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Dynamic building model for building simulation in a professional tool - UNIZGFER skyscraper building

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Abstract (for dissemination)	This deliverable presents the thermodynamic model of the skyscraper building of the University of Zagreb Faculty of Electrical Engineering and Computing. The model is created in IDA ICE professional building modelling software and its performance verified against energy consumption data from energy bills.
Keyword List	dynamic building model, construction data, simulation scenarios, heating/cooling building demand, zone temperature dynamics, building data

Revision history

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Executive summary

This deliverable gives a comprehensive report on development and validation of the dynamic model of the University of Zagreb Faculty of Electrical Engineering and Computing (UNIZGFER) skyscraper building. The building comprises the basement, 13 floors (+ the ground floor), and a flat roof. Two building floors (9th and 10th) are equipped with an advanced central control unit for heating/cooling, which enables data acquisition from the building zone side to a central database. The goal of the 3Smart project is to equip the rest of the building with sensors and data acquisition equipment so as to include the whole building into one common Building Energy Management System (BEMS). One of the key parts for development of BEMS is dynamic model of the building, which is derived in this deliverable.

This deliverable is structured as follows. Chapter 1 gives basic information on building infrastructure. Detailed building construction data are described in Chapter 2. Based on all the information given, detailed building model is constructed in simulation software IDA-ICE [8] and presented within Chapter 3. Simulation scenario is specified in Chapter 4, while simulation results and verification of the developed model based on data from energy bills are given in Chapter 5.

1. Basic building architecture

Construction of the UNIZGFER skyscraper (Figure 1) was finished in 1963. It was designed by Božidar Tušek, renowned Croatian architect. The building has a flat roof, 13 floors, the ground floor, and the basement.

Figure 1: UNIZGFER skyscraper building.

1.1 Location and orientation of the building

The building is located at Unska 3, Zagreb (spatial coordinates [45,80° N, 15,97° E]) and has east-west orientation (Figure 2, Figure 3) with deviation of 5 ° from the east-west axis (Figure 4).

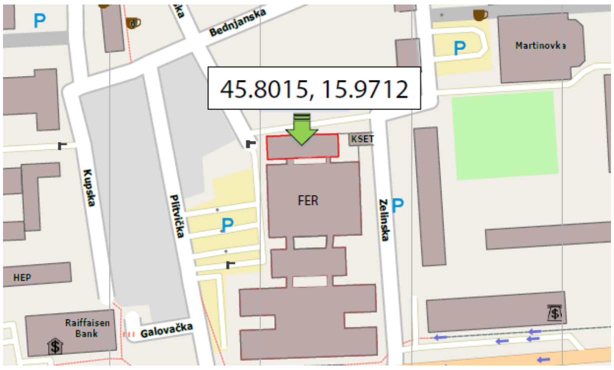

Figure 2: Location of the FER skyscraper

Figure 3: Google maps screenshot of the FER skyscraper

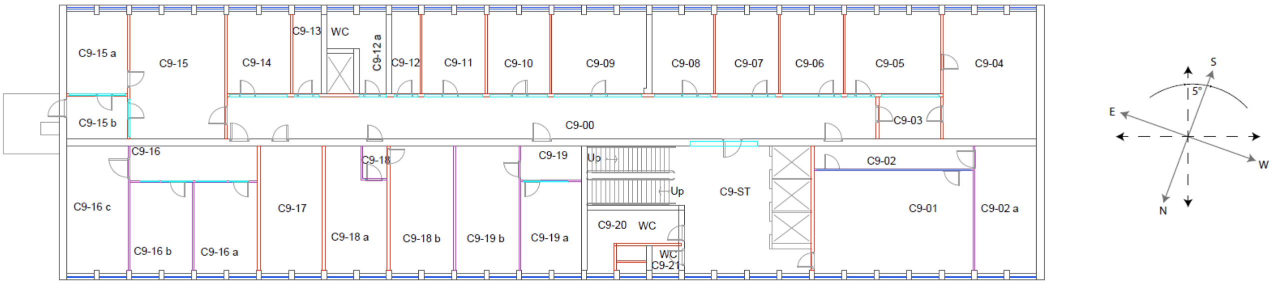

Figure 4: Typical floor arrangement (floors 1-12 of the FER skyscraper) and the building orientation.

1.2 Building shape and construction

The building has a rectangular shape with an east-west axis. External dimensions of the building (length x width x height) are: 53,05 m × 15,46 m x 55,32 m.

2. Building construction and materials

The main building skeleton is made of a reinforced concrete. The building envelope consists of reinforced concrete walls on the east and west side of the building and 58 uniformly distributed bearing pillars per each floor on the north and south face of the building. The walls between pillars are typical brick walls covered with asbestos-cement boards. Original internal walls from 1963 are made of bricks, while later upgrades are made of drywall. Since the building dates from the early 60s, the insulation in the ceiling is made of plaster and reed.

1.2.1. External building walls

East- and west-facing parts of external building envelope are made of reinforced concrete in the basement (Figure 5), while in the rest of the building reinforced concrete is combined with reed and bricks (Figure 6).

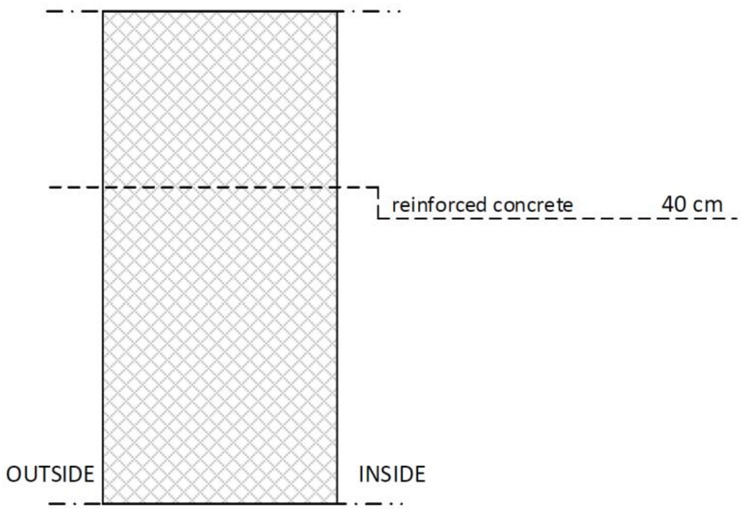

Figure 5: East- and west-facing external walls in the basement (EW1).

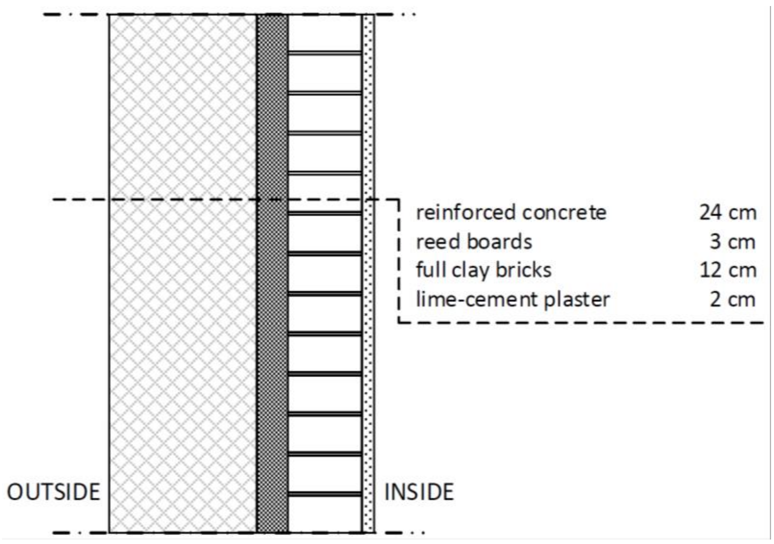

Figure 6: East- and west-facing external walls from the ground floor to 13th floor (EW2).

South- and north-facing building envelope consists of 58 uniformly distributed reinforced concrete bearing pillars from ground-floor up to the 12th floor. The dimensions of pillars are 25 cm × 45 cm. The space between the pillars is filled with 40 cm reinforced concrete in the basement and with brick walls in the rest of the building (Figure 7).

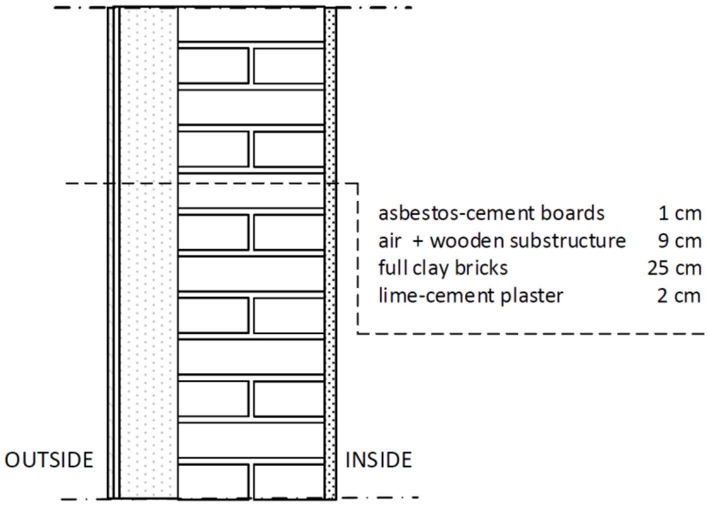

Figure 7: South- and north-facing external walls from ground-floor to 12th floor (EW3).

The detailed cross section view of a south- and north-facing external wall is given in Appendix 1. The south- and north-facing external walls on the 13th floor are made of bricks and insulated with lime-cement plaster and Styrofoam (Figure 8).

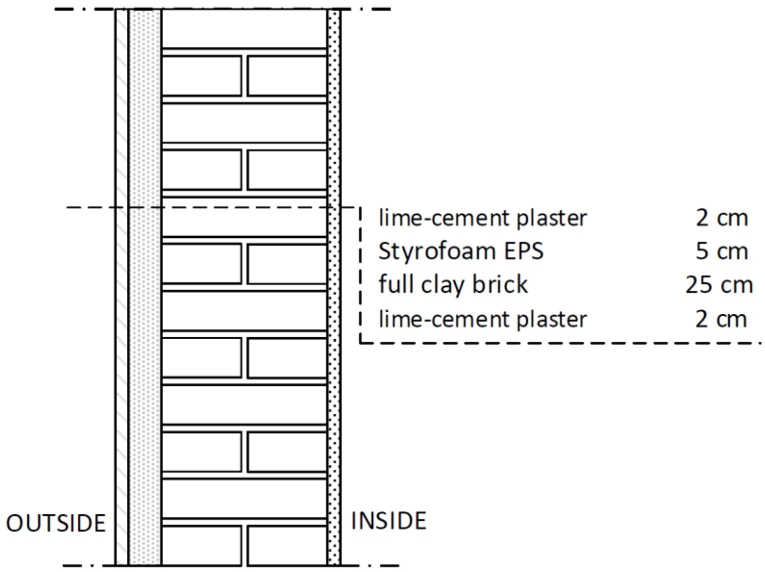

Figure 8: South- and north-facing external walls on the 13th floor (EW4).

1.2.2. Internal walls

There are two types of internal walls, bearing reinforced concrete walls and partition walls made of bricks. Bearing walls are made as 25 cm, 30 cm and 50 cm thick reinforced concrete with 1 cm lime-cement plaster insulation on each side (BW1, BW2, BW3) (Figure 9).

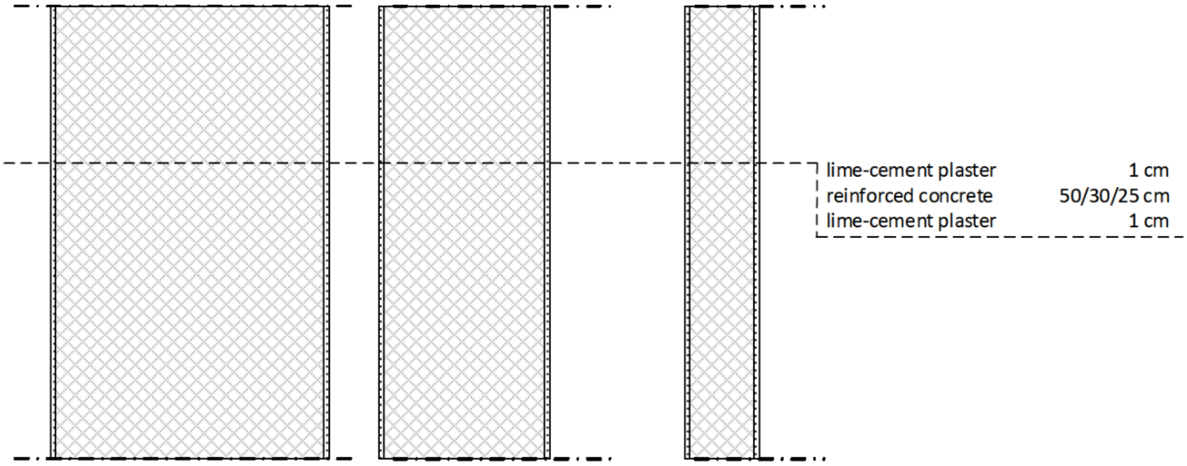

Figure 9: Internal bearing walls (BW1-BW3).

Brick walls are made in two standard variations, as 7 cm thick walls (PW1) (Figure 10) and as 13 cm thick walls (PW2) (Figure 11).

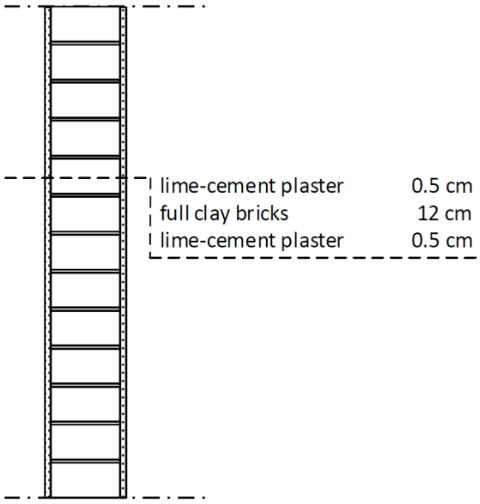

Figure 10: Internal partition brick walls (PW1).

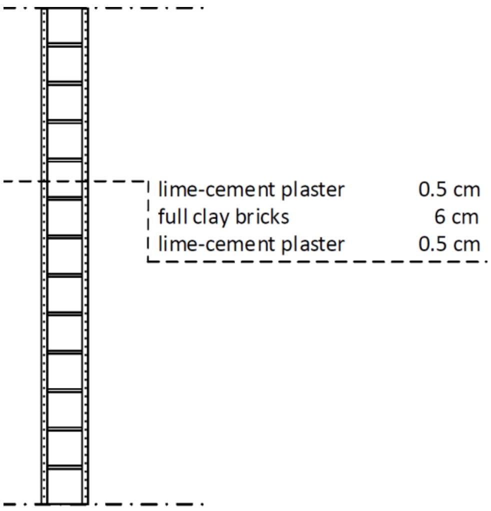

Figure 11: Internal partition brick walls (PW2).

Drywalls are made in two standard variation, as 10 cm thick walls with single gypsum board on each side and 7 cm mineral wool insulation (PW3) (Figure 12) or as 15 cm thick walls with double gypsum boards on each side and 10 cm mineral wool insulation (PW4) (Figure 13).

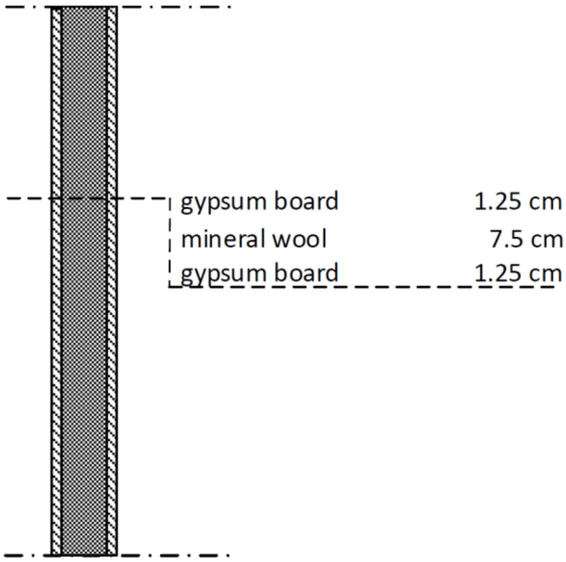

Figure 12: Internal partition gypsum wall (PW6).

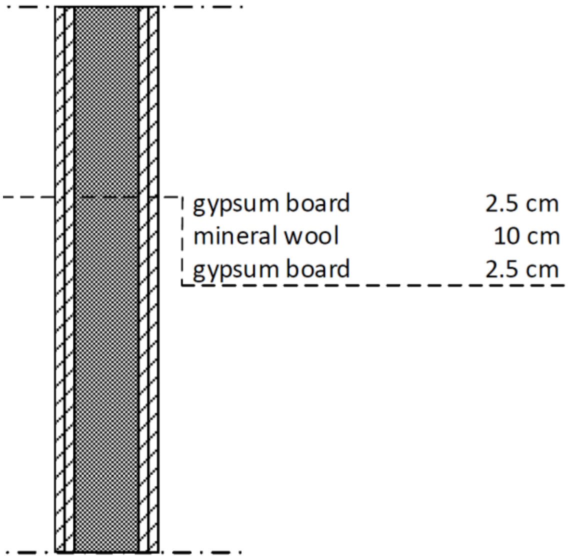

Figure 13: Internal partition gypsum wall (PW7).

1.2.3. Floors and ceilings

Typical floors/ceilings in the building are made of 5 cm thick reinforced concrete positioned on 13 cm thick and 35 cm high reinforced concrete bearing beams. There are 2 main types of floor covering, wooden oak parquet (FC1) and terazzo (FC2), both 6 cm thick. Ceilings are the same across the building, made of 5 cm reed and cement plaster. The cross section of FC1 and FC2 are shown in Figure 14.

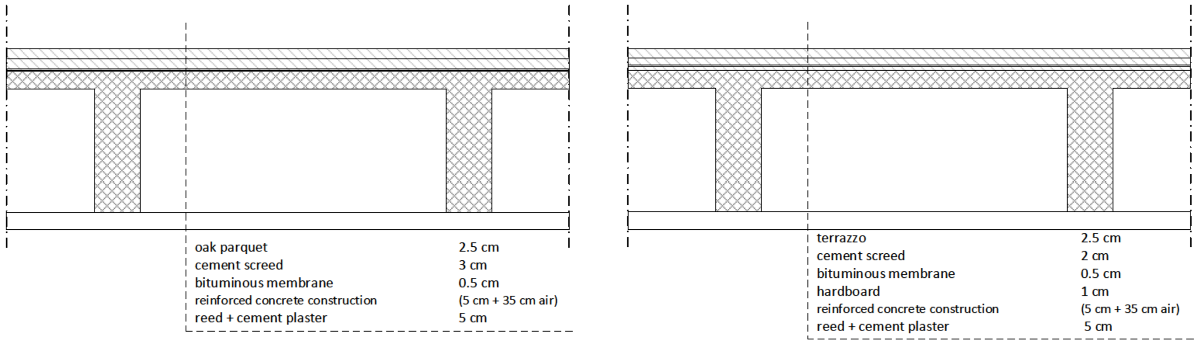

Figure 14: Floors/Ceilings across the Faculty building (FC1, FC2).

The basement floor is made of 80 cm thick reinforced concrete covered with bituminous membrane to assure hydro-isolation, 3 cm thick cement screed and oak parquet (FC3) (Figure 15).

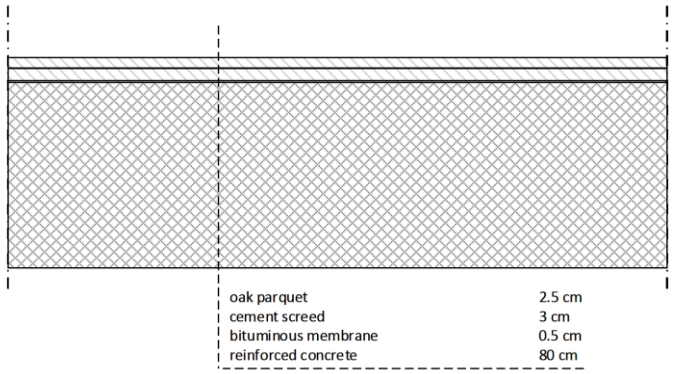

Figure 15: Basement floor (FC3).

The 13th floor has an enclosed terrace so the ceiling of the 12th floor is additionally insulated (FC4) (Figure 16). The terrace floors are made of 4 cm concrete tiles, insulated with 1 cm bituminous membrane, 1 cm cement screed, 6 cm concrete, additional 0.5 cm bituminous membrane and 1.5 cm hardboard (FC5) (Figure 17).

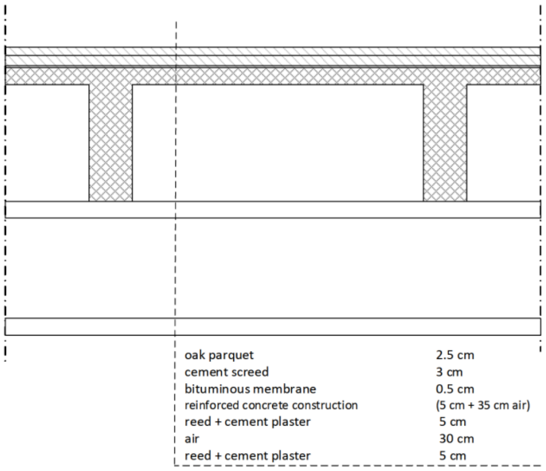

Figure 16: 12th floor ceiling/ 13th floor floor (FC4).

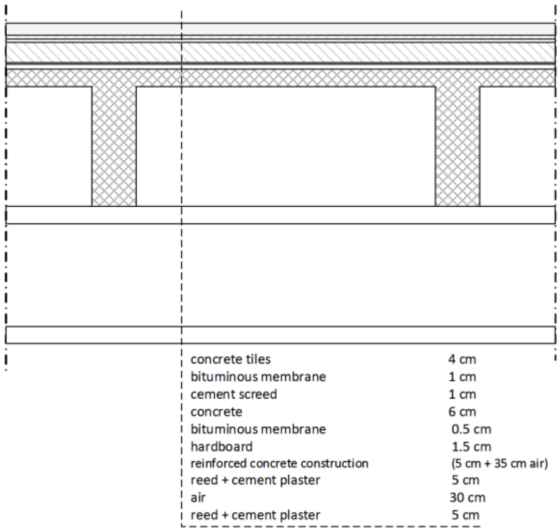

Figure 17: 12th floor ceiling/13th floor floor across the terrace (FC5).

1.2.4. Roof

The building roof (FC7) is made as a flat roof (Figure 18), with ceiling made of gypsum board placed on typical ceiling reinforced concrete composition insulated with 1 cm cement screed, 2 cm bituminous membrane, 10 cm extruded polystyrene foam (XPS), 1.5 cm thick geotextile fabric and covered with 5-7 cm gravel.

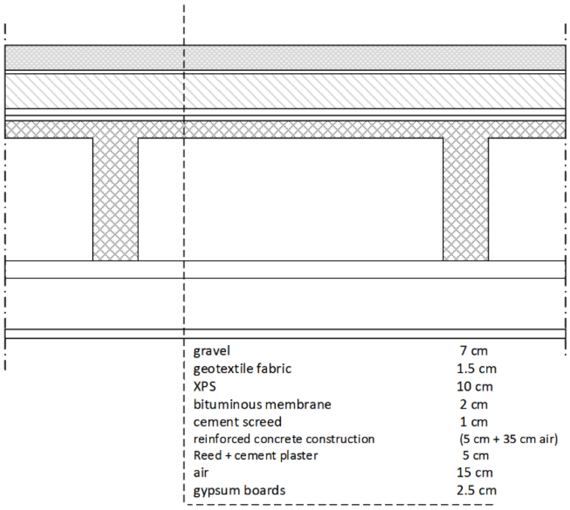

Figure 18: Flat building roof.

1.2.5. Windows and doors (openings)

During renovation in 2003 the old building windows were replaced by the new, double glazing aluminium frame windows 6/12/5 (6 mm of clear float glass from outside, 12 mm of air, 5 mm of clear float glass from inside). North- and south-faced envelope walls (Figure 19, Figure 20) from ground floor up to 12th floor have the same windows with total area of each window equal 3,04 m^2 (WT1) (Figure 21).

Figure 19: North-facing building envelope.

Figure 20: South-facing building envelope

Approximately 30% of the total window WT1 area goes to the frame. Total glazing area is 2,1 m^2 and the total frame area is 0,935 m^2. Upper part of the window has only ability to twist while the bottom has ability to twist and tilt. Frame is made of the FEAL profiles, TERMO 65 series (Figure 22).

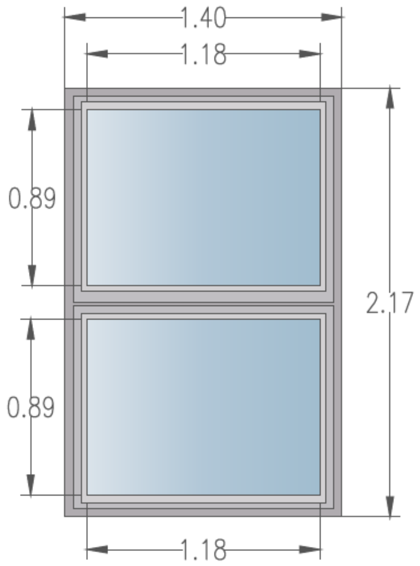

Figure 21: Dimensions of windows in floors span ground floor – 12th floor (WT1).

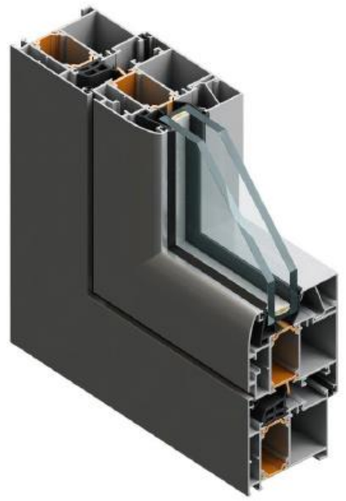

Figure 22: FEAL THERMO 65 series profile.

13th floor windows are 1 m wide and 2 m high (WT2) (Figure 23) while basement windows are 1.5 m wide and 2.32 m high (WT3).

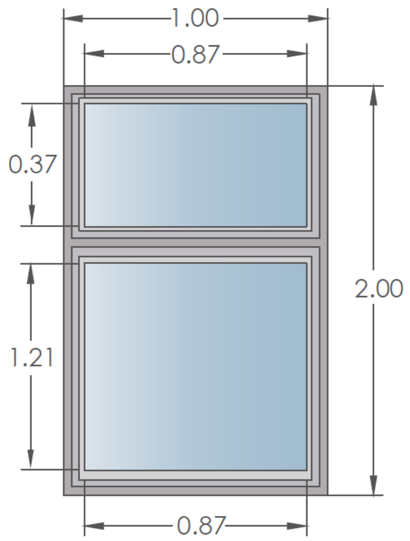

Figure 23: Dimensions of the 13th floor windows (WT2).

Thermal properties of the WT1 windows, waterproofing, wind resistance and soundproofing were tested at Civil Engineering Institute of Croatia. The obtained thermal properties are shown in Table 1, while other properties can be found in [1].

Table 1: Heat transfer coefficients of the window characteristic parts.

	glazing	frame	jamb
Total area [m^2]	2.1	0.332	0.603
Heat transfer coefficient [$W/(m^2K)$]	2.85	2.21	2.13

Overall heat transfer coefficient k_o of WT1 is calculated as:

$$k_o = \frac{2.1 \cdot 2.85 + 0.332 \cdot 2.21 + 0.603 \cdot 2.13}{2.85 + 2.21 + 2.13} = 2.63.$$

The Solar Heat Gain Coefficient (SHGC) dependence in relation to the Sun inclination angle calculated for the WT1 windows with Window software [2] is shown in Table 2:

Table 2: The SHGC valued dependence on the incidence angle.

Incidence angle [°]	0	10	20	30	40	50	60	70	80	90
SHGC	0.723	0.723	0.720	0.714	0.700	0.671	0.605	0.471	0.244	0.000

Hemispherical averaged solar heat gain coefficient for WT1 is 0.626. It is assumed that windows WT2 and WT3 have the same properties. East- and west-facing envelope walls are completely closed, i.e., without windows (Figure 24). East-facing envelope walls have one emergency exit per floor (Figure 25).

Figure 24: West-facing building envelope.

Figure 25: East-facing building envelope.

Doors through the building are typical standard size wooden doors made from oak. Three most typical door dimensions are 82/205 cm, 90/205 cm and 102/205 cm (Figure 26). Door dimensions can be found in AutoCAD floor plans in Appendix 2. Entrance doors to the departments are made of glass with iron frames. Restroom doors are made of glass with wooden door frame.

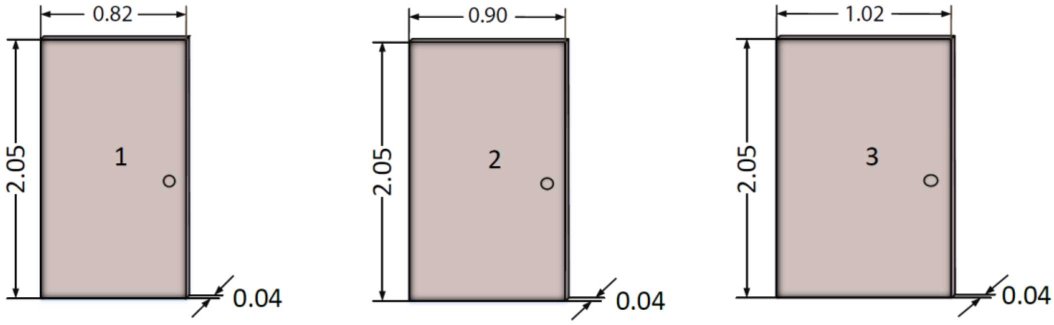

Figure 26: Three most common door types in the building (D1,D2,D3).

To assure enough light in the hallway and other rooms without external windows, glass partitions are installed across the south hallway wall and other zones where needed (Figure 27). Partitions in the gypsum walls are installed additionally after the 1963 and are made from polycarbonate boards. Other partitions are made of 6 mm float glass. All partitions span across the full wall width in height of approximately 0.85 m.

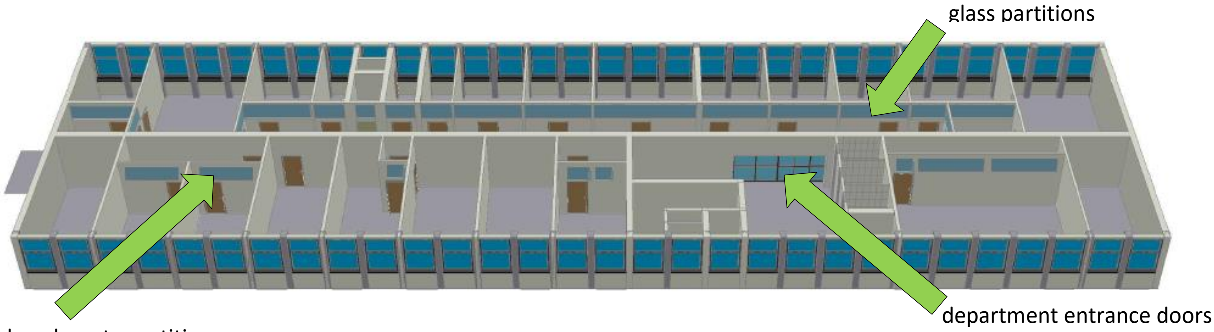

Figure 27: Typical floor configuration for the building.

1.2.6. Thermal bridges

Thermal bridges values given in Table 3, obtained as a result of building examination as a standard procedure for obtaining energy certificate are adopted.

Table 3: Thermal bridges.

Thermal bridge	W/K/(m joint)
external wall/internal slab	0,65
external wall/internal wall	0,50
external walls inner corner	-0,15
external wall bearing columns	0,90
external windows/door perimeter	0,05

Other values are adopted from the examination of similar building placed in Zagreb, Savska cesta 88 (Table 1Table 4) [3-5]. Thermal bridges for FER building defined in IDA-ICE are shown in Figure 28.

Table 4: Thermal bridges values adopted from the on-site examination of similar building placed in Zagreb, Savska cesta 88.

Thermal bridge	W/K/(m joint)
external wall / external wall	0,08
roof / external wall	0,09
external wall / external slab	0,14
balcony floor / external wall	0,60
external slab/internal wall	0,06
roof / internal wall	0,07
total envelope area	0.025 W/K/(m^2 envelope)

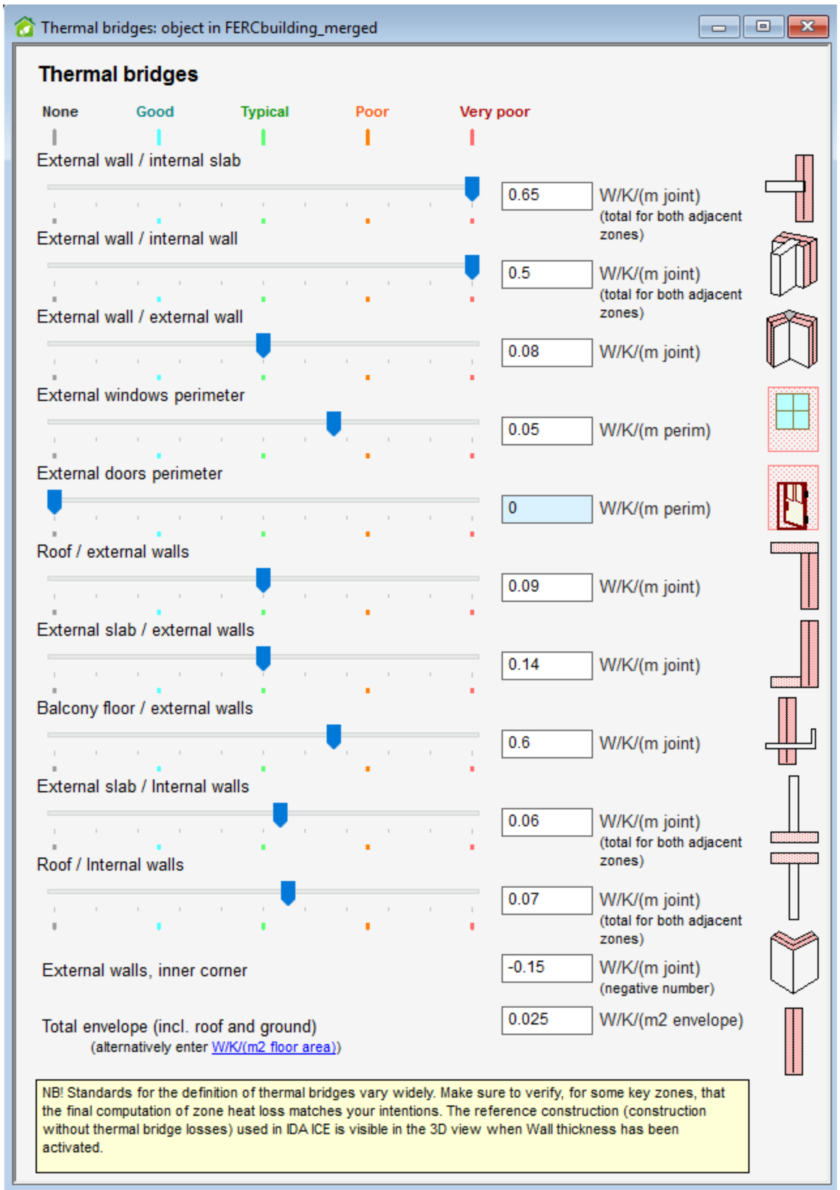

Figure 28: FER Building thermal bridges defined in IDA-ICE.

1.2.7. Infiltration

Infiltration value is adopted from the results of blower-door test performed on a similar building placed in Zagreb, Savska cesta 88 where infiltration of 3.7 air changes per hour (ACH) at pressure difference 50 Pa is measured [6],[7]. Infiltration for FER building defined in IDA-ICE is shown in Figure 29.

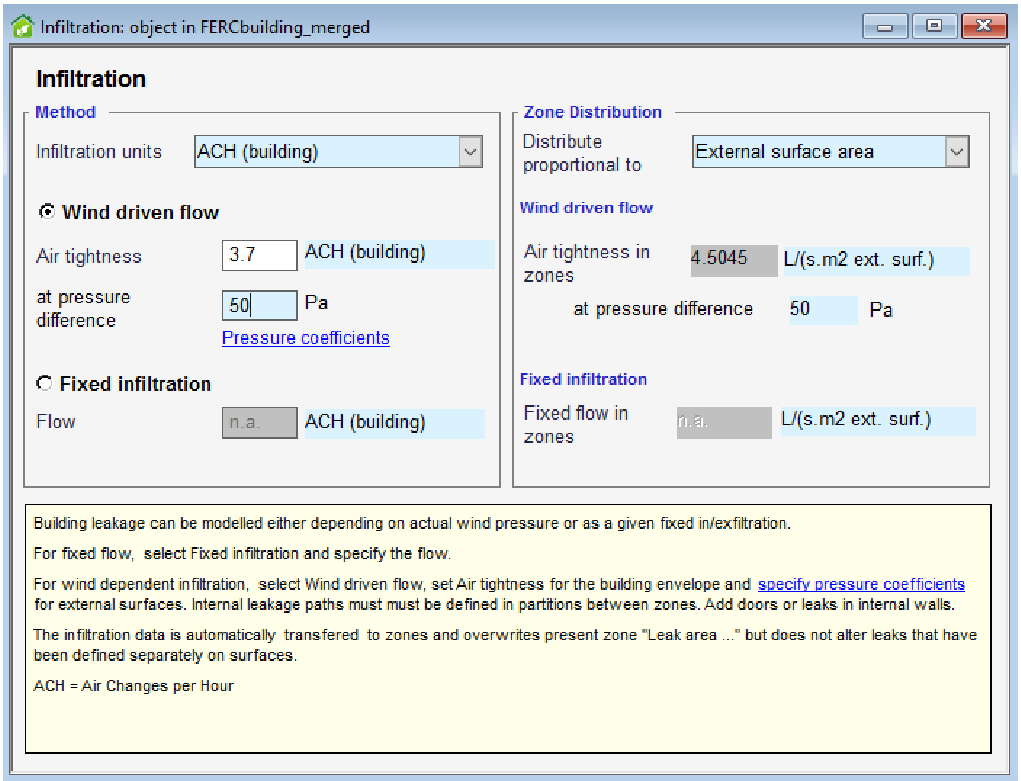

Figure 29: Infiltration for FER building defined in IDA-ICE.

1.2.8. Heating/cooling system installations

Heating/cooling installations within the UNIZGFER building consist of parallel-connected two-pipe Fan Coil Units (FCUs) for seasonal heating or cooling installed in the offices, classrooms and laboratories, and typical water radiators installed in secondary zones as restrooms, kitchenettes and stairways. Supply duct for FCUs and radiators are separated. Heating medium is supplied from district heating system, while cooling medium is locally produced within the Faculty cooling station.

2.1 Detailed properties of construction materials

Detailed thermal properties of construction materials used in the building are given in Table 5.

Table 5: Detailed properties of construction material used in the building.

Material	Thermal conductivity [W/(m K)]	Density [kg/m^3]	Specific heat capacity [J/(kg K)]
reinforced concrete	2.60	2500	1000
concrete	1.4	2300	880
reed boards	0.055	155	2000
full clay bricks	0.721	1922	837
lime-cement plaster	0.50	1300	1000
asbestos-cement board	0.58	1900	1000
air	0.23	1.2	1006
expanded polystyrene (EPS)	0.035	29	1213
gypsum	0.16	950	840
mineral wool	0.035	30	1000
oak parquet	0.19	700	2390
cement screed	0.41	1200	840
plaster ceiling tiles	0.380	1120	840
bituminous membrane	0.023	1100	2600
concrete tiles	1.100	2100	837
terrazzo flooring	1.802	2243	837
hardboard	0.130	2000	9
roof gravel	1.442	1674	881
geotextile	-	0.2	-
extruded polystyrene (XPS)	0.040	35	1500
aluminium	160	2800	896
clear float glass	1.45	2500	910
polycarbonate board	0.20	1200	1200
iron	80.2	447	7870

3. Building simulation model in IDA-ICE software

Based on all the information given, detailed building model is constructed in simulation software IDA-ICE [8]. 2D view of the 6th floor layout is given in Figure 30. Figure 31 shows 3D view of the 6th floor, while 3D view of the whole building is given in Figure 32. 3D view of typical zones is shown in Figure 33 and Figure 34.

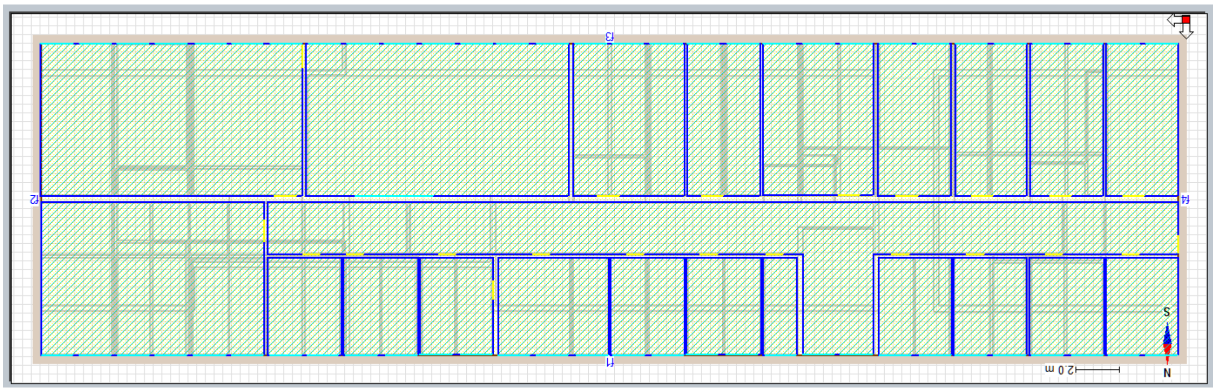

Figure 30: IDA-ICE 2D layout of the 6th floor.

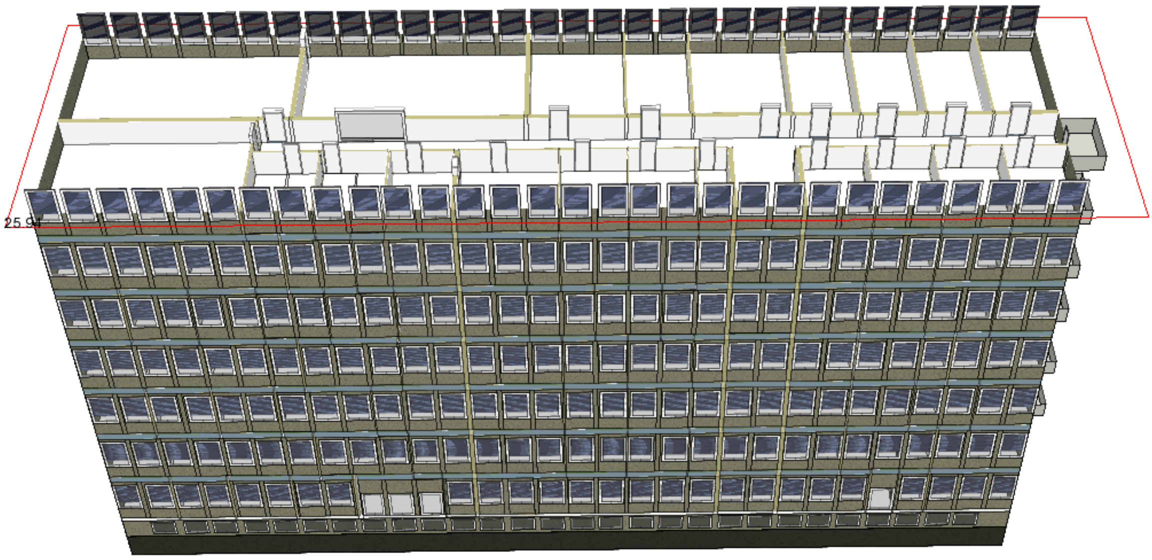

Figure 31: IDA-ICE 3D view of the 6th floor layout.

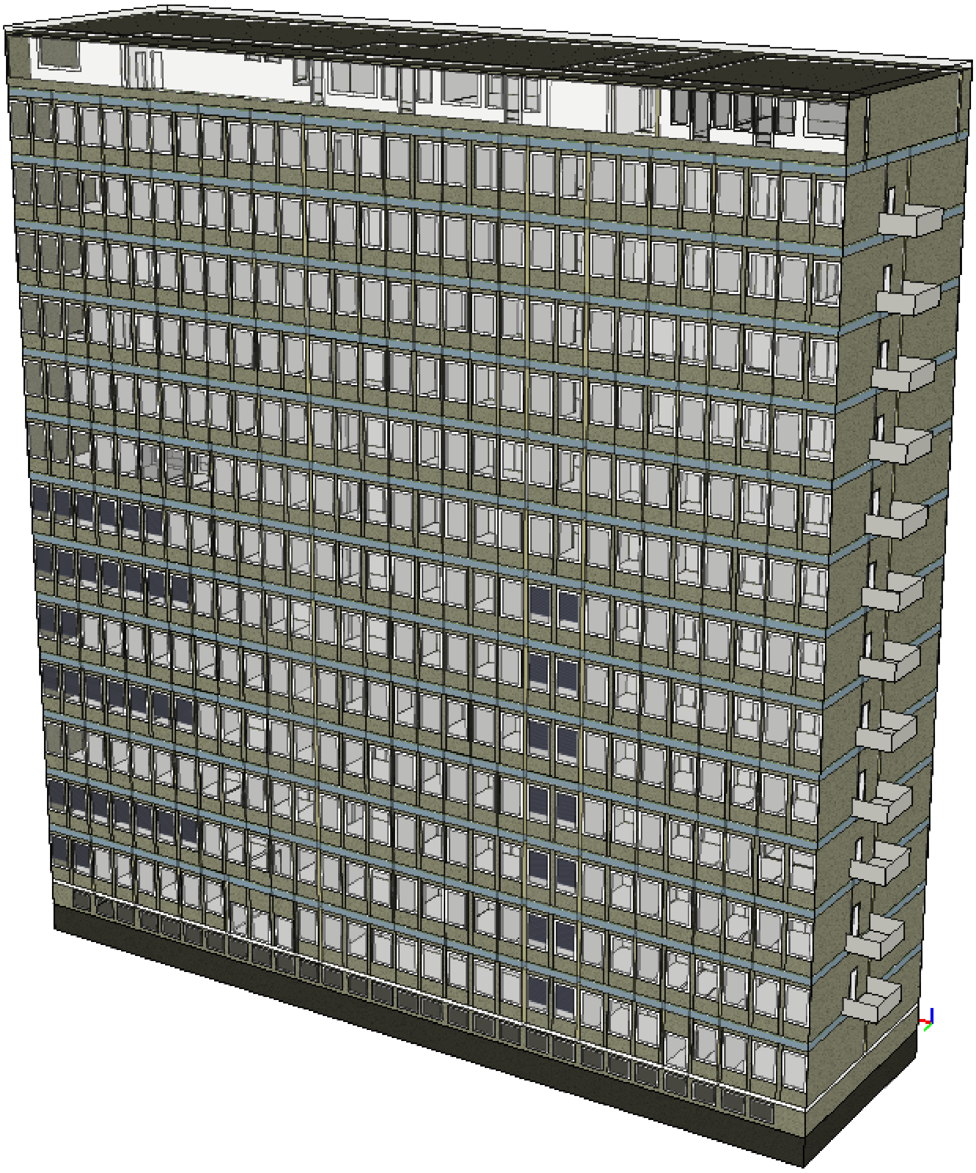

Figure 32: IDA-ICE 3D view of the FER Building.

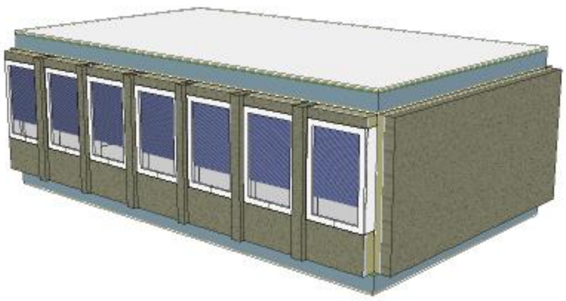

Figure 33: Typical zone used as laboratory or classroom.

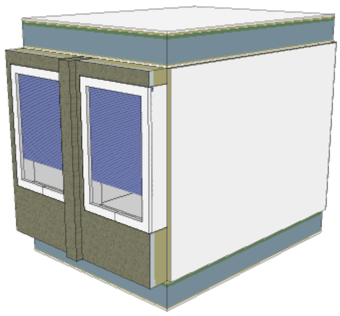

Figure 34: Typical zone used for offices.

4. Simulation scenario

4.1 Simulation scenario

Simulation scenario is chosen to fit the building occupancy profile, heating and cooling demands and window opening scenarios.

5.1.1 Heating/cooling system setup

Heating and cooling system in the building is a typical two-pipe system which implies seasonal heating and cooling. The cooling season covers approximately[1] the period from May 15th until October 1st. The rest of the year only heating is available. On a daily basis heating/cooling system operates in two regimes, the daily regime defined with working hours from 6:00-18:00 h and the night regime outside working hours.

Heating season

In the heating season temperature is regulated in both regimes. In the daily regime, the user can set arbitrary comfort conditions within some reasonable temperature range. During the night regime temperature requirements in all zones must meet temperature not less than 16°C thus preventing the temperature in zones to fall beneath the 16°C which might cause additional cost to heat up the zones again, due to the large thermal capacity of the walls. Radiators are installed only in zones which are not used regularly or are used just for a short period like hallways, restrooms, kitchenettes. During daily regime temperature in those zones is regulated to 20°C. In offices and other zones equipped with Fan Coil Units (FCUs) temperature is regulated to 22°C. Since most classrooms and laboratories are unoccupied most of the day, temperature in such zones is regulated only when they are occupied. During weekends, building is operated in the same way as in the night regime.

Cooling season

In the cooling season temperature is regulated only during the daily regime. In offices and other zones equipped with FCUs temperature is regulated to 24°C while radiators are not operable. Since most classrooms and laboratories are unoccupied most of the day, temperature in such zones is regulated only when they are occupied. During weekends building temperature is not regulated.

[1] The exact date of cooling start and cooling end depends on the weather in particular year.

5.1.2 Occupancy schedules

Occupancy schedules for the zones used as offices are generated in accordance with the zones occupancy on the official Faculty web page and working hours defined as in Figure 35. It is assumed that offices are not occupied during weekends and holidays.

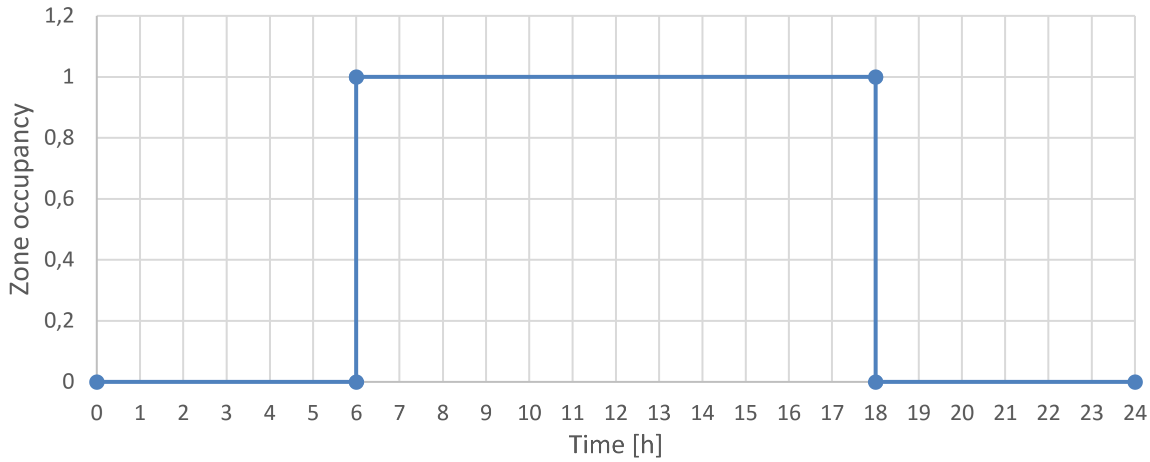

Figure 35: Zone occupancy schedule during workweek.

For classrooms, it is assumed that two lectures with 30 persons present are held daily during workdays. The lectures are assumed to be held in the morning from 10:00-12:00 h, and later from 14:00-16:00 h. To simulate the occupancy of restrooms, kitchenettes, hallways and stairways, cumulative occupancy is simulated such that every 2 hour those zones are occupied 20 minutes per 10 persons. To speed up the simulations, door opening is not simulated due to the usually short duration of such interrupts.

5.1.3 Window opening control

Since building does not have air handling units installed, the fresh air supply depends completely on window opening. Open windows with active heating/cooling are major sources of unnecessary energy dissipation. Since window opening is inevitable for ensuring healthy working environment, in the simulation scenario windows are opened three times a day per 10 minutes during workhours (Figure 36). In normal office zone only one window is opened, while in larger zones two windows are opened at the same time.

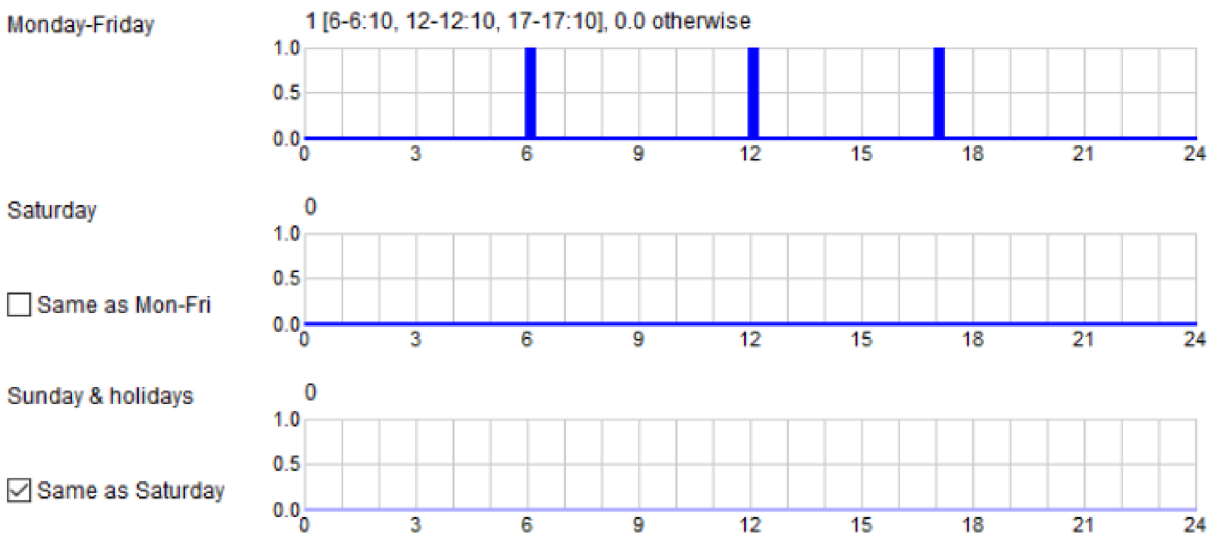

Figure 36: Fixed window opening schedule defined in IDA-ICE.

More advanced simulation with automatic CO_2 based window opening control is also possible. In such configuration windows are opened automatically when CO_2 level in zone exceeds the 900 ppm threshold and are closed automatically when CO_2 concentration falls beneath 700 ppm. Realization of such a control in IDA-ICE is shown in **Error! Reference source not found.**, Figure 38, **Error! Reference source not found.** and Figure 40.

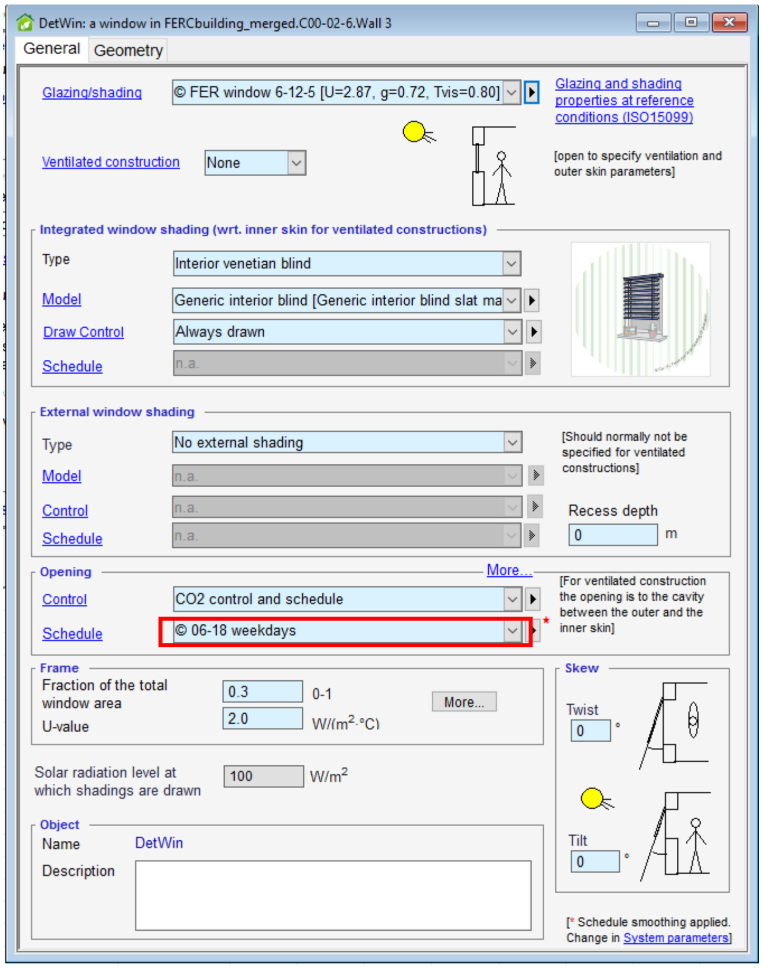

Figure 37: Windows opening control defined in IDA-ICE.

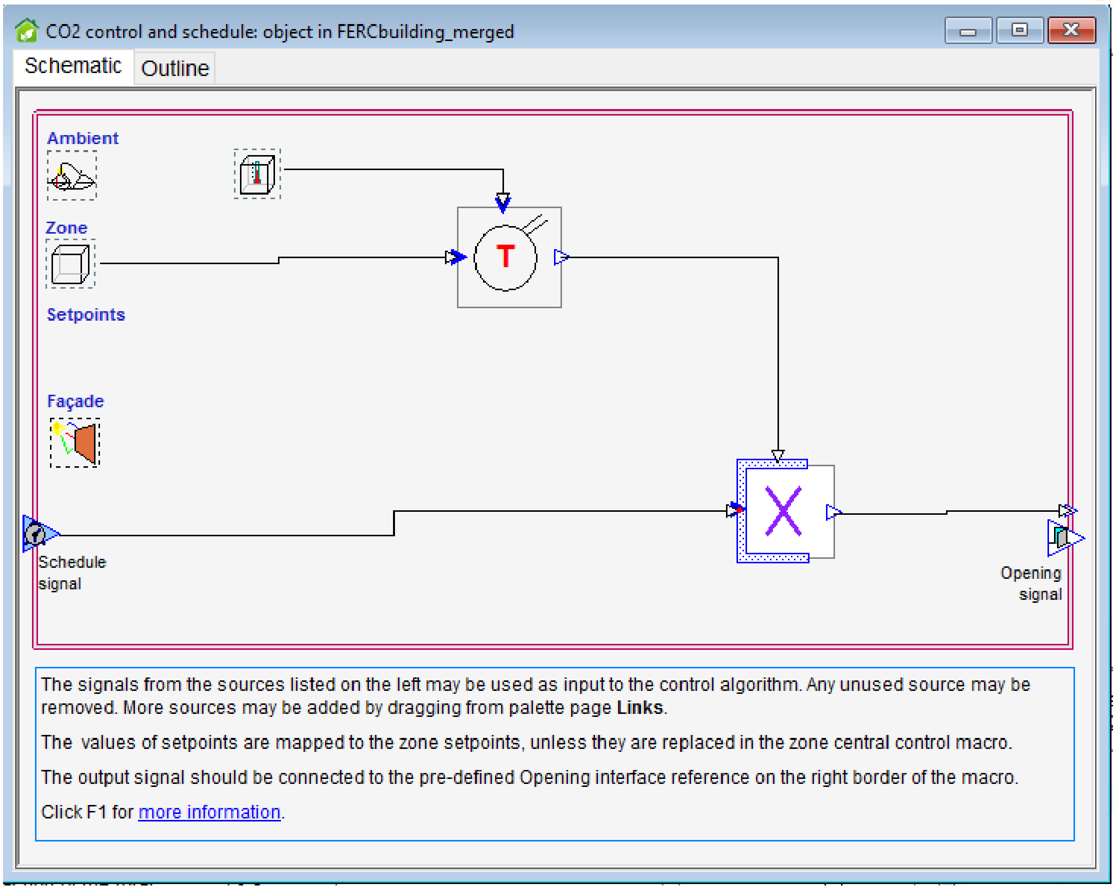

Figure 38: Windows opening control macro defined in IDA-ICE.

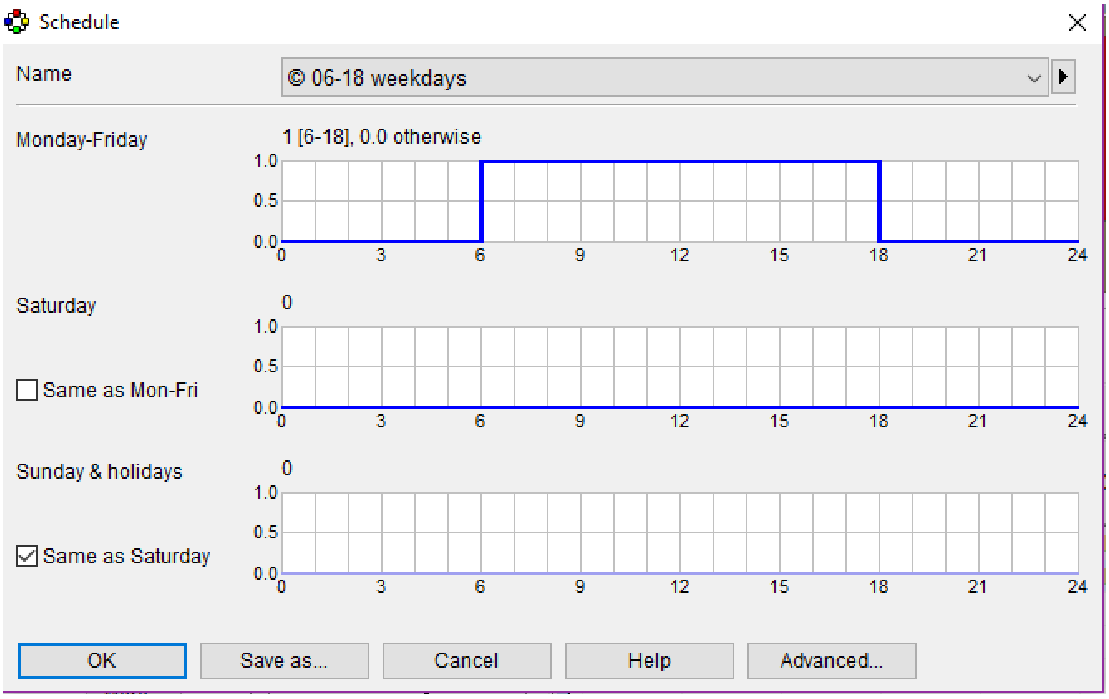

Figure 39: Occupancy schedule used for control of window opening.

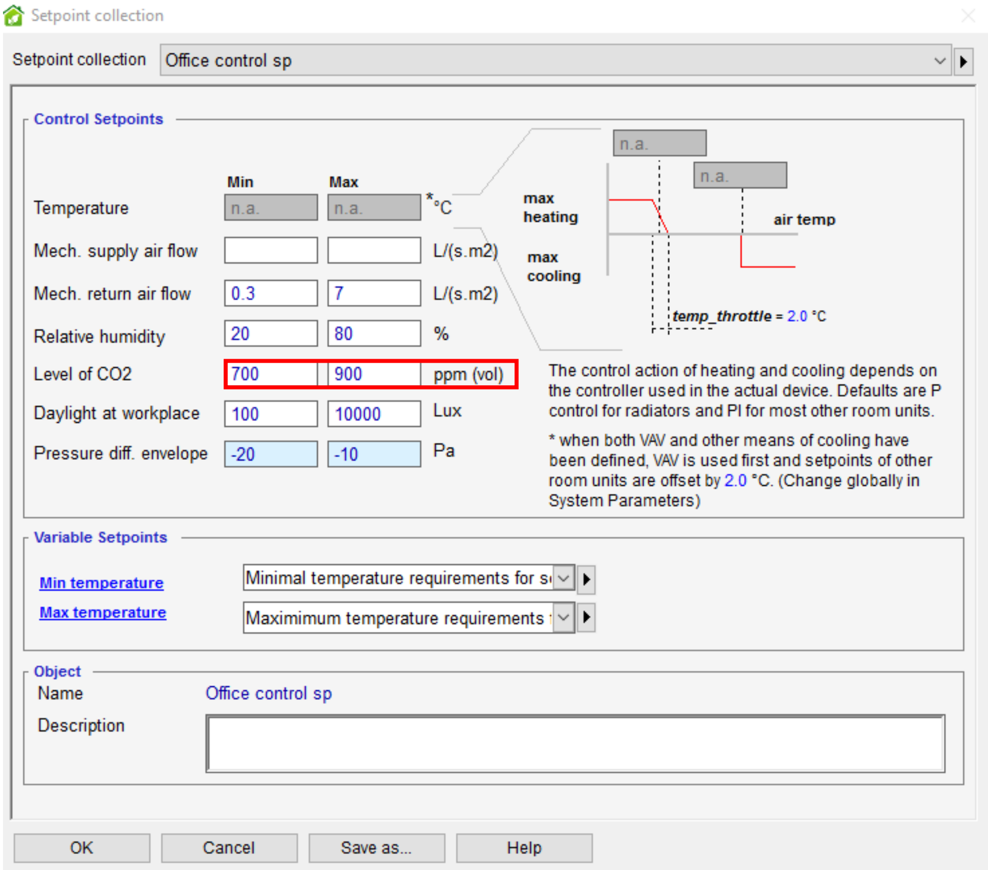

Figure 40: Acceptable office CO2 levels.

For large buildings with over 100 zones such simulations are numerically too demanding, hence a fixed window opening schedule is used in this deliverable. It is important to note that heating and cooling are not shut down when windows are opened to simulate the existing building management system.

5.1.4 Electrical equipment, lighting

Lighting in the building consists of the fluorescent lamps which do not contribute significantly to overall thermal energy consumption. Lighting is simulated such that the lights are on when zone is occupied and light intensity is below 500 Lux. The lights are turned off when daylight in office reaches 10000 Lux. Installed light power is determined as 10 W/m^2. Electrical equipment is allocated across the model such that every person in every permanently occupied zone, e.g. offices, has its own personal computer and monitor, resulting with estimated 200 W of electrical equipment per person active only during workhours.

5.1.5 Weather data

Weather data used for simulations are data gathered for year 2014 on a meteorological station close to the Faculty building (Figure 41). The data are provided by Croatian Meteorological and Hydrological Service. The data comprises outdoor temperature, direct and diffuse solar irradiance, wind speed and direction, and humidity.

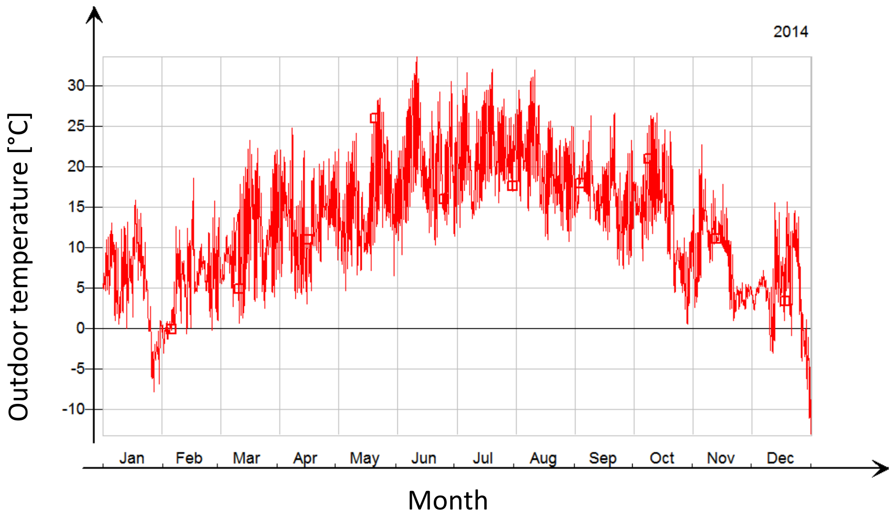

Figure 41: Historical outdoor temperature measurements for 2014.

5. Simulation results

Monthly energy demand for the simulation scenario defined in Chapter 4, for heating and cooling season in 2014 is given in Table 6 and Table 7.

Table 6: Monthly zone level thermal energy consumption during heating season in 2014. 2014.

Month		Thermal energy consumption (zone level) [kWh]	
		Fan coils	Radiators
1.	January	108.671,00	12.892,00
2.	February	90.323,00	10.825,00
3.	March	39.719,00	3.820,00
4.	April	12.802,00	898,30
5.	May	3.778,50	192,20
6.	June	**Cooling season**	
7.	July		
8.	August		
9.	September		
10.	October	19.847,00	1.795,00
11.	November	65.332,00	7.699,00
12.	December	112.658,00	12.953,00
	Overall:	**453.130,50**	**51.074,50**

Table 7: Monthly zone level thermal energy consumption during cooling season in 2014. 2014.

Month		Thermal energy consumption (zone level) [kWh]	
		Fan coils	Radiators
1.	January	**Heating season**	
2.	February		
3.	March		
4.	April		
5.	May	5.095,0	-
6.	June	16.453,00	-
7.	July	19.301,00	-
8.	August	18.347,00	-
9.	September	7.002,90	-
10.	October	**Heating season**	
11.	November		
12.	December		
	Overall:	**66.198,90**	-

Monthly energy consumption for both seasons in 2014 is shown on graph depicted on Figure 42. Presented results are measured as the energy consumed within the zone. Typical efficiency of fan coil systems is approximately 0.93 while efficiency of radiators is approximately 0.80 [9]. By taking these efficiencies into account total heating demand for the building in 2014 for the given scenario is given in Table 8. Total floor area of the building is 10.690,80 m^2 so thermal energy demand for heating in 2014 is **51,55 kWh/m^2**.

Table 8: Monthly plant level thermal energy consumption during 2014.

		2014	
Month		Thermal energy (plant) [MWh]	
1.	January	132,97	**Heating season**
2.	February	110,65	
3.	March	47,48	
4.	April	14,89	
5.	May	4,30	5,48
6.	June	**Cooling season**	17,69
7.	July		20,75
8.	August		19,73
9.	September		7,53
10.	October	23,58	**Heating season**
11.	November	79,87	
12.	December	137,33	
	Overall:	**551,08**	**71,18**

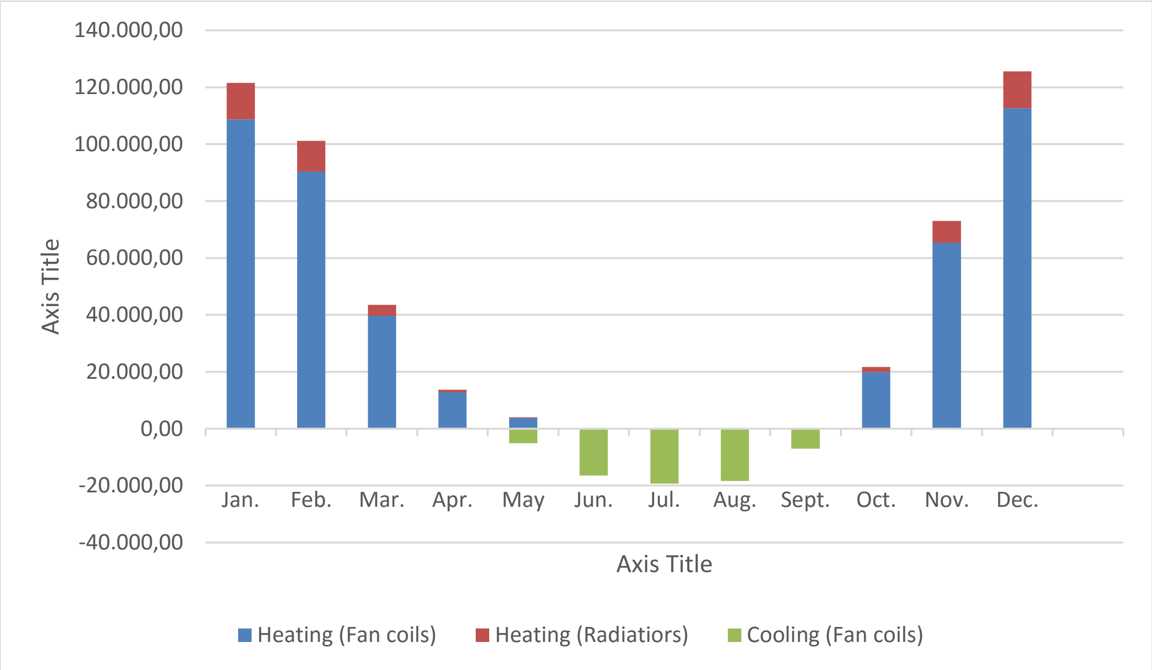

Figure 42: Monthly energy consumption for heating/cooling in 2014.

Detailed consumption report from building simulation software IDA-ICE containing light and electronic equipment consumption data can be found in Appendix 4.

5.1 Zone level dynamics

When running the simulation, one can choose an arbitrary sampling time for the zone level data such as mean air temperature, operative temperature, heat from heating and/or cooling room units, window thermal losses, heat from lighting, heat from occupants, etc. Such information can be of great importance for running a building model identification procedure when data from a real building are missing or are hard to reach. To capture the behaviour and impact of all disturbances affecting the building behaviour minute sampling time has been chosen. Simulation results for typical south oriented zone with the construction as shown on Figure 34 are shown on **Error! Reference source not found.** and Figure 44.

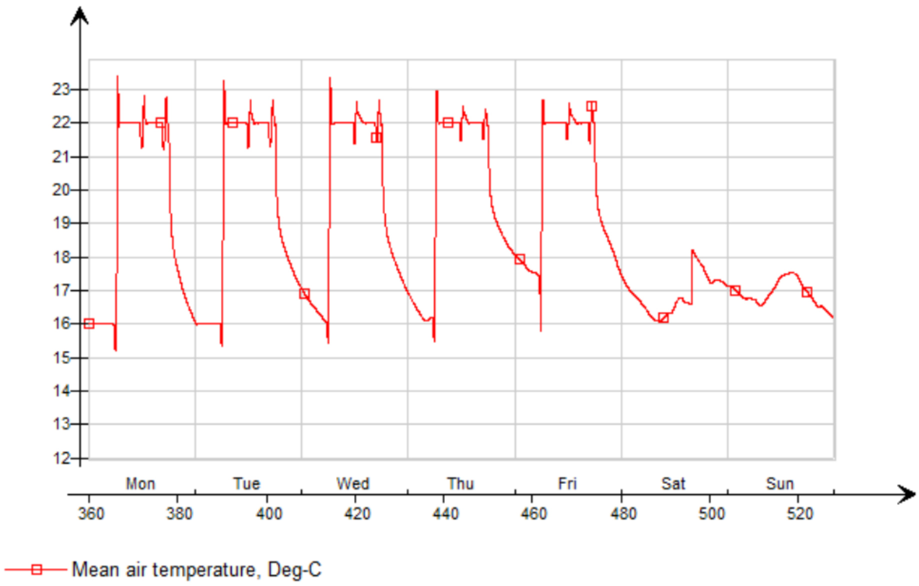

Figure 43: Simulation results for typical south oriented office for the period from January 16th – 22nd 2014.

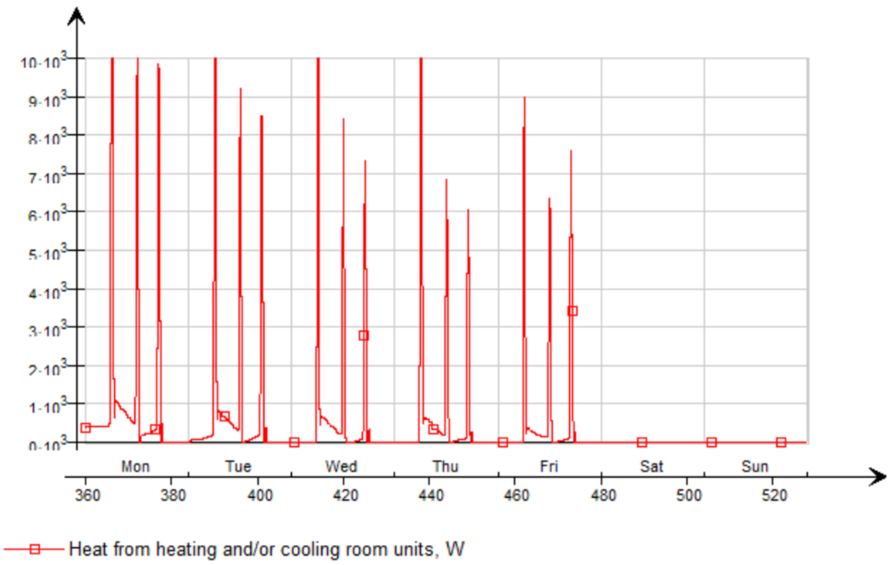

Figure 44: Simulation results for typical south oriented office for the period from January 16th – 22nd 2014.

Spikes on the right part of the Figure are due to the window opening impact. Total heat balance for the selected zone in the week from January 16th-22nd in 2014 is shown in Figure 45.

Detailed heat balance for zone

IDA Indoor Climate and Energy	4.71 License: IDA40:ED182/Q5B3F (educational license)
Object:	C04-11.Heat balance
System:	C:\Users\mladen\Desktop\FER - Czgrada - Simulacije\FER_Czgrada_2014 \FERCbuilding.idm
Description:	
Simulated:	19.6.2017. 1:45:34 [2469]
Saved:	19.6.2017. 9:51:19

Week	Variables									
	Heat from air flows, W	Heat from occupants (incl. latent), W	Heat from equipment, W	Heat from walls and floors (structure), W	Heat from lighting, W	Heat from solar - direct and diffuse, W	Heat from heating and/or cooling room units, W	Heat from windows (including absorbed solar) and openings, W	Heat from thermal bridges, W	Net losses, W
3	-271.8	44.79	106.6	-151.5	53.28	11.38	489.9	-222.5	-78.16	0.0
mean	-271.8	44.79	106.6	-151.5	53.28	11.38	489.9	-222.5	-78.16	0.0
mean*168.0 h	-45654.8	7524.6	17902.2	-25454.6	8951.1	1912.1	82296.2	-37384.4	-13131.6	0.0
min	-271.8	44.79	106.6	-151.5	53.28	11.38	489.9	-222.5	-78.16	0.0
max	-271.8	44.79	106.6	-151.5	53.28	11.38	489.9	-222.5	-78.16	0.0

Figure 45: Detailed heat balance for the selected zone in week from January 16th-22nd 2014 (screenshot of IDA-ICE report).

Daily zone temperature variations for an arbitrary selected north oriented zone are shown on Figure 46.

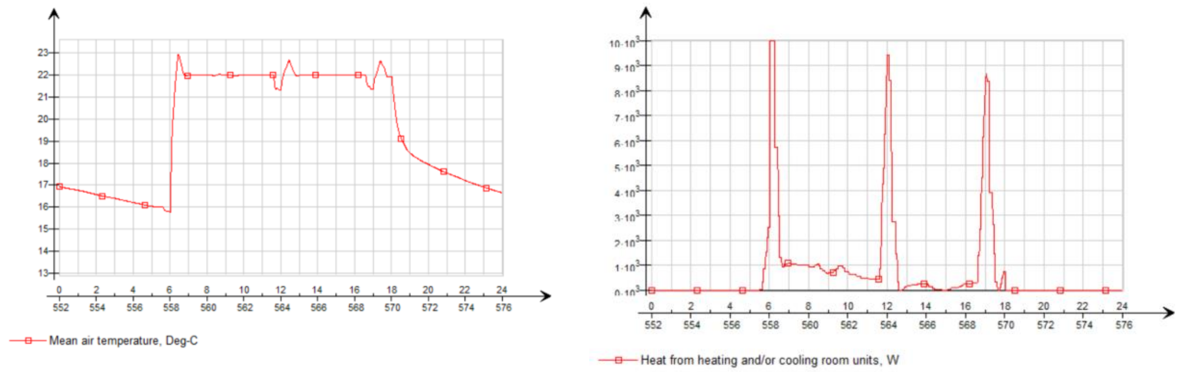

Figure 46: Simulation results for an arbitrary selected north oriented zone on January 24th 2014.

5.2 Comparison with the real data

Real building thermal energy consumption data for the heating season 2014 are given in Table 9,

Table 9: Thermal energy consumption data in 2014.

		2014
Month		Thermal energy (plant) [MWh]
1.	January	127,00
2.	February	155,00
3.	March	72,00
4.	April	14,00
5.	May	0,00
6.	June	**Cooling season**
7.	July	
8.	August	
9.	September	
10.	October	24,00
11.	November	87,00
12.	December	133,00
	Overall:	**612,00**

The overall costs for the heating demand of FER building were 233.325,00 HRK in 2014. Overall measured energy consumption for UNIZGFER building in 2014 was 612,00 MWh (Table 9). Simulated energy demand for the same year is 551,08 MWh (Table 8). When compared with the simulation results, the real consumption in 2014 is in average 11% higher. This implies possible energy savings over 11%, i.e. over 25.000,00 HRK per year when the building usage would be aligned with the presumed simulation scenario. The expected savings are even higher with implemented advanced options such as automatic heating/cooling shut down with open windows detected (was not implemented in simulation scenarios).

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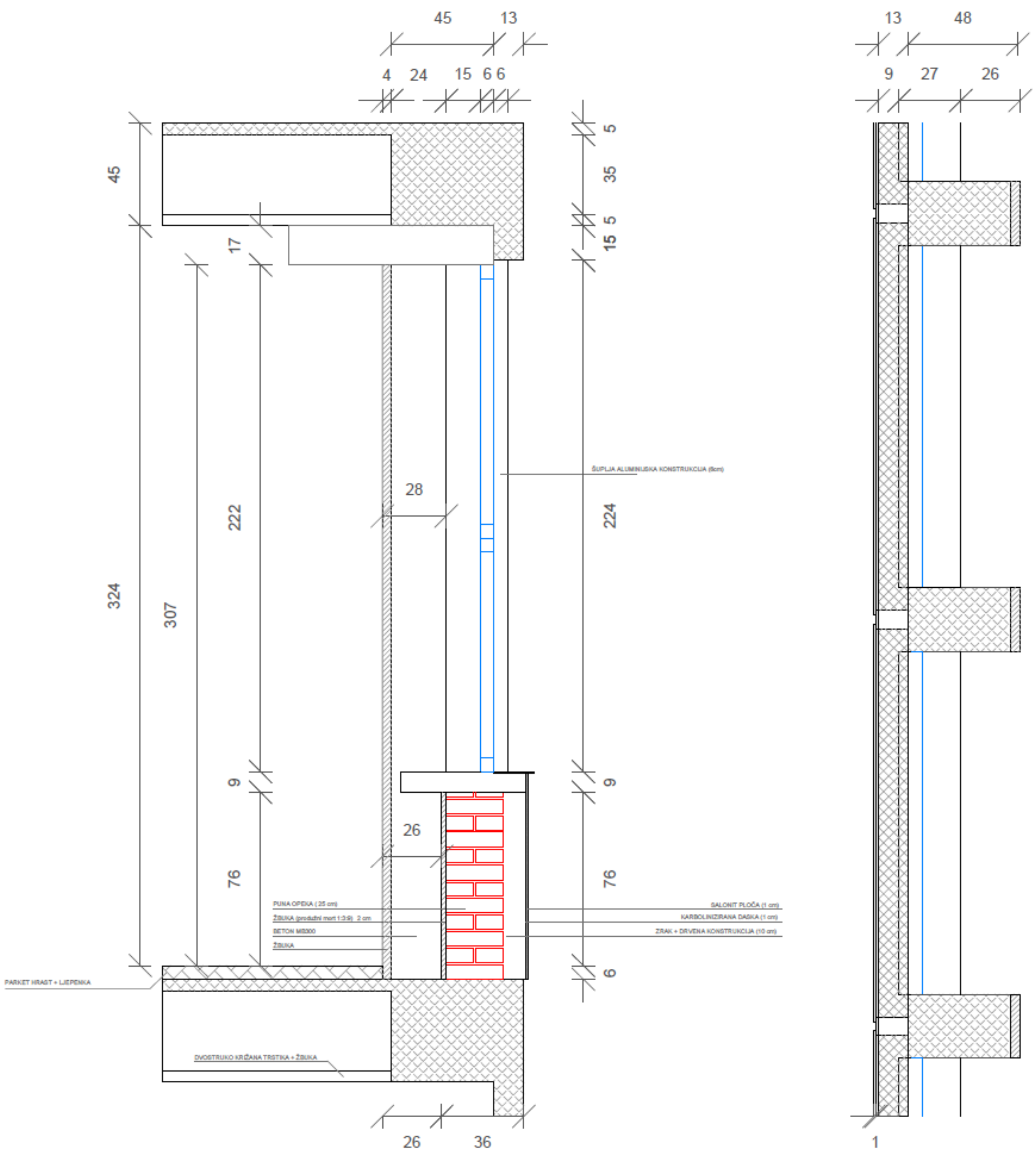
Appendix 1: The detailed cross section view of a south- and north-facing external wall



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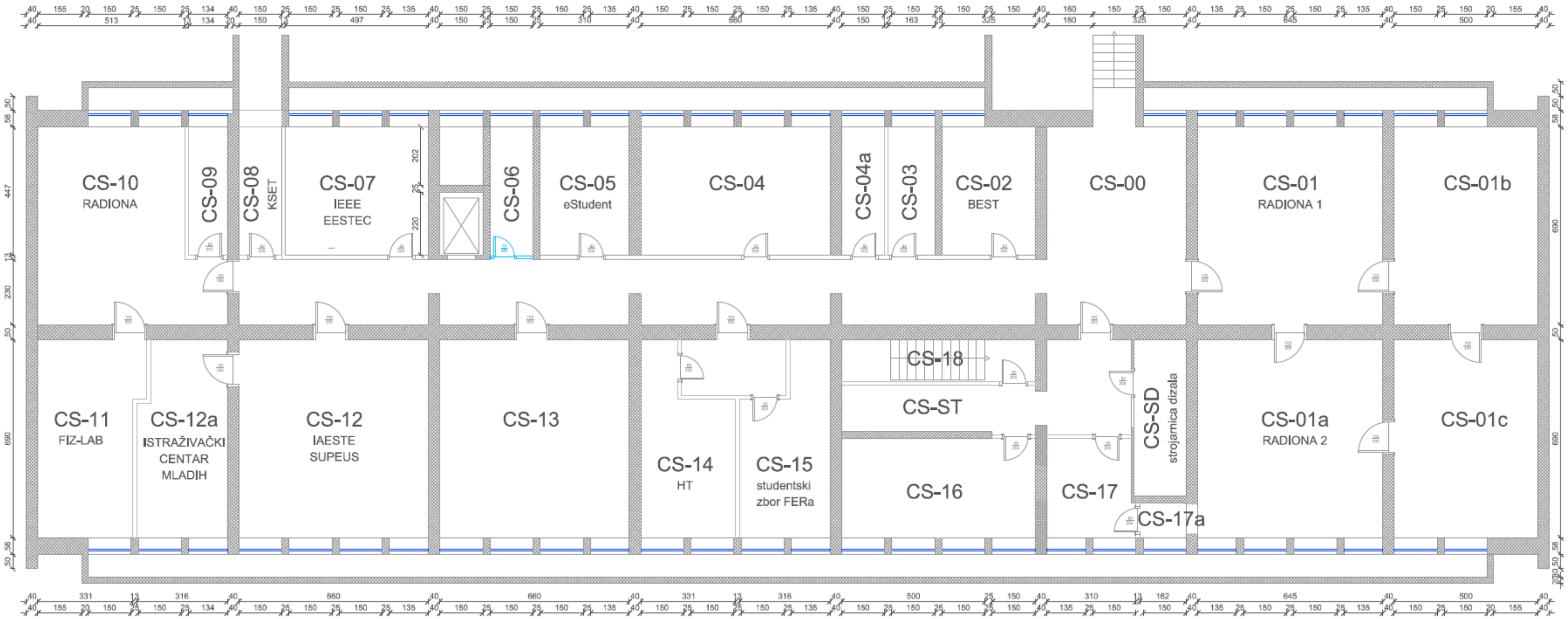
Appendix 2: FER skyscraper floor plans



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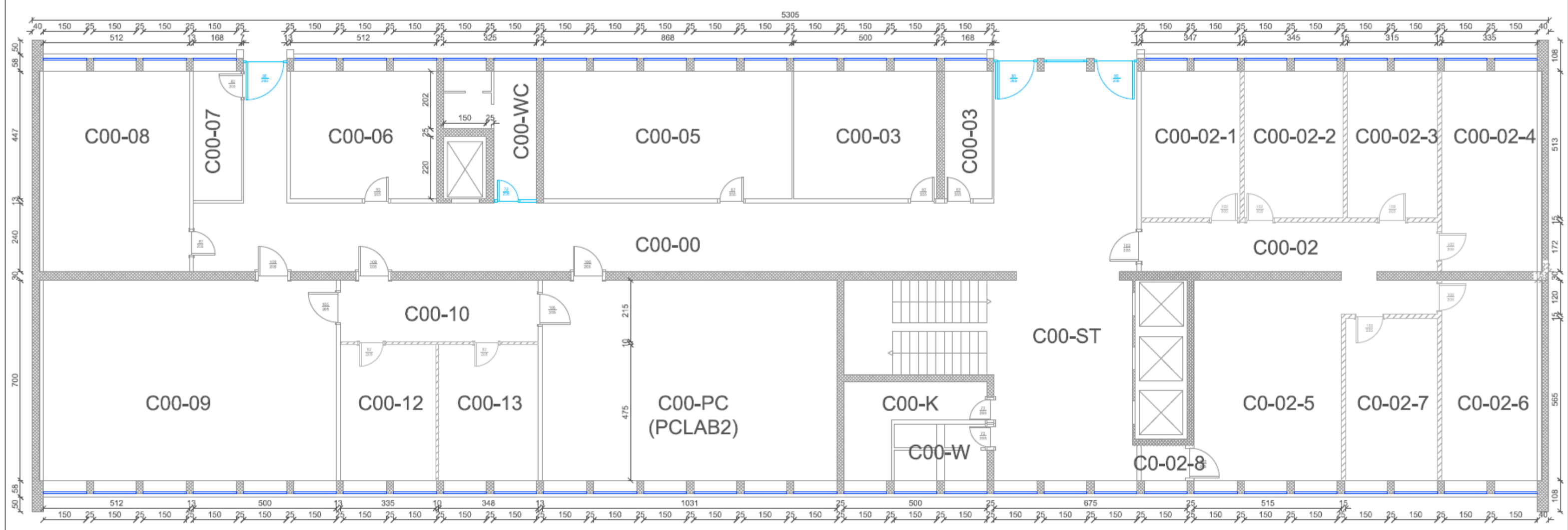

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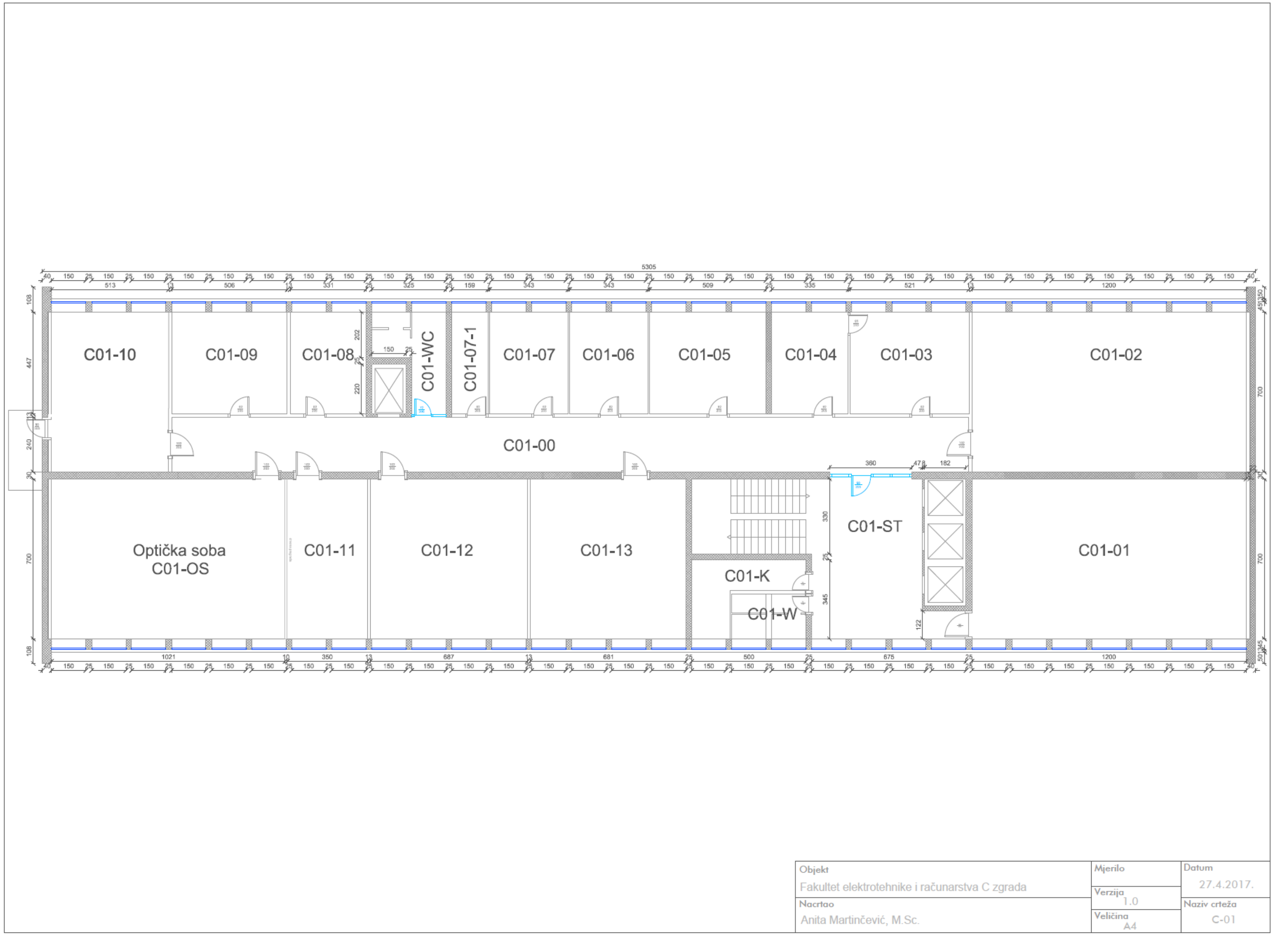
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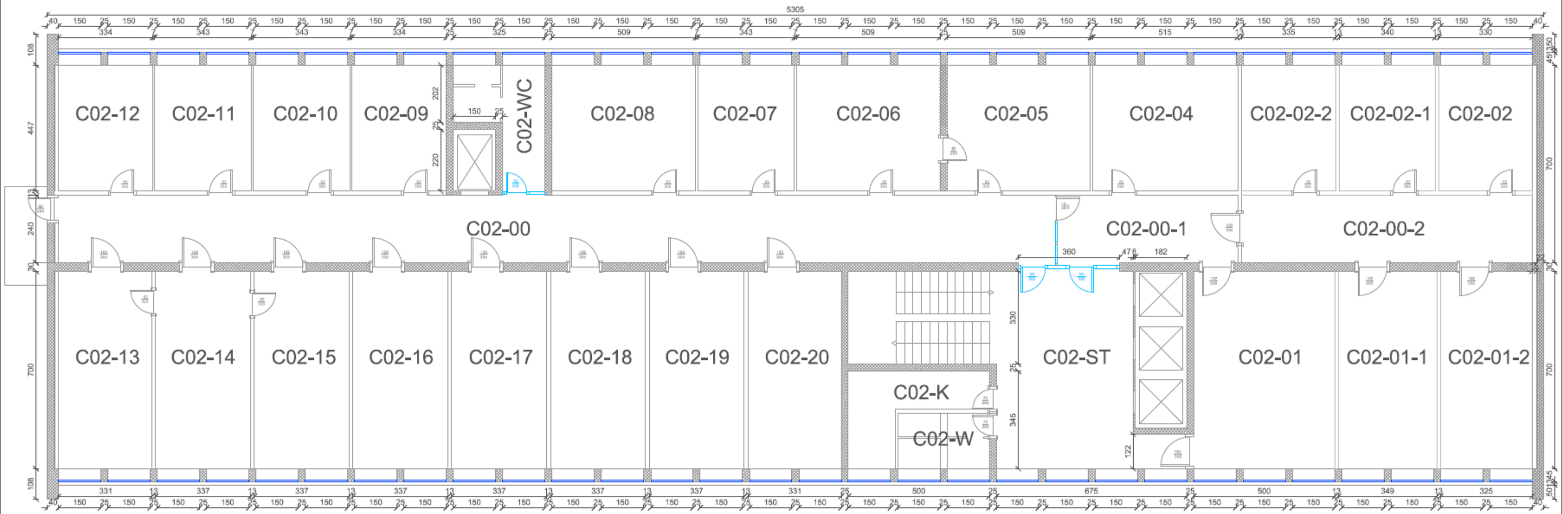

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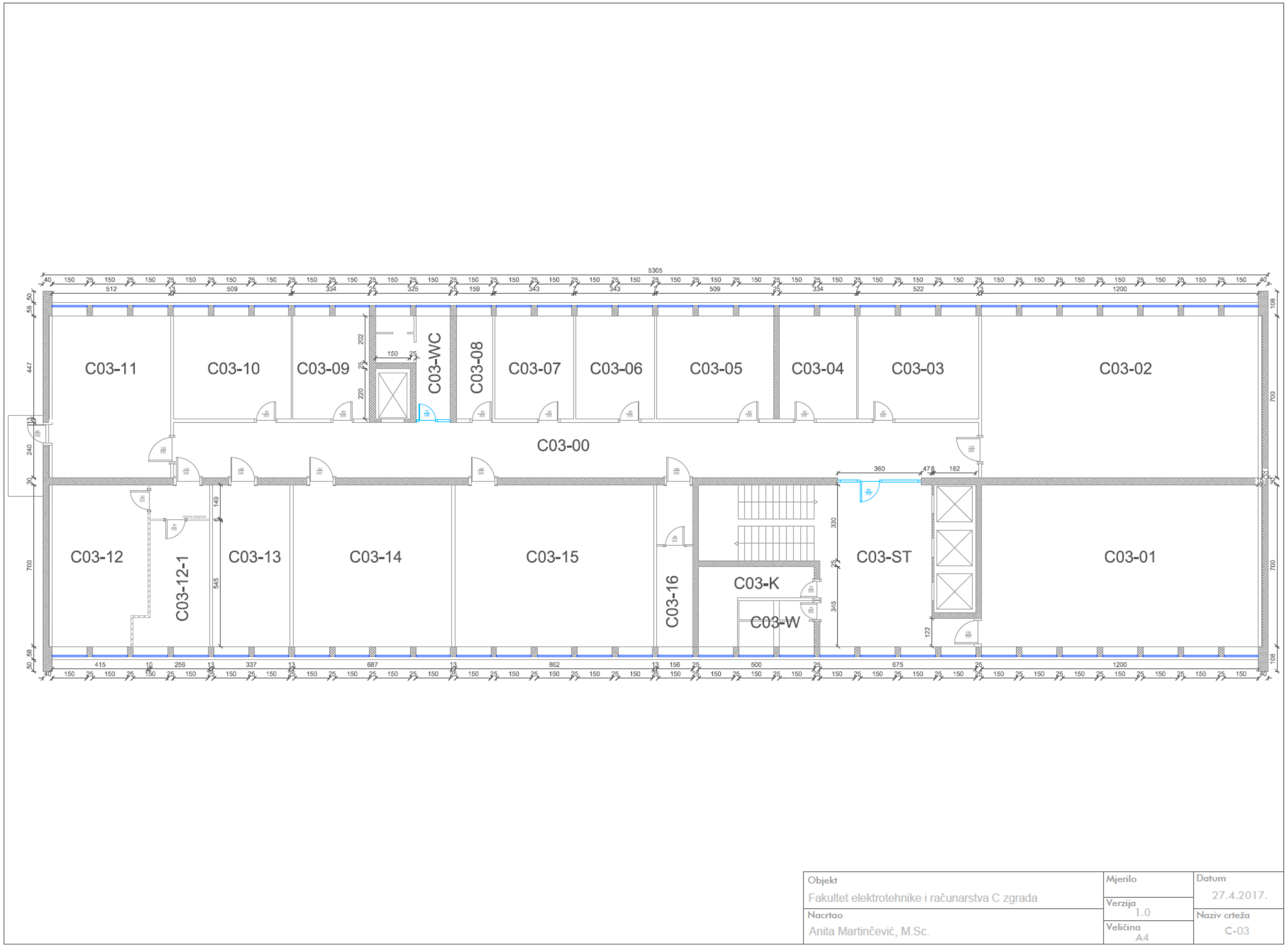
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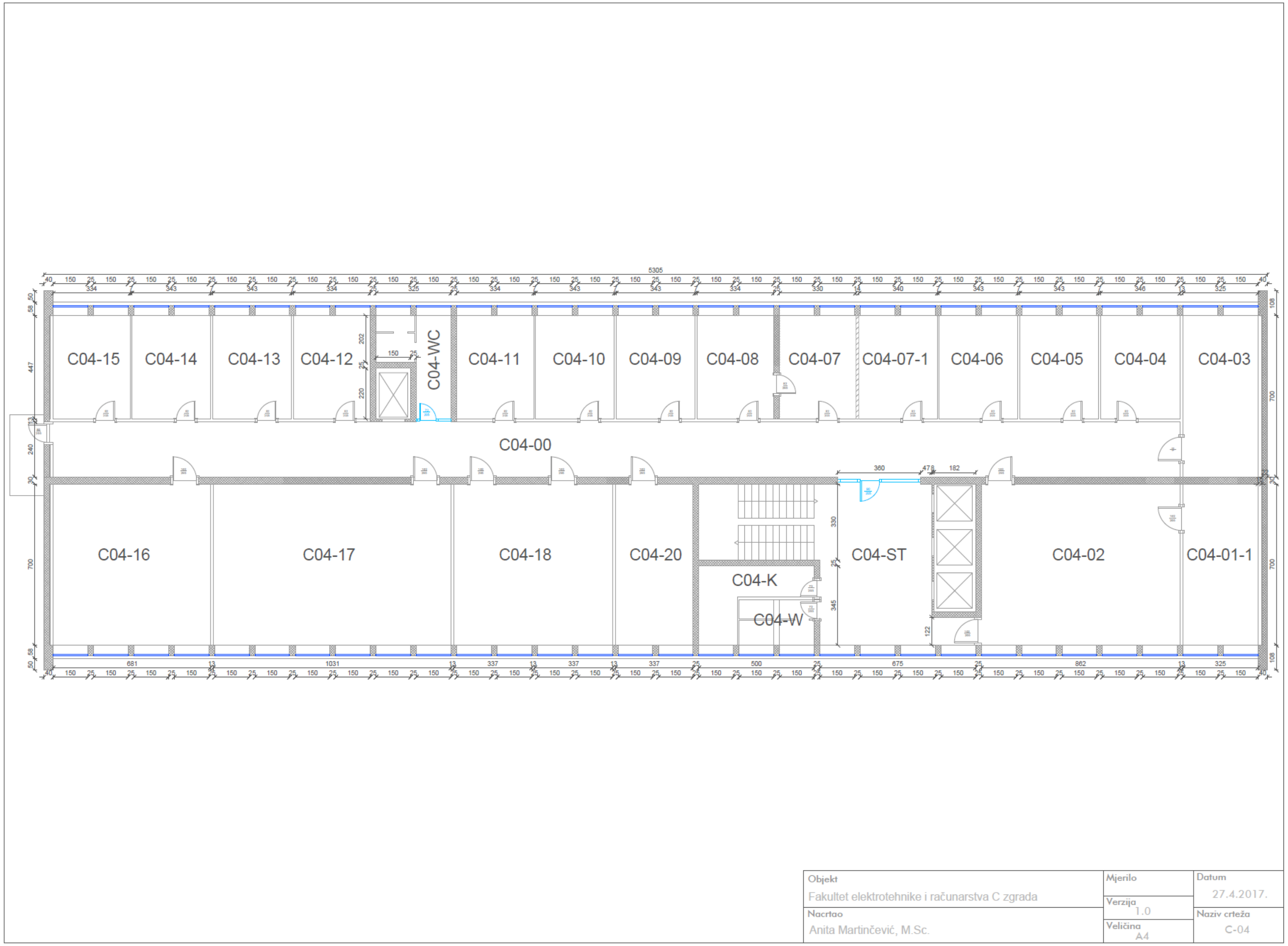
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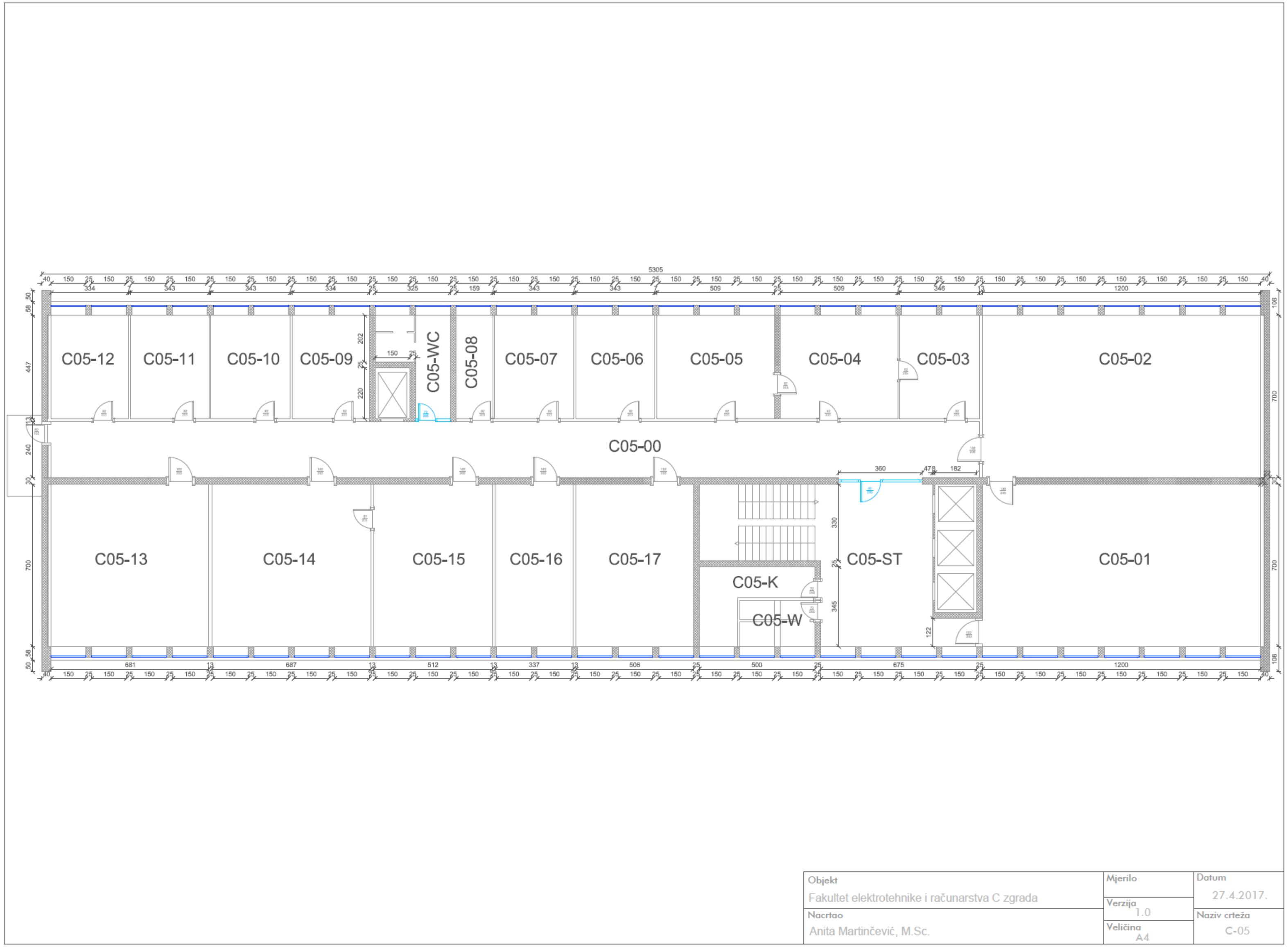
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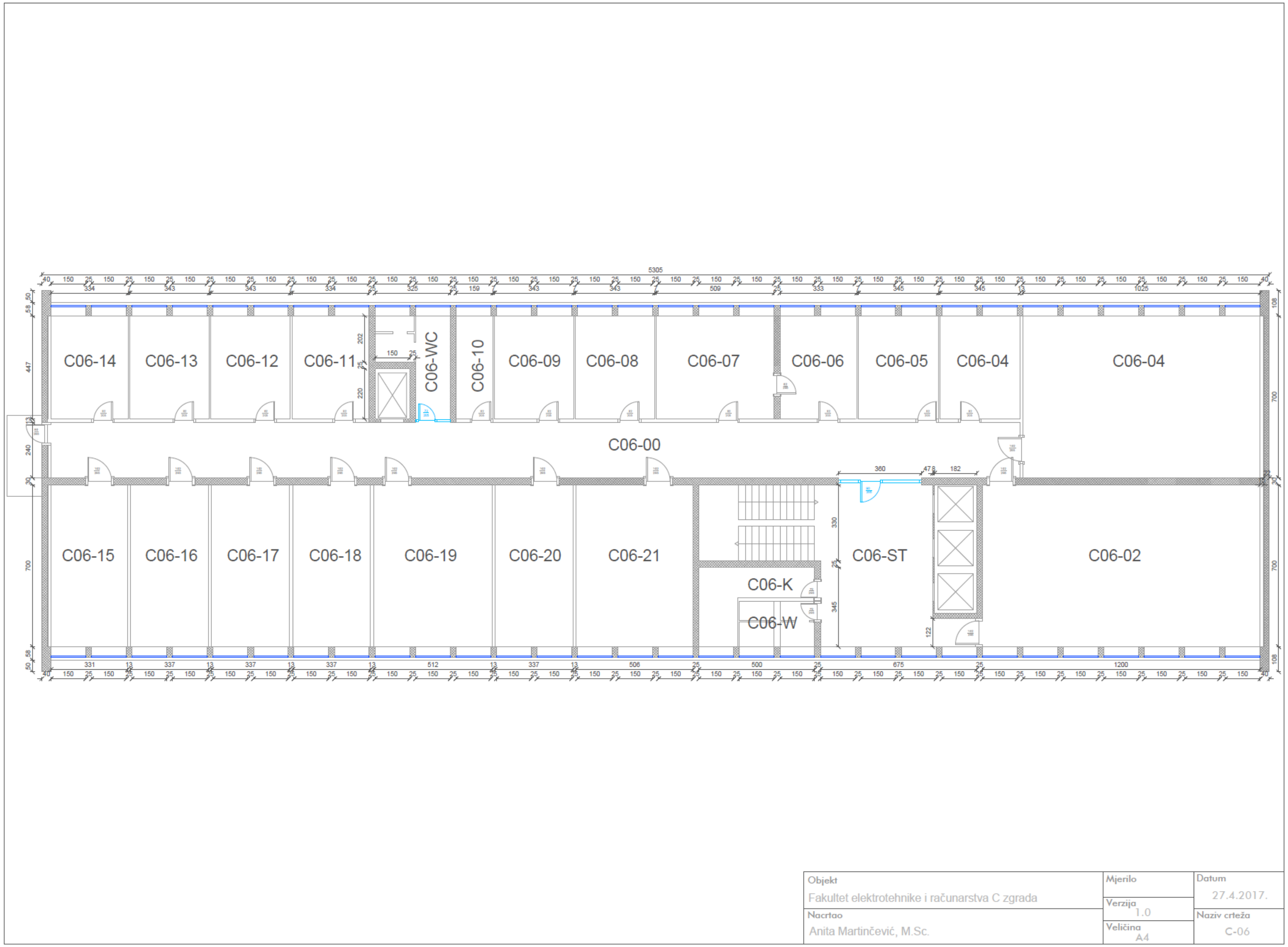
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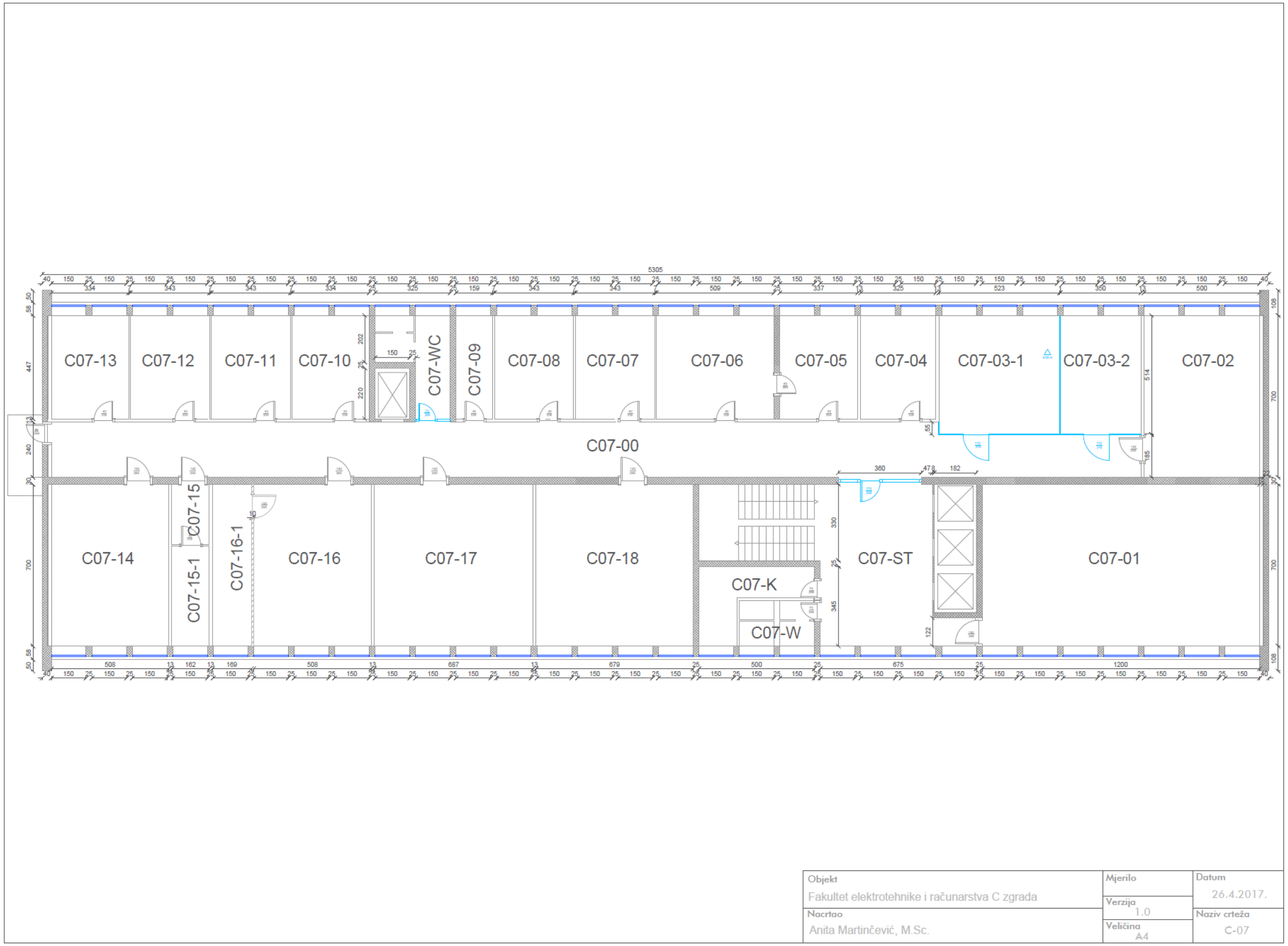
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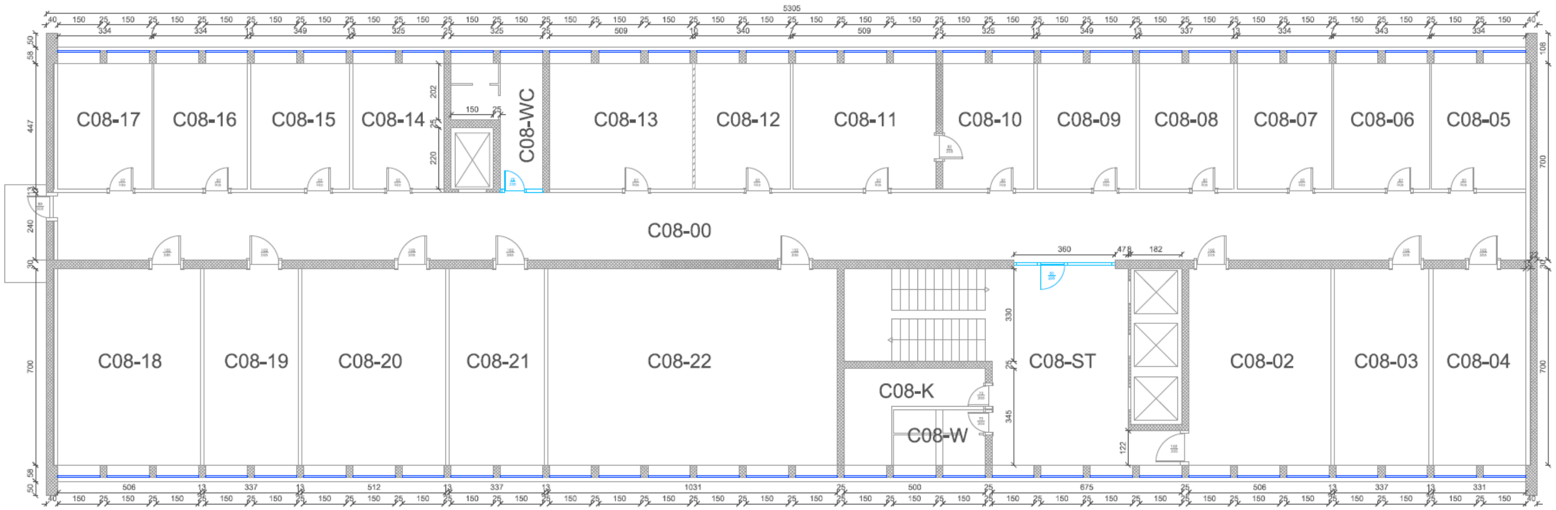

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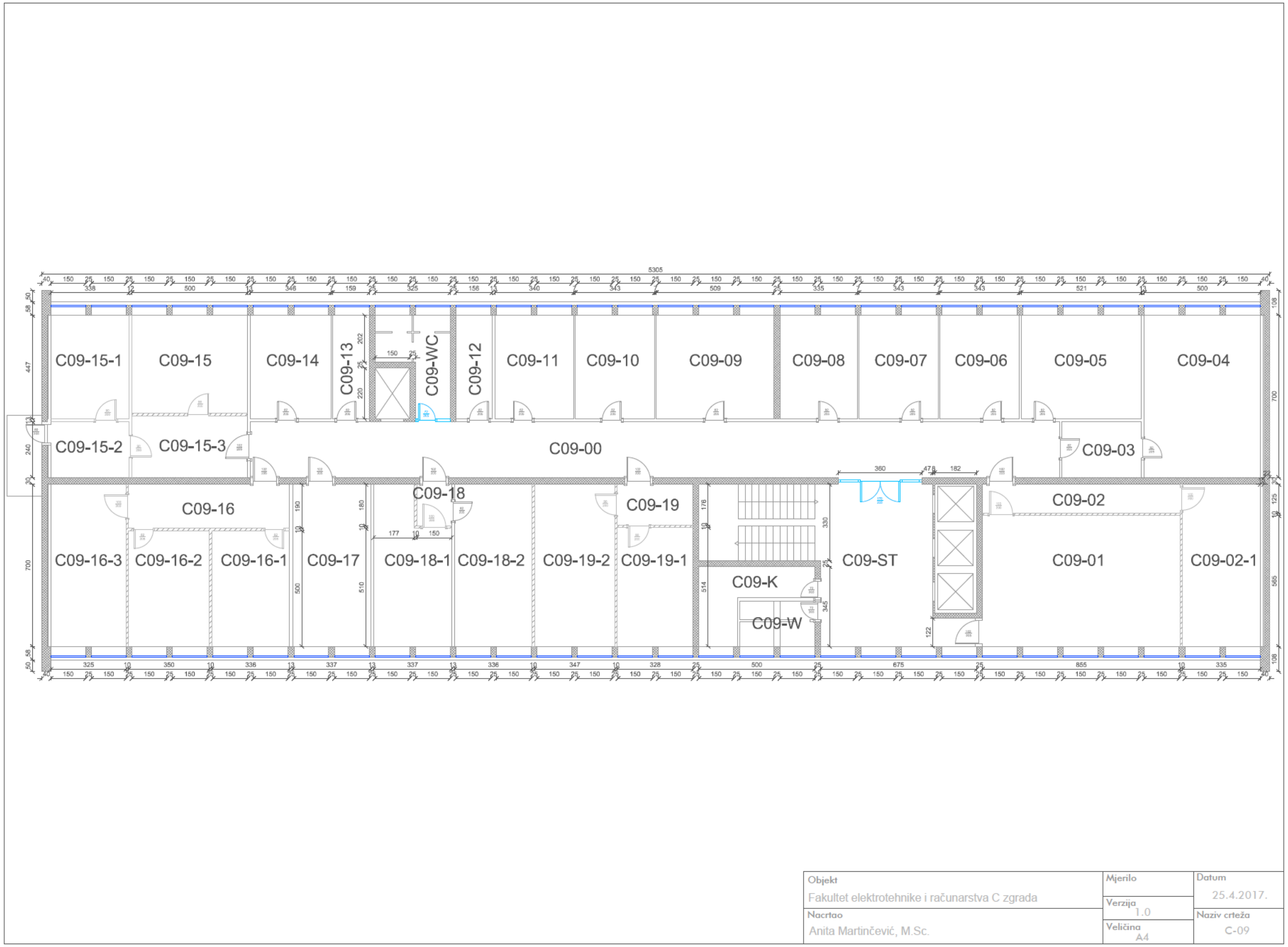
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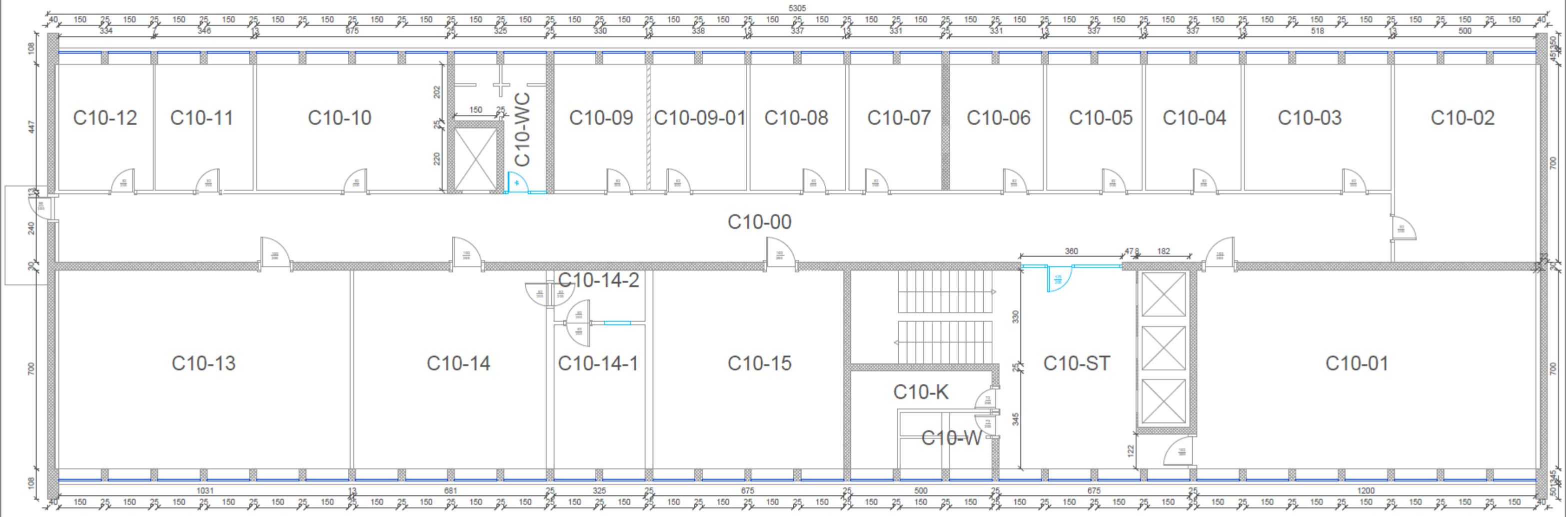

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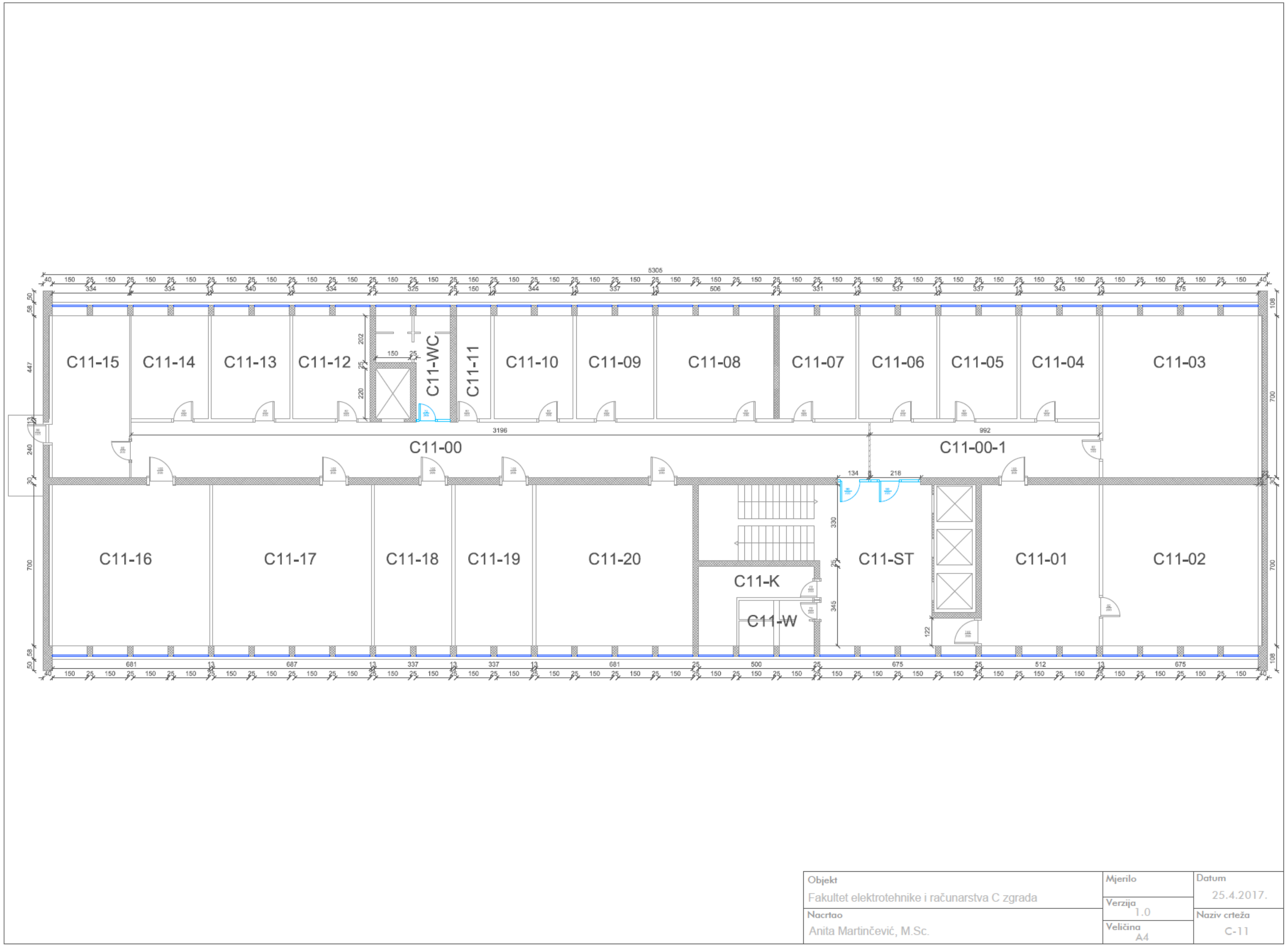
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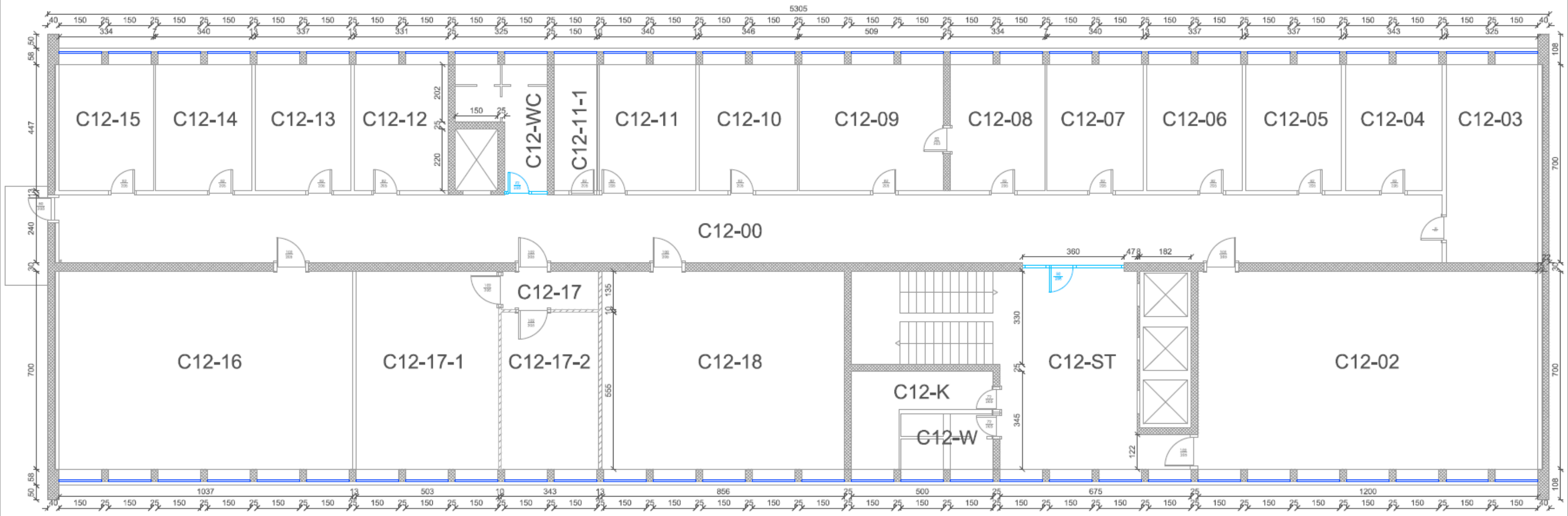
C11-07
C11-06
C11-05
C11-04
C11-03
C11-00
C11-00-1
C11-16
C11-17
C11-18
C11-19
C11-20
C11-K
C11-W
C11-ST
C11-01
C11-02
Objekt
Fakultet elektrotehnike i računarstva C zgrada
Nacrtao
Anita Martinčević, M.Sc.
Mjerilo
Verzija
1.0
Veličina
A4
Datum
25.4.2017.
Naziv crteža
C-11



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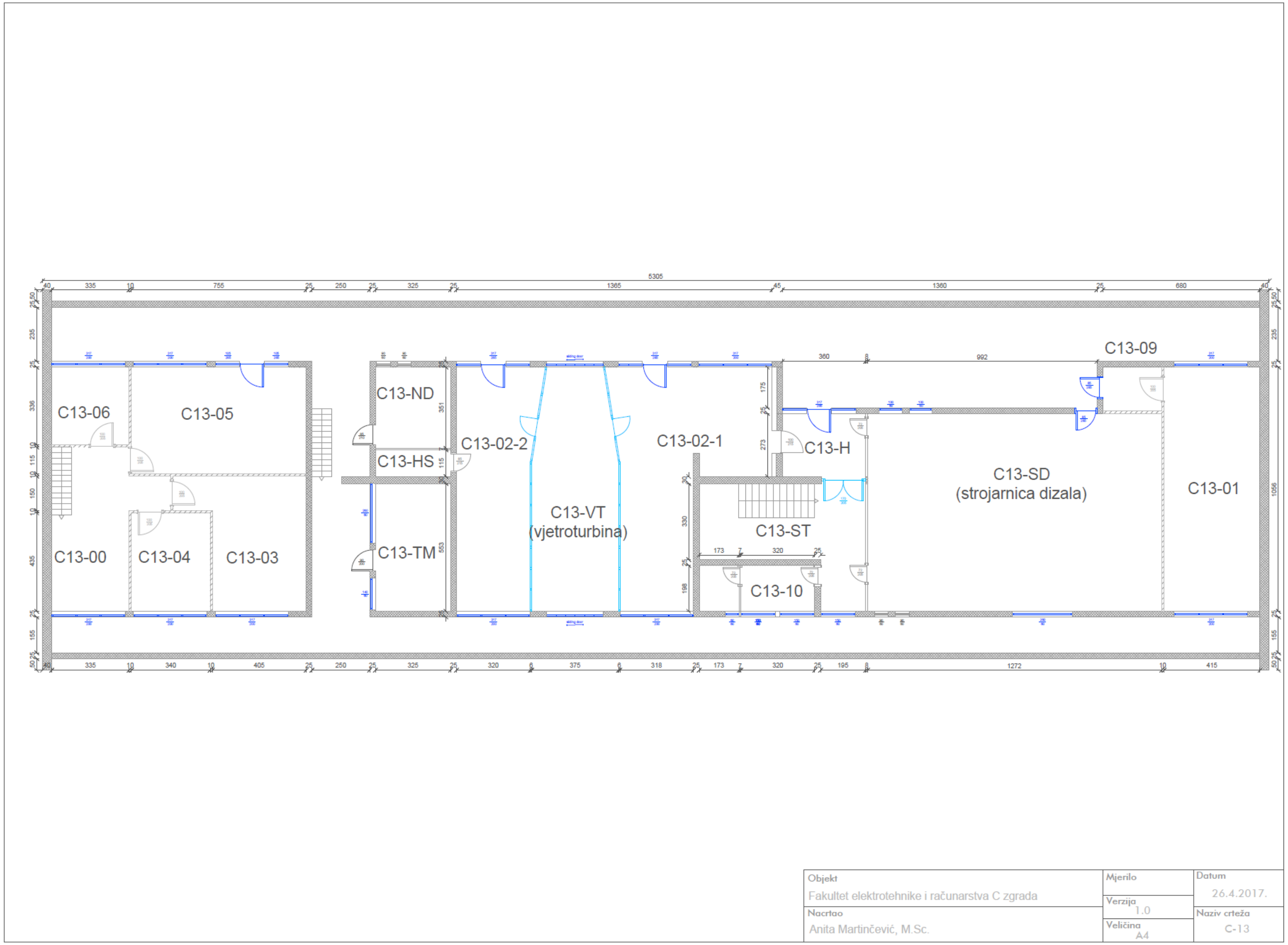
Fakultet elektrotehnike i računarstva C zgrada	Verzija 1.0	26.4.2017.
Nacrtao Anita Martinčević, M.Sc.	Veličina A4	Naziv crteža C-12


C13-06
C13-05
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C13-04
C13-03
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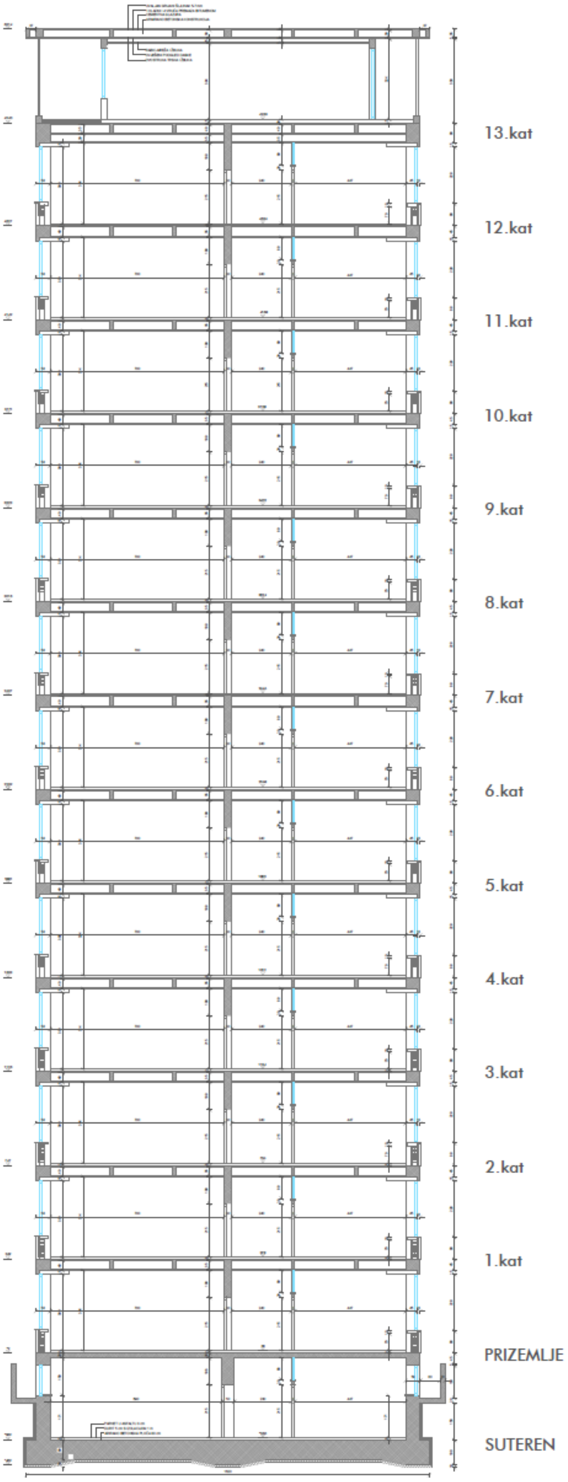
C13-HS
C13-TM
C13-02-2
C13-VT
(vjetroturbina)
C13-02-1
C13-H
C13-ST
C13-10
C13-09
C13-SD
(strojarnica dizala)
C13-01
Objekt
Fakultet elektrotehnike i računarstva C zgrada
Nacrtao
Anita Martinčević, M.Sc.
Mjerilo
Verzija
1.0
Veličina
A4
Datum
26.4.2017.
Naziv crteža
C-13

Appendix 3: FER skyscraper cross-section (north-south orientation)



OBJEKT	MJERILO	DATUM
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NACRTAO Anita Martinčević, M.Sc.	VELIČINA	NAZIV CRTEŽA Presjek istok-zapad

Appendix 4: Detailed IDA-ICE simulation report for FER building in 2014.

EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		Building	
		Model floor area	10690.8 m^2
Customer		Model volume	34774.0 m^3
Created by	Anita Martincevic	Model ground area	747.0 m^2
Location	Zagreb/FER	Model envelope area	7799.3 m^2
Climate file	Zagreb_2014	Window/Envelope	33.2 %
Case	FERCbuilding_merged	Average U-value	1.784 W/(m^2 K)
Simulated	12.6.2017. 15:57:31	Envelope area per Volume	0.2243 m^2/m^3

Building Comfort Reference

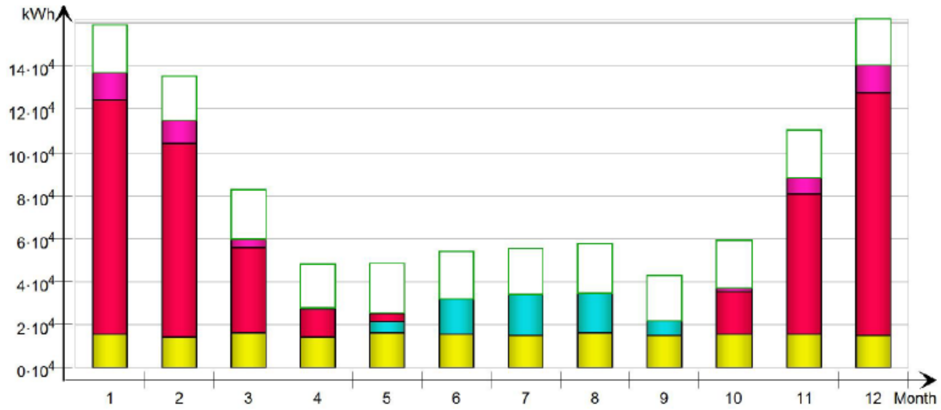
Percentage of hours when operative temperature is above 27°C in worst zone	19 %
Percentage of hours when operative temperature is above 27°C in average zone	6 %
Percentage of total occupant hours with thermal dissatisfaction	9 %

Delivered Energy Overview

	Purchased energy		Peak demand
	kWh	kWh/m^2	kW
Lighting, facility	183518	17.2	75.72
Ventilokonvektori_hladjenje	66199	6.2	265.3
HVAC aux	0	0.0	0.0
Total, Facility electric	249717	23.4	
Ventilokonvektori_grijanje	453130	42.4	2755.0
Domestic hot water	0	0.0	0.0
Total, Facility fuel*	453130	42.4	
Radijatori	51075	4.8	158.1
Total, Facility district	51075	4.8	
Total	753922	70.5	
Equipment, tenant	262348	24.5	86.05
Total, Tenant electric	262348	24.5	
Grand total	1016270	95.1	

*heating value

Monthly Purchased/Sold Energy



Month	Facility electric			Facility fuel (heating value)		Facility district	Tenant electric
	Lighting, facility	Ventilokonvektori_hladjenje	HVAC aux	Ventilokonvektori_grijanje	Domestic hot water	Radijatori	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	15525.0	0.0	0.0	108671.0	0.0	12892.0	22201.0
2	14107.0	0.0	0.0	90323.0	0.0	10825.0	20179.0
3	16229.0	0.0	0.0	39719.0	0.0	3820.0	23184.0
4	14114.0	0.0	0.0	12802.0	0.0	898.3	20218.0
5	16227.0	5095.0	0.0	3778.5	0.0	192.2	23182.0
6	15540.0	16453.0	0.0	0.0	0.0	0.0	22181.0
7	14845.0	19301.0	0.0	0.0	0.0	0.0	21223.0
8	16250.0	18347.0	0.0	0.0	0.0	0.0	23183.0
9	14820.2	7002.9	0.0	0.0	0.0	0.0	21197.3
10	15521.0	0.0	0.0	19847.0	0.0	1795.0	22199.0
11	15525.0	0.0	0.0	65332.0	0.0	7699.0	22183.0
12	14815.0	0.0	0.0	112658.0	0.0	12953.0	21218.0
Total	183518.2	66198.9	0.0	453130.5	0.0	51074.5	262348.3

IDA Indoor Climate and Energy
Version: 4.71
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