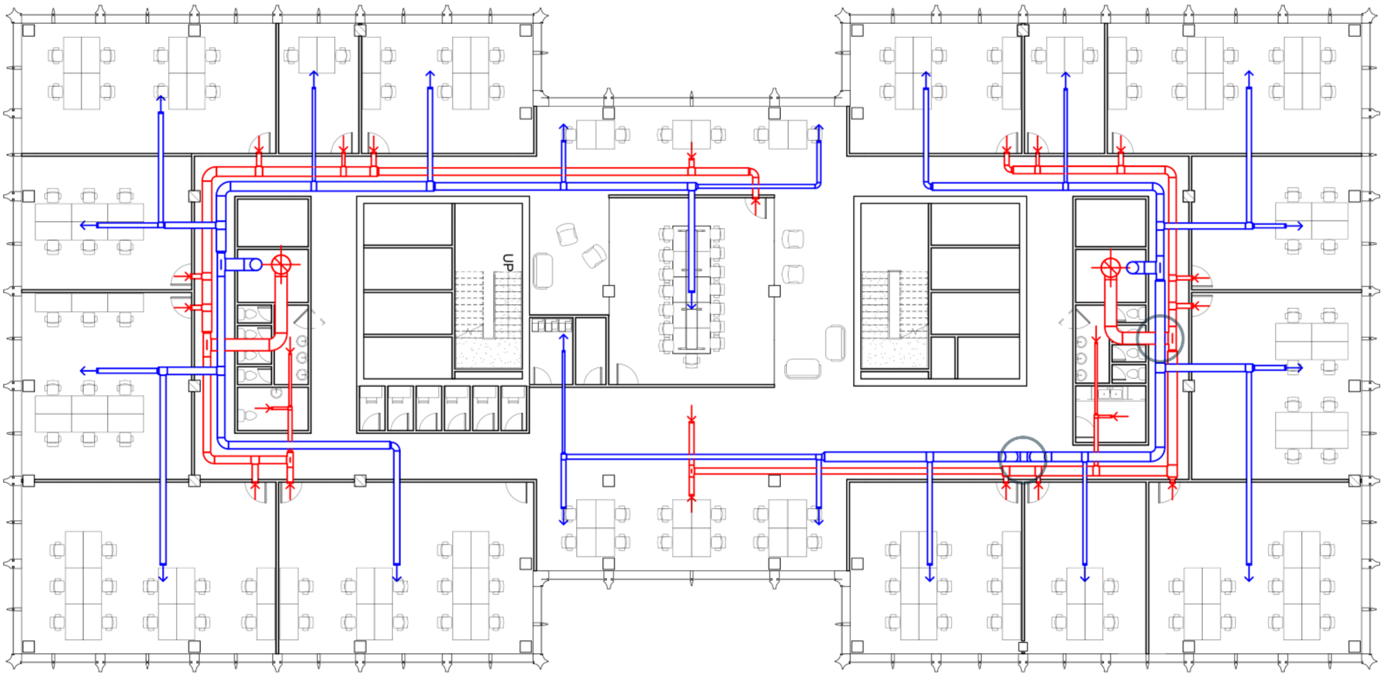


Figure 5: Ventilation ducts routing

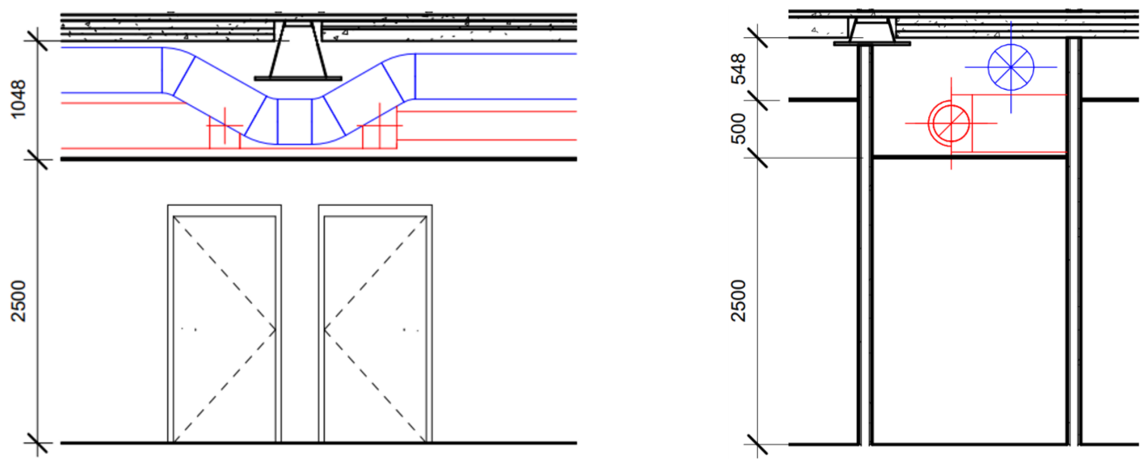


Figure 6: Cross sections of critical routings

3.2 AHU DIMENSIONING

AHUs are located at the technical floors on Level -1, Level 9 and on the roof. The system consists of 10 AHUs. The café, the auditorium and the skybar has separate AHUs. Ventilation on the office floors is controlled by on-off CAV dampers. The dampers are controlled by a sensor in the specific room. When the sensor registers presence in the room, the dampers open to 100% and closes to 20% when no presence. Figure 7 visualizes the schematic of the ventilation system.

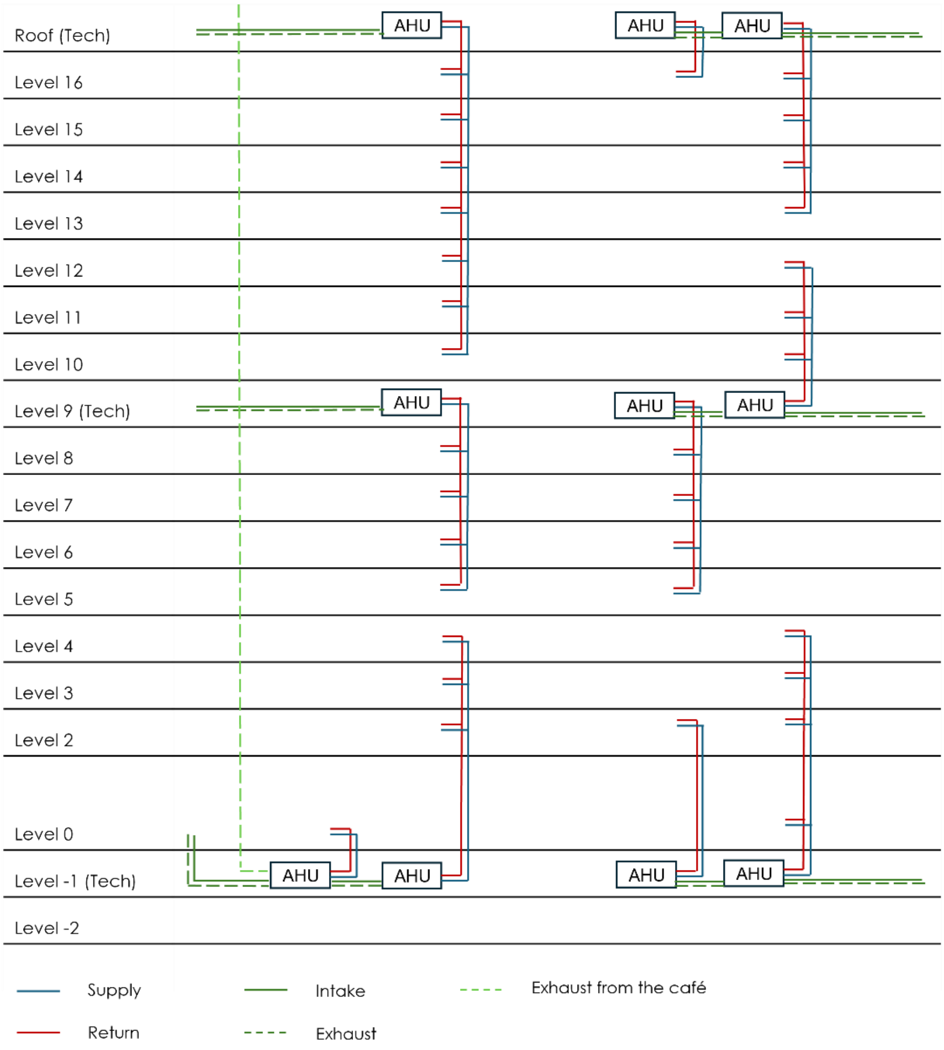


Figure 7: AHU schematic

Based on the placement of the AHUs and supply routes, the vertical duct dimensions and dimensions of the AHU are found. Table 4 Table 1shows the specifications of the system. The AHU-model is model C1 with rotating heat exchanger. The AHU is chosen based on datasheets provided in course 41936 Advanced Building Design [2]. SFP is not given in the datasheets, so a SFP ≥ 1800 J/m^3 is assumed in accordance with BR18. Relevant datasheets can be found in Appendix D.

Table 4: AHU sizing

	AIR FLOW RATE [m^3/s]	VERTICAL DUCT SIZE [mm]	AHU DIMENSION (WxHxL) [mm]
Level -1 (Tech)			
Café	0.5	400	970x970x2160
Student- and office floor (Level 2-4)	2.4	800	2020x2020x2910
Auditorium	0.6	400	970x970x2160
Ground-, student- and office floor (Level 0-4)	2.7	800	2020x2020x2910

Level 9 (Tech)			
Office floors (Level 5-8)	3.4	800	2170x2240x3280
Office floors (Level 5-8)	3.1	800	2170x2240x3280
Office floors (Level 10-12)	2.3	630	1720x1720x3060
Roof (Tech)			
Office floors (Level 10-16)	4.9	1000	2320x2540x3210
Offices floors (Level 13-16)	2.0	800	1570x1570x2760
Skybar	0.5	400	970x970x2160

3.3 FIRE VENTILATION

Evacuation routes, in the case of fire, are placed in the two cores. An enclosed staircase and a lift for firefighters ensures vertical evacuation routes. To keep staircases and lifts free from smoke during the fire, ventilation is used to create pressurized zones. Staircases and one elevator in each core lead to an anteroom in the core that also should be kept free of smoke. At Figure 8, the core is illustrated with space for fire ventilation driven by a fan placed on the roof to ensure the needed pressure as well as space for air-release.

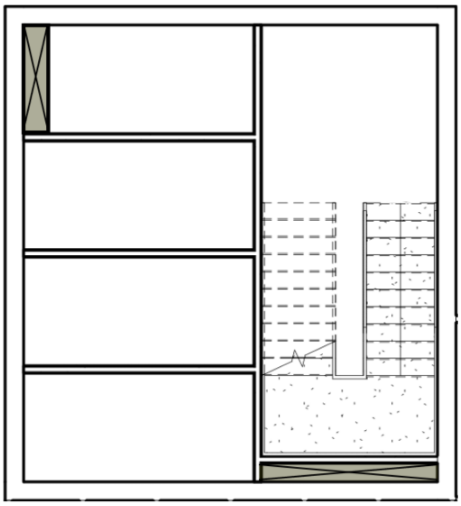


Figure 8: Fire ventilation

4 HYDRAULIC SYSTEMS

4.1 COOLING

The building is cooled using water though chilled ceilings. A waterborne system offers more advantages in high-rise buildings compared to air-based cooling systems, primarily in terms of space- and energy efficiency and minimal risk of draft. However, it should be noted that the panels are costly to operate, and it is estimated that only 60-70% of the ceiling can be used for cooling. This limitation arises from the space requirements for other installations in the ceiling, including ventilation and artificial lighting.

Figure 9: DAMPA Køleloft from TechnoKlima.

A chilled ceiling of the type DAMPA Klimaloft from TechnoKlima is used. See Figure 9. DAMPA Klimaloft is 600x600mm panels with a design cooling output of 120 W/m² [3]. Due to the space limitations, a useful cooling output of 72 W/m² is considered.

The cooling load needed in the entire building is dimensioned in IDA ICA based on the cooling load of an office floor. The cooling load of the office floor is 36.6 kW. The cooling needed in the entire building is estimated to 585.6 kW, based on the calculated cooling load at the office floor. Space requirement for the district cooling unit in the basement is visualized in Figure 13.

The cooling system is supplied by the district cooling grid, and by a heat exchanger the system is supplied with water in two sets of pipes with supply and return in each shaft. For chilled ceilings, the pressure is PN6 allowing 60 m of water column. Two sets of PN6 are chosen for minimizing the pressure and ensuring that the pressure limitation do not exceed.

4.2 HEATING

The building is heated with radiators or convectors, that are placed under the windows along the façade. The windows are placed 0.85 m above the floor, which ensures room for radiators or convectors. Generally, radiators will be placed with a minimum height of 100 mm between floor and radiator and a minimum height of 50 mm from the top of the radiator to the bottom of the window frame, to ensure room for air flow. A water heating system is chosen to make use of the large heating capacity of water compared to air. The heating requirement is calculated to cover the heat loss of each room. The heat loss from exterior walls, windows and ventilation is determined in accordance with DS 418 [1]. A safety margin of 15% is added to the calculations.

Heat losses for each room are presented in Table 5. The heat loss caused by ventilation is calculated based on ventilation flows as presented in Section 3. Transmission loss is calculated based on U-values presented in Section 2. It is assumed that no, or only negligible, transmission loss occurs between floors, as the same room temperature is assumed. Therefore, no transmission loss upwards or downwards is included in the calculation of the office floor at Level 5. The heat loss calculations can be found in Appendix E.

Table 5: Calculated heat losses

ROOM	**HEAT DEMAND [W]**	**ROOM**	**HEAT DEMAND [W]**	**ROOM**	**HEAT DEMAND [W]**
1	5822	7	3426	13	5332
2	2690	8	1421	14	1421
3	4465	9	6567	15	3719
4	5849	10	6884	O1	4215
5	2594	11	4683	O2	5552
6	4485	12	3180	Corridor	8022
				Total	**80327 W**

The designed heating system can provide 60 W/m². The office floor is 1479 m². Therefore, the heating system can provide 88.740 W in total, which covers the need.

4.3 DOMESTIC WATER

The domestic water system is pressurized by a zone-divided booster system. Zone-divided system is chosen because it is more favorable than a single booster system in case of electricity fallouts. The pressure difference between the upper and lower outlet follows the recommendation of maximum 300 kPa, meaning that each pressure zone must have height <30 m. The pressure zones are important for domestic water systems because of noise. It is assumed that the noise from the water installations meets the requirements in BR18 of ≤30 dB. Figure 10 shows the necessary pressure zones.

		Height [m]	Hydrostatic Pressure [kPa]	
Roof		64.6		
Level	16	60.8		0
Level	15	57		37
Level	14	53.2		74
Level	13	49.4		111
Level	12	45.6		149
Level	11	41.8		186
Level	10	38		223
Level	9	34.2		260
Level	8	30.4	0	
Level	7	26.6	37	
Level	6	22.8	74	
Level	5	19	111	
Level	4	15.2	149	
Level	3	11.4	186	
Level	2	7.6	256	
Level	0	0	297	
Level	-1	-3.8		
Level	-2	-7.6		

Figure 10: Pressure zones

Domestic hot water (DHW) and domestic cold water (DCW) are supplied by the district heating grid and city water. The domestic water system is divided in two pressure zones, as showed in Figure 10. In the basement, plate heat exchangers are installed for DWH, from which each shaft is supplied with hot water. The water is then circulated back to ensure hot water circulation for remaining the waiting time for hot water <10 s. Only vertical circulation is needed since the toilets are placed close to the shafts. A central hot water tank is installed in the basement serving both pressure zones. DCW is supplied to the building directly form the city water.

4.4 FIRE

The fire system consists of sprinkler pipes, wet riser pipes and hose reel pipes, which are placed in the anterooms. The system is connected to the city water grid and the fire risers have booster pumps to ensure the necessary water pressure in case of fire.

4.5 SEWAGE AND DRAINAGE

Sewage and drainage are vented by double pipe system. The speed of the water is reduced by elbows on the downpipe from the wastewater.

5 INSTALLATION SPACE PLANNING

The principle of the installations described above is visualized for one technical shaft in Figure 11. Additionally, the IT-system consisting of lightning and electricity are also shown.

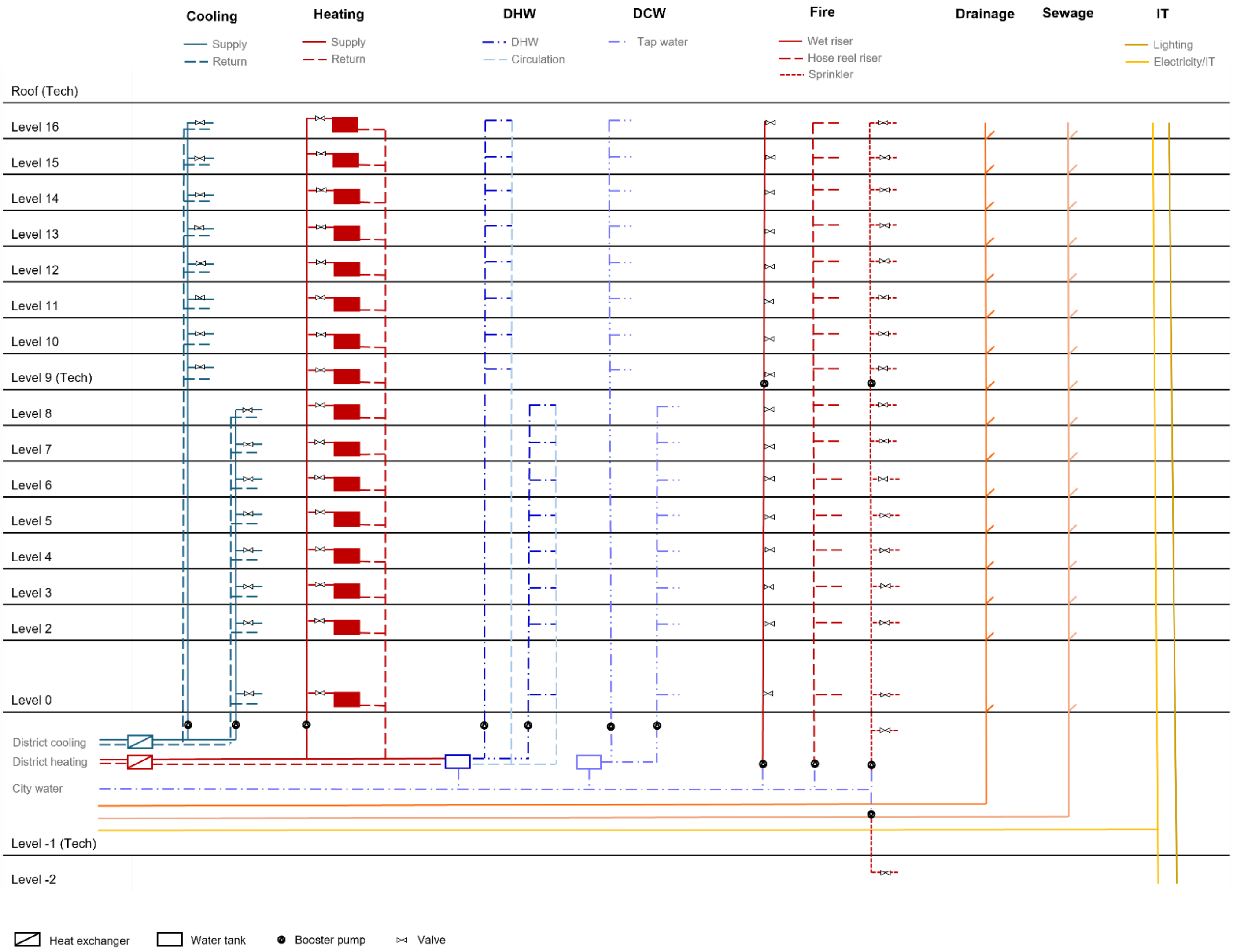


Figure 11: Vertical routing schematic

At Figure 12, an illustration of one of the technical shafts in the basement is shown. The figure presents all the installations in the technical rooms, showing enough space for both the ventilation- and hydraulic systems including navigation and service area. The technical shaft is divided into a wet and a dry shaft. The shaft is placed adjacent to toilets and the hallway to route large ducts strategically. Two shafts are placed all the way through the building with accessibility at each floor.

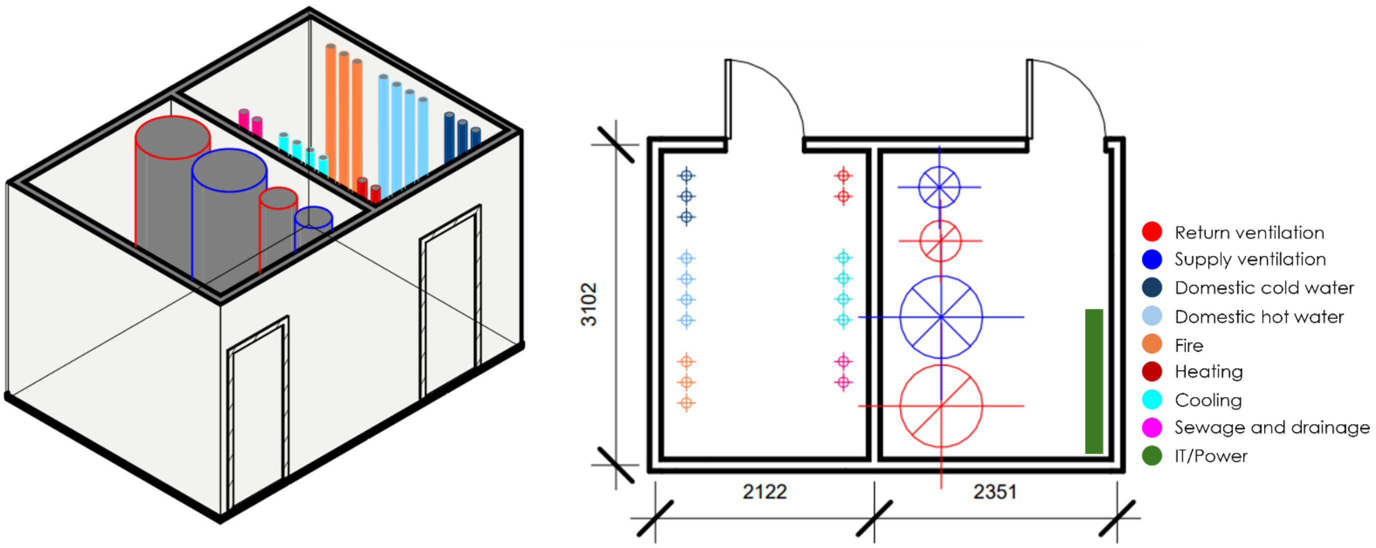


Figure 12: Technical shaft in the basement.

Figure 13 illustrates Level -1 in the basement, which is divided into two parts: bike parking and technical floor. The technical part is heated. The figure shows the allocated space for all the technical service stations and the rounding to the technical rooms. Due to a large cooling demand to the building, a large share of the space in the basement is allocated to heating and cooling devices, especially to the district cooling unit.

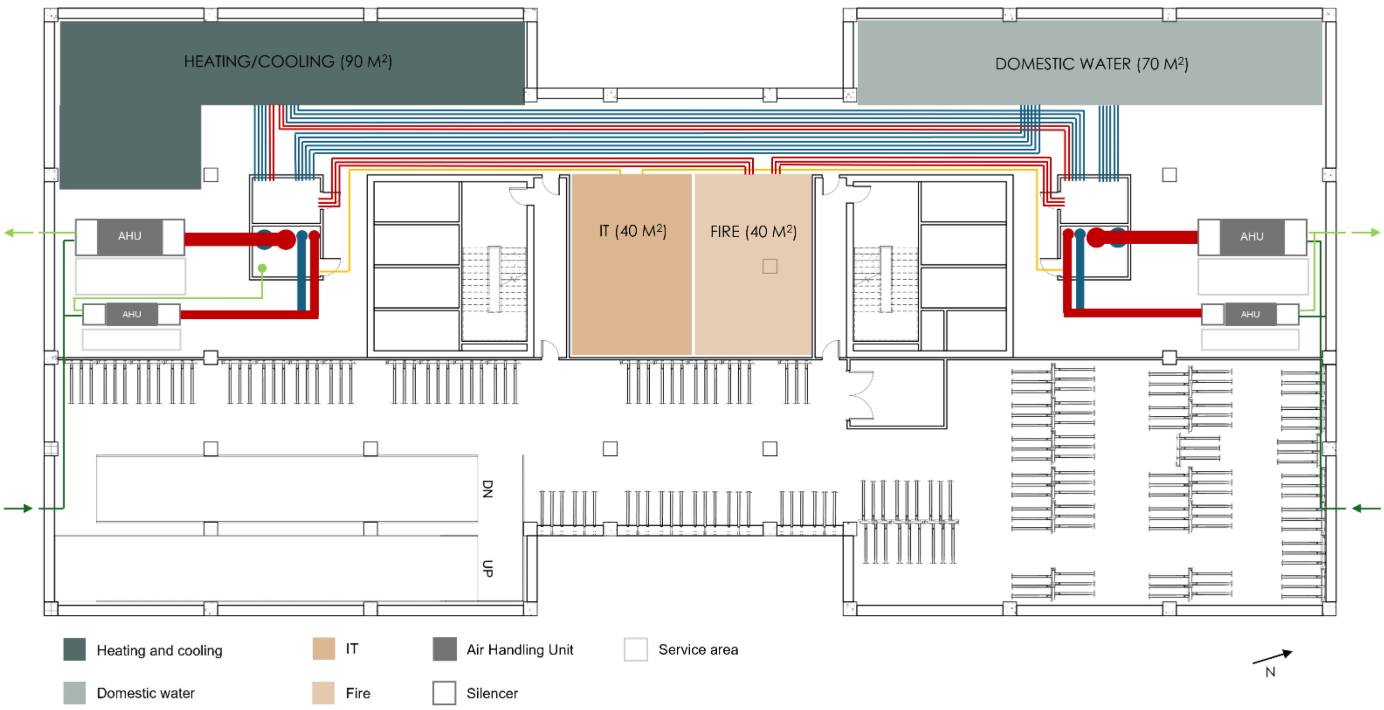


Figure 13: Space planning basement

6 OPTIMIZATION

During the design phase, optimization of design parameters was essential to reach the final design. Optimization within the MEP subject was highly focused on the sometimes contradictory parameters of ensuring sufficient daylight while keeping an acceptable the indoor climate, here especially regarding thermal comfort. Multiple simulations of daylight and indoor climate was performed to reach a good solution. Continuously consultancy with architects and structure team was highly relevant during the optimization. At Figure 14, some main parameter variations are highlighted.

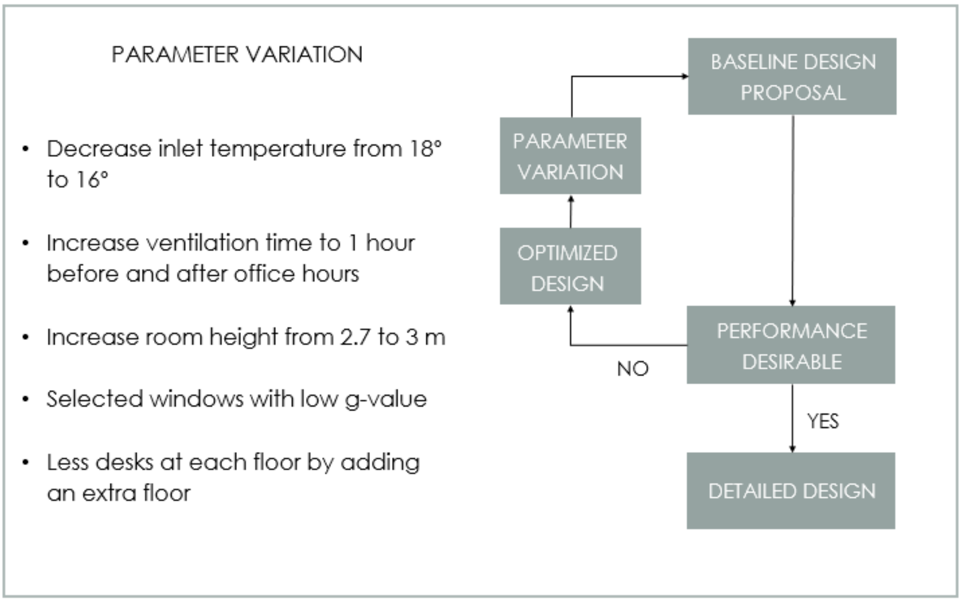


Figure 14: Parameter optimization

7 DAYLIGHT

The daylight is evaluated through IDA ICE. Two types of glazing are used. Windows towards south and south-east are generally facing good daylight conditions. Therefore, windows on both the southern and south-eastern façade are designed with a glazing having a lower g-value and light transmittance to accommodate thermal comfort. The properties of the two types of glazing are shown in Table 6: Glazing properties. Estimates of 3-layers energy glazing U-values as well as a realistic relation between the g-value and Light Transmittance of the glazing are based on information from Glasindustrien [4]. Windows with low g-value are highlighted at the floor plan illustrated at Figure 15.

Table 6: Glazing properties

	GLAZING 1	**GLAZING 2**
U-value [W/m^{2}K]	0.52	0.52
g-value [-]	0.53	0.35
Light Transmittance [-]	0.74	0.70

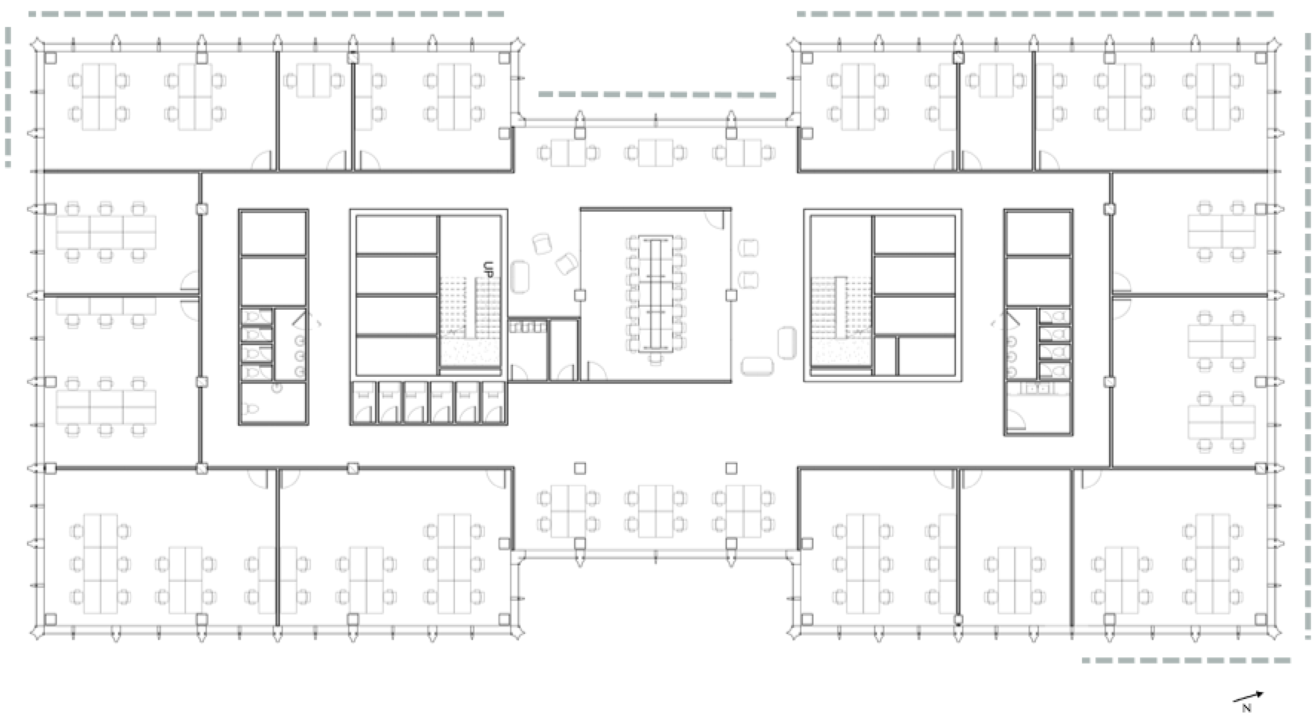


Figure 15: Facades with low g-value windows

Windows are aligned with the façade, and the external wall is 350 mm thick. The evaluation is performed on a surface 0.85 m above the floor with a 0.5 m distance from the walls, following the standard DS/EN 17037 [5]. The simulation uses the weather file DRY_2001-2010.epw and is evaluated over a full year. For offices a minimum of 300 lux at 50% of the area in 50% of the time is required according to the Danish Building Regulation. The analysis is divided into different zones representing the relevant area, where permanent office desks are placed. Windows are placed in a height of 0.85 m from the floor, to make optimal use of the glazed area in terms of energy and daylight balance. Windows have a height of 1.267 m. In Table 7, results of the analysis can be seen.

Table 7: Spatial daylight autonomy results

ZONE	sDA300/50%	ZONE	sDA300/50%
1	84.43	10	89.25
2	75.49	11	62.44
3	86.84	12	56.08
4	78.15	13	89.61
5	92.53	14	100
6	61.82	15	100
7	100	Open office 1	98.52
8	100	Open office 2	97.18
9	67.89		

At Figure 16, an illustration of the daylight penetration at a generic office floor can be seen. The color-code indicates the percentage of time, where daylight is higher than 300 lux.

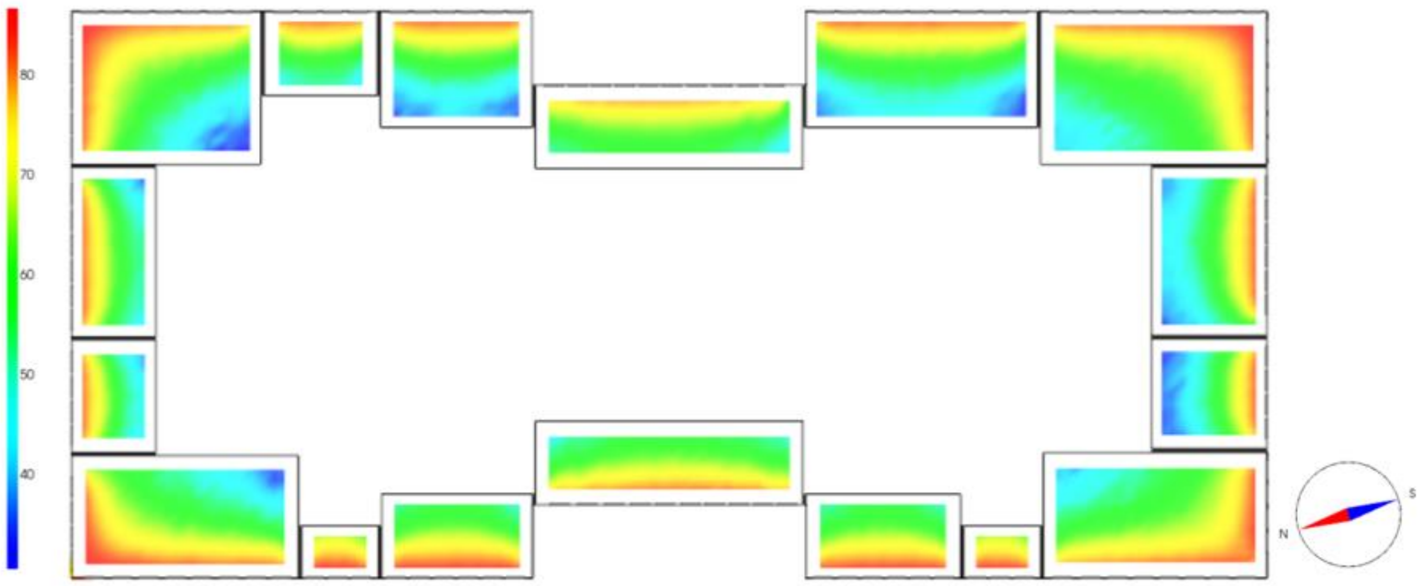


Figure 16: Daylight results illustration

At the façade, horizontal and vertical fins with the depth of 390 mm influence the daylight. The effect of the shading objects is evaluated for two critical zones, zone 11 and 12. Results are presented in

Table 8, showing that the requirement is fulfilled when shading is included. An illustration showing the layout with shading in IDA ICE can be found in Appendix F.

Table 8: Spatial daylight autonomy with shading

ZONE	sDA300/50%
11	62.06
12	55.67

8 THERMAL COMFORT

The thermal comfort at a generic office floor is evaluated using IDA ICE. The model contains 17 different zones representing the office areas. All zones have a floor to ceiling height of 3 m and constructions corresponding to the ones presented in Section 2.

In Table 9 below, input parameters for internal loads can be found. Figure 17 shows the occupancy schedule used. Thermal comfort calculations are performed without blinds, to illustrate the worst-case scenario. Lighting is modelled to follow both setpoints and schedule. Lighting is off, when the average daylight in the room exceeds 300 lux.

Table 9: IDA ICE Internal load inputs

	LOAD	**SCHEDULE**
Occupancy (1.2 MET)	80% of desks	Weekdays: MEP Occupancy Weekends: Off
Light	5 W/m2	Weekdays: MEP Occupancy Weekends: Off
Equipment	60 W/person	Weekdays: MEP Occupancy Weekends: Off

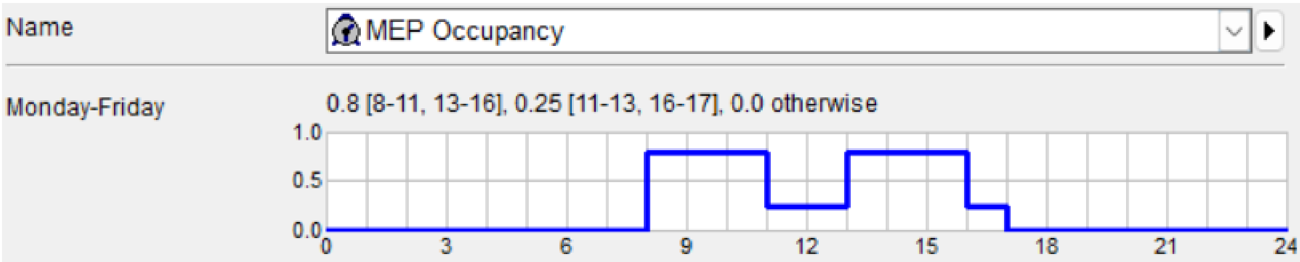


Figure 17: Occupancy schedule for offices

A constant air volume is used with supply and return air flow dimensioned for each zone according to the recommended air flow for Category II in EN 16798. The ventilation rate for each zone is described in Section 3 and presented in Appendix B. Each zone has a cooling unit with the capacity of 72 W/m2 and a heater having the capacity of 60 W/m2, in accordance with the presented in Section 4. In Table 10, further simulation inputs are presented.

Table 10: IDE ICE input

Ventilation	CAV
Inlet temperature	16 degrees
Heat exchanger efficiency	0.8
Cooling capacity	72 W/m2
Heating capacity	60 W/ m2
Cooling setpoint	21 degrees
Heating setpoint	25 degrees

In Table 11, simulation results are presented for selected rooms. The selected rooms are chosen to represent the office floor. Therefore, different zone types are chosen. Results for all zones can be found in Appendix G. Results show that offices comply with the thermal requirement of no more than 100 hours above 26 degrees and a maximum of 25 hours above 27 degrees. The maximum CO_2-concentration does not exceed 800 ppm above outdoor concentration in any offices. The minimum relative humidity shows to be in the lower end. Minimum and maximum operative temperatures are within an acceptable range.

Table 11: IDA ICE Thermal results

ZONE TYPE	H > 26° [H]	H > 27° [H]	MAX CO_2 [PPM]	MIN T_{OP} [°C]	MAX T_{OP} [°C]	MIN RH [%]
N corner	10.2	0	743.2	20.3	26.1	8.2
S corner	65.1	0	670.2	20.5	26.0	7.9
Ø corner	6.7	0	737.7	20.3	26.1	8.2
W corner	7.8	0	705.1	20.7	25.9	8.3
Small office	0	0	748.8	20.7	25.9	8.3
Open office	69.6	0	737.6	20.5	26.5	7.9

At Figure 18, the operative temperatures over a full year during office hours (9-17) are presented for the two most critical rooms, Open office 2 and Room 10, which is the south corner zone. The operative temperature does not drop below 20 degrees during the period.

OPEN OFFICE 2 ROOM 10 (SOUTH CORNER)

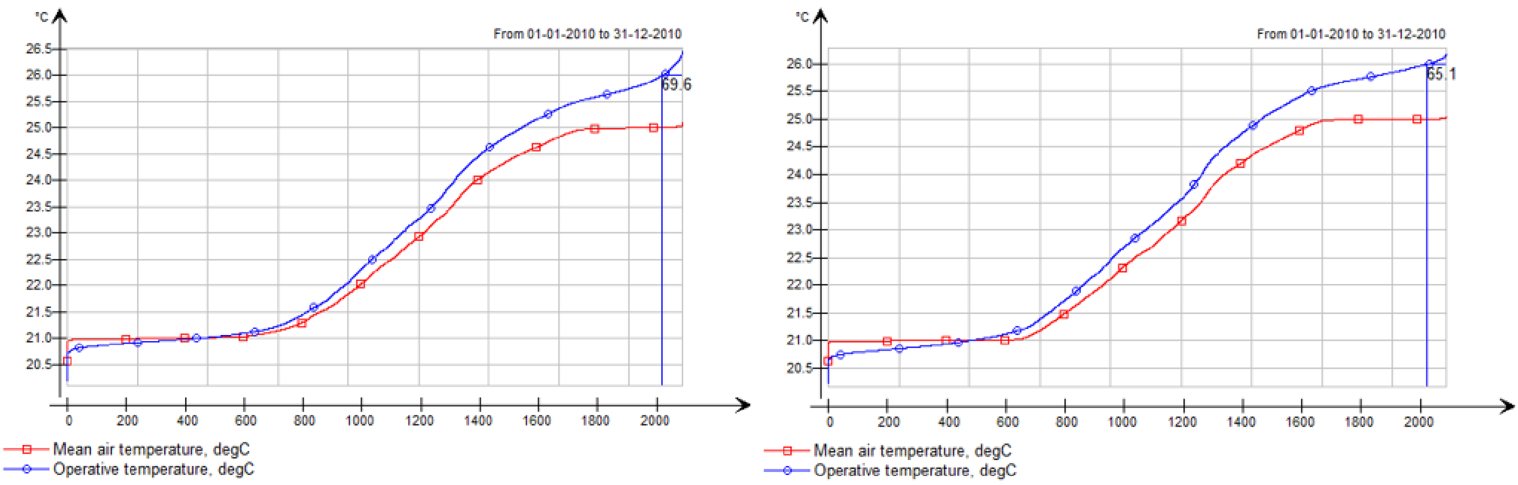


Figure 18: Operative temperatures

The IDA ICE energy balance simulation is presented at Figure 19 for Room 10 both for a winter- and summer week to provide an overview of simulation parameters influence on the energy balance. The energy balance for the Open Office 2 is illustrated in Appendix H.

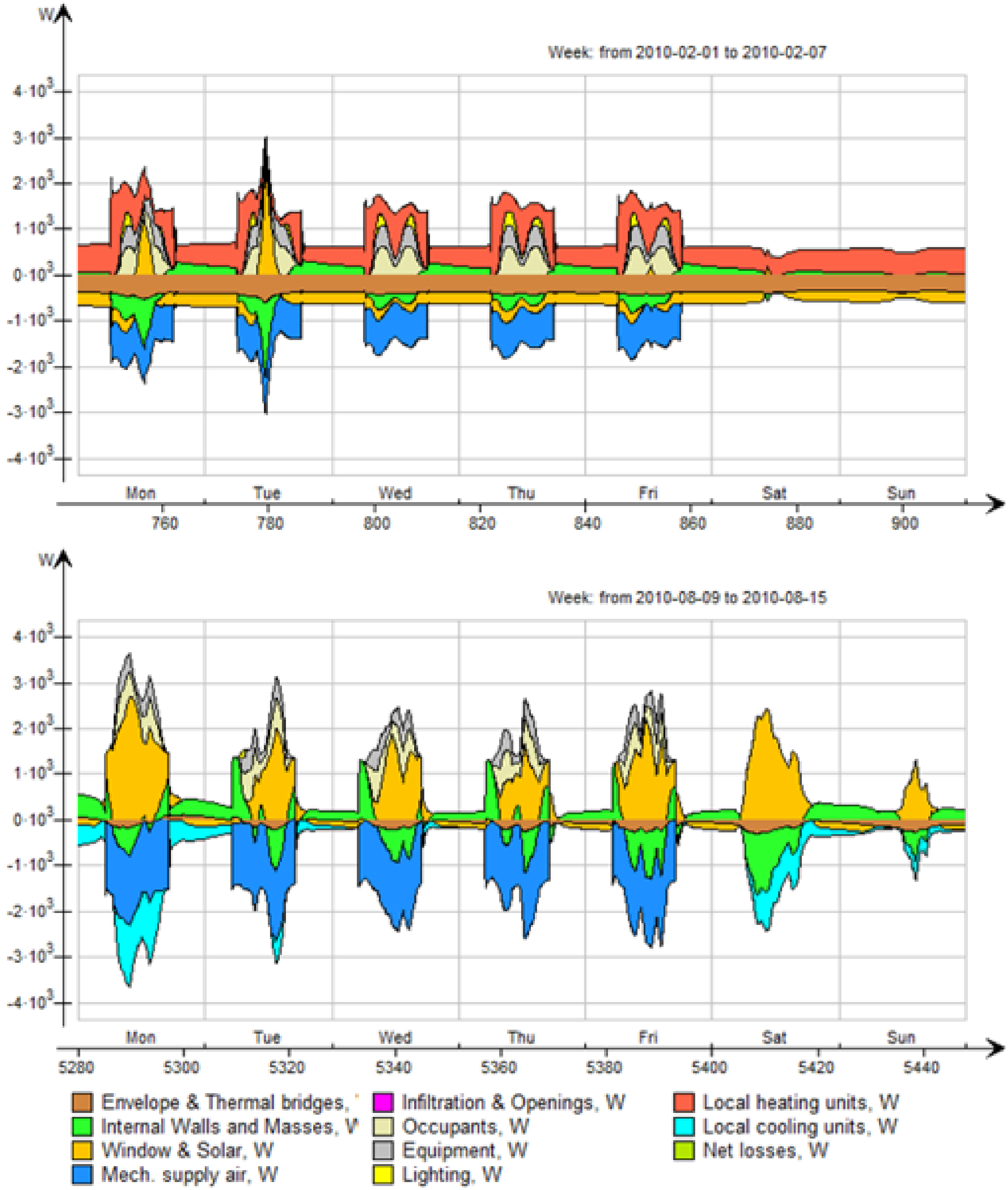


Figure 19: IDA ICE Energy Balance winter week (top) and summer week (bottom)

8.1 ENERGY RESILIENCE

To test the energy resilience of the building, the cooling and heating system is turned off on a summer and winter day, respectively. The breakdown occurs during peak hours from 12-16. At Figure 20, the effect on the room temperature hereof is illustrated. When the cooling system breaks down the 21st of July, the temperature rises quickly, and a rise of 2 degrees of the operative temperature occurs within four hours. If a breakdown of the heating system occurs the 21st of January, the operative temperature does not drop 2 degrees. This indicates that the building is most sensitive to changes of the cooling system.

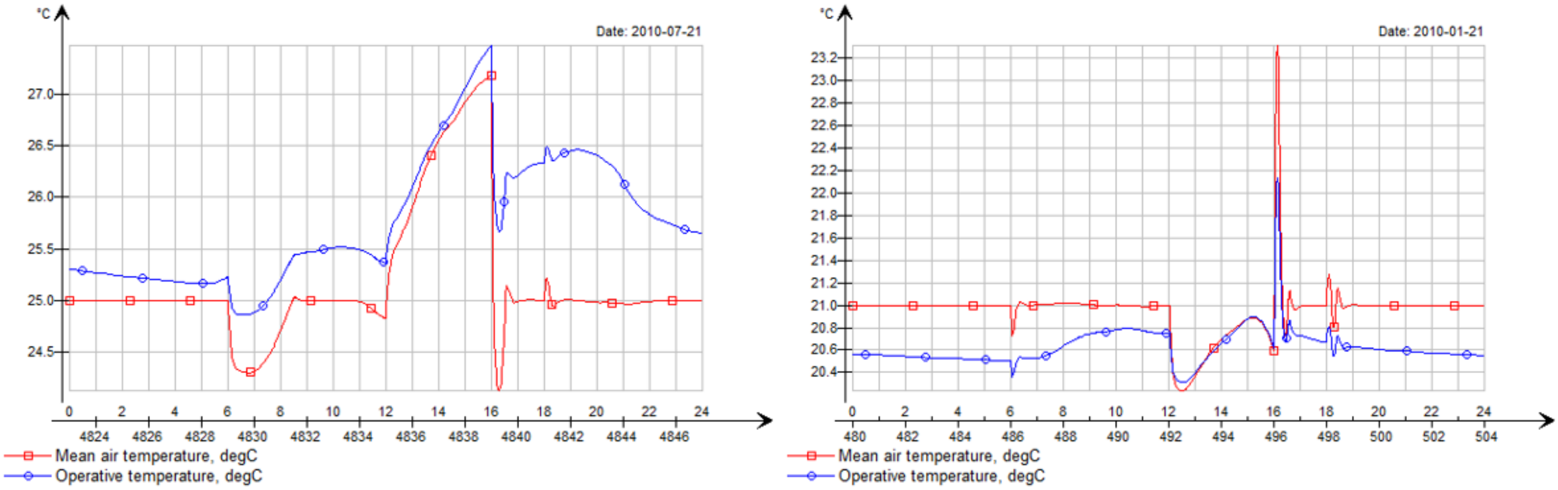


Figure 20: Cooling and heating break

9 ACOUSTICS

An acoustic concept is considered for the building. The slabs between floors are well insulated to minimize noise pollution between floors. Offices are separated by walls and doors into smaller office areas. At each office floor, phone booths are available for meetings and phone calls, minimizing noise pollution from colleagues in open office spaces.

The technical shafts are not placed adjacent to meeting rooms and offices which minimizes noise disturbances. Main ventilation ducts are mainly placed in the corridors and over the toilets. Ventilation routing is planned to have only small duct ramifications above office spaces. Ducts are designed with silencers.

The reverberation time is analyzed for room 1, using Sabine's equation. In Table 12, surface areas and absorption coefficients are presented [6], [7], [8].

Table 12: Absorption areas and coefficients in Room 1

	SURFACE AREA [m²]	**MATERIAL ABSORPTION, α**
Painted gypsum wall	102.2	0.05
Glazing	23.6	0.03
Wood floor	64.6	0.07
Acoustic ceiling	64.6	0.6
Door	1.8	0.04

With the volume of Room 1 at 193.9 m^3, the reverberation time is determined to be 0.63 s. Calculations can be found in Appendix I. To compare, the Danish Building code recommends a reverberation time of ≤ 0.6 s.

10 ENERGY FRAME CALCULATION

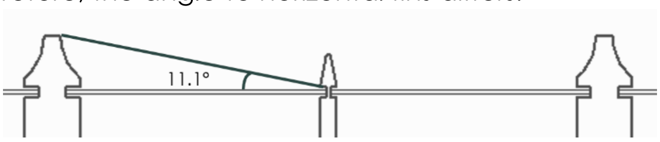
To comply with the Danish building code, the energy frame should not exceed 41+1000/heated floor area kWh/m^2 per year. The energy frame is calculated using Be18. The following section provides main inputs and results of the energy frame calculation. Additionally, extracted key outputs, model input parameters and results are to be found in Appendix J.

The building has a developed area of 1479 m^2, and 16 floors. The site rotation is set to 73 degrees from north. The heat capacity of the building is set to 76 Wh/K m^2 calculated based on Table 7 in [9] for a medium compact building. The building type is "other" and has a use time of 45 hours/week from 8 to 17.

In the energy frame calculation, U-values presented in Section 2 are used. A heat loss coefficient of 0.2 W/mK is assumed in joins between external walls and roof based on the minimum values according to the Danish building code. A heat loss coefficient of 0.28 W/mK is used for joins between external walls towards the cold basement, based on Table 6.13.7a in DS 418 [1].

The glazed area of the building is divided into 12 representative areas to account for different g-values, orientation and shading objects from the façade. All windows have a glass fraction of 0.9 and U-value of 1.265 W/m^2K. Windows with a low g-value are marked at Figure 15: Facades with low g-value windowsFigure 15 in Section 7.

The façade has both vertical and horizontal terrazzo fins of 390 mm, that can cause a minor shadow on the glazed area. The angle to the façade objects from the windows is calculated and included in Be18. Figure 21 shows this. Horizontal fins are only placed at every second floor. Therefore, the angle to horizontal fins differs.



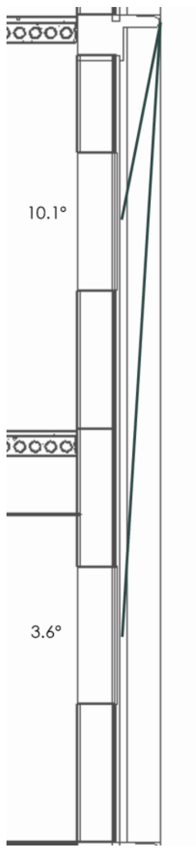


Figure 21: Horizontal and vertical shading

Some input values for ventilation are presented in Table 13. A working time of ventilation at 70% and 40% respectively for the auditorium and cafeteria is assumed. The mechanical ventilation during summer and winter is the same, since the ventilation is dimensioned with the main purpose of maintaining good air quality, while room cooling not the main purpose. For the auditorium and cafeteria average values from DS/EN 16798-2 [10] Table B.6 and B.7 are used. For offices and meeting rooms the mechanical ventilation used for the calculation is 1.2 l/s m^2. As Appendix B shows, the calculated ventilation flow for offices and meeting rooms are higher, due to a large occupancy in these zones. Ventilation by infiltration is calculated to comply with the Danish building code with q_{50}. The SEL value is estimated to an average value of 1.2, except for rooms not in use where the SEL is estimated to be 0.8 KJ/m^3. It is assumed that the SEL will be higher during peak periods and lower during off-peak periods. Therefore, an average value is chosen.

Table 13: Be18 ventilation input

ZONE	**F_O**	**q_m l/s m²**	**SEL KJ/m³**	**q_n l/s m²**	**q_i l/s m²**
Offices	1	1.2	1.2	0.082	0.042
Corridors	1	0.7	1.2	0.082	0.042
Meeting Rooms	1	1.2	1.2	0.082	0.042
Auditorium in use	0.7	4.05	1.2	0.082	0.042
Auditorium empty	0.3	0.7	0.8	0.082	0.042
Canteen in use	0.4	5.4	1.2	0.082	0.042
Canteen empty	0.6	0.7	0.8	0.082	0.042
Student area	1	1.2	1.2	0.082	0.042
Ground floor	1	0.7	1.2	0.082	0.042

For internal heat loads, 4 W/m² is included to account for heat load from persons, and 6 W/ m² for apparatus during use time as suggested in [9] for "other" buildings.

Lighting for offices, meeting rooms, auditorium and cafeteria is controlled by daylight. In Table 14 selected input parameters concerning lighting can be seen. For offices, 1 W/m² is further included for desk lamps during occupancy hours. At the office floor, the average daylight factor was found to be 2.7. This value is assumed to be representative for the student area and ground floor as well.

Table 14: Be18 lighting input

ZONES	**$Almen_{min}$ W/m²**	**$Almen_{inst}$ W/m²**	**Lux**	**DF%**	**F_O**
Offices	0.2	5	300	2.7	1
Meeting rooms	0.2	5	300	1	0.7
Staircase	0.2	5	100	0	1
Café	0.2	5	200	2	0.6
Auditorium	0.2	10	300	1	0.7
Corridor	0.2	3	200	0	1
Technical floor	0.2	5	100	0	0.3
Student area	0.2	5	300	2.7	1
Ground floor	0.2	3	200	2.7	1
Toilets	0.2	3	100	0	1
Technical shaft	0.2	3	100	0	0.3
Rest	0.2	3	100	0	0.7

Furthermore, Pipes for heating, heat pumps and pipes for hot water circulation is included in the energy frame calculation.

The energy frame calculation of the building results in a total energy demand of 39.1 kWh/m², which shows compliance with the Danish Building Regulation.

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