D6.1 Appendix A Summary Sheet

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Author(s):	Juan Rodríguez, Kirsten Höttges (FHG)
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D6.1 Appendix A Center for Sustainable building: Short Description
This document describes the demonstration building Center for Sustainable building
Keywords: Center for Sustainable, offices, demonstration building, Kassel

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Appendix A: Center for Sustainable Building. Kassel (Germany)

The ZUB has been designed as an example of a low energy building. To reach this aim, the annual heating demand of the building, which was projected as approximately 25kWh/m^{2}a, turned out to be 21.2kWh/m^{2}a. This is only 27% of the maximum allowed value, according to the German Energy code “Wärmeschutzverordnung 95”, which was in force at the time of the planning.

Figure 1: ZUB building in Kassel (Germany)

To save electrical energy, both natural lighting and ventilation strategies have been implemented. Solar gains have been utilized through the glazing of the south facing façade to decrease the thermal needs during the heating season.

To monitor the aims and verify the concepts and achievements of this project, an intensive measurement program has been underway. Over a period of four years, all the planning and construction processes have been followed, and, for at least two years, measurements of all important parameters of this building have been recorded. Approximately 1300 measurement points, such as temperatures and heat and energy flows, are being monitored. In addition, the thermal / indoor comfort and indoor air quality is being reported and controlled. Studies on the building behavior are being done in two especially equipped office rooms.

The final energy consumption for heating, building services and lighting was measured at 42 and 31.7kWh/m^{2}a for the years 2002 and 2003. This is just 60%, respectively 45%, of the maximum allowed value of 70kWh/m^{2}a from the research program.

The overall annual electricity consumption for those years was measured at 21.6 and 18.7kWh/m^{2}a respectively. These values are close to the target value of the Swiss Standard SIA of 17kWh/m^{2}a.

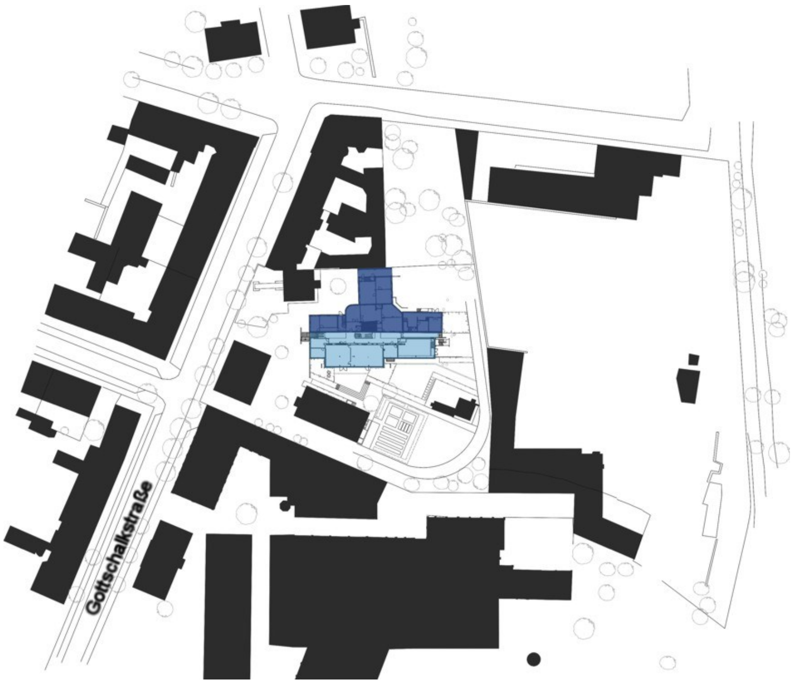


Figure 2: Location of the ZUB building in Kassel

1.1 General building information

Table 1: General information of ZUB building

Name	Zentrums für Umweltbewusstes Bauen	Envelopment area	University Campus, Residential Zone
Address	Gottschalkstraße 28A	Glazed area	1001.3 m^2
City / Post code	34127	Form factor (S/V)	0.418
Country	Germany	Heated Area (m^2)	596 m^2
Contact Person	Michael Krause	Heated Volume (m^3)	1880.56 m^3
e-mail of contact person	michael.krause@ibp.fraunhofer.de	Cooled Area (m^2)	596 m^2
Location (coordinates)	51°19'33.22"N, 09°30'16.88"E	Cooled Volume (m^3)	1880.56 m^3
Orientation	340° (-20ºSouth)	Heating degree days (15.5ºC)	2435
Altitude (m)	170m	Cooling degree days (15.5ºC)	139
Year of construction	2001	Average power consumption (kWh/m^2a)	7
Typology of	Office building	Average thermal	24.7

building		consumption (kWh/m^2a)	
Floors	3	Heating system	Radiant floors activated by energy delivered by the University district heating ring
Built area	2129 m^2	Cooling system	Geothermal exchange
Net usable area	1732 m^2	DHW system	N/A

Table 2: Climate values for Kassel

	T (ºC)	TM (ºC)	Tm (ºC)	R (mm)	RH (%)	DR (d)	DN (d)	DT (d)	DF (d)	DH (d)	DD (d)	I (h/mo)
Jan	1.5	4.2	-1.5	29	84	11	8	-	3	-	-	37.2
Feb	2	5.9	-1.5	25.4	80	9	9	-	4	-	-	64.4
Mar	5	10.1	0.8	26.4	75	11	8	-	4	-	-	108.5
Apr	8.5	14.4	3	30.3	70	9	3	-	3	-	-	144
May	13	19.4	7	36.1	69	10	0	-	5	-	-	195.3
Jun	16	22.1	10	33.7	70	11	0	-	5	-	-	189
Jul	17.5	24.4	11.9	41.4	70	9	0	-	6	-	-	195.3
Aug	17.5	24.4	11.8	47	72	9	0	-	7	-	-	189
Sep	13.5	19.5	8.6	34.6	78	9	0	-	10	-	-	136.4
Oct	9.5	14.1	5.1	33	82	9	0	-	12	-	-	99.2
Nov	4.5	8	1.6	33.4	84	11	4	-	7	-	-	45
Dec	1.5	4.3	-1	32	85	13	9	-	4	-	-	31
Total	9.15	14.25	4.65	33.54	76.58	10.1	3.4	-	5.83	-	-	119.53

T: monthly average temperature; TM: monthly average of highest daily temperatures; Tm: monthly average of lowest daily temperatures; R: monthly average of rainfall; RH: monthly average of relative humidity; DR: monthly average of rainy days (rainfall ≥ 1mm); DN: monthly average of snow days; DT: monthly average of storm days; DF: monthly average of foggy days; DH: monthly average of frost days; DD: monthly average of cloudless days; I: monthly average of sunny hours **¡Error! No se encuentra el origen de la referencia.**

2 Building use: distribution and occupancy

ZUB is a three-plant building extension with basement directly connected to the previously existing building with an atrium that unifies and distributes the new spaces.

The basement accommodates technical rooms, services, and an experimental area designed to to allow large-scale experimental facilities.

On the ground floor occur most of the public events of ZUB. Depending on the event requirements, the foyer and be part in two. Also a kitchen exists to provide an infrastructure for the meetings while in the first and second floor are all the offices and a meeting room with capacity up to 20 persons. A walk able terrace is accessible from the offices of the first floor.

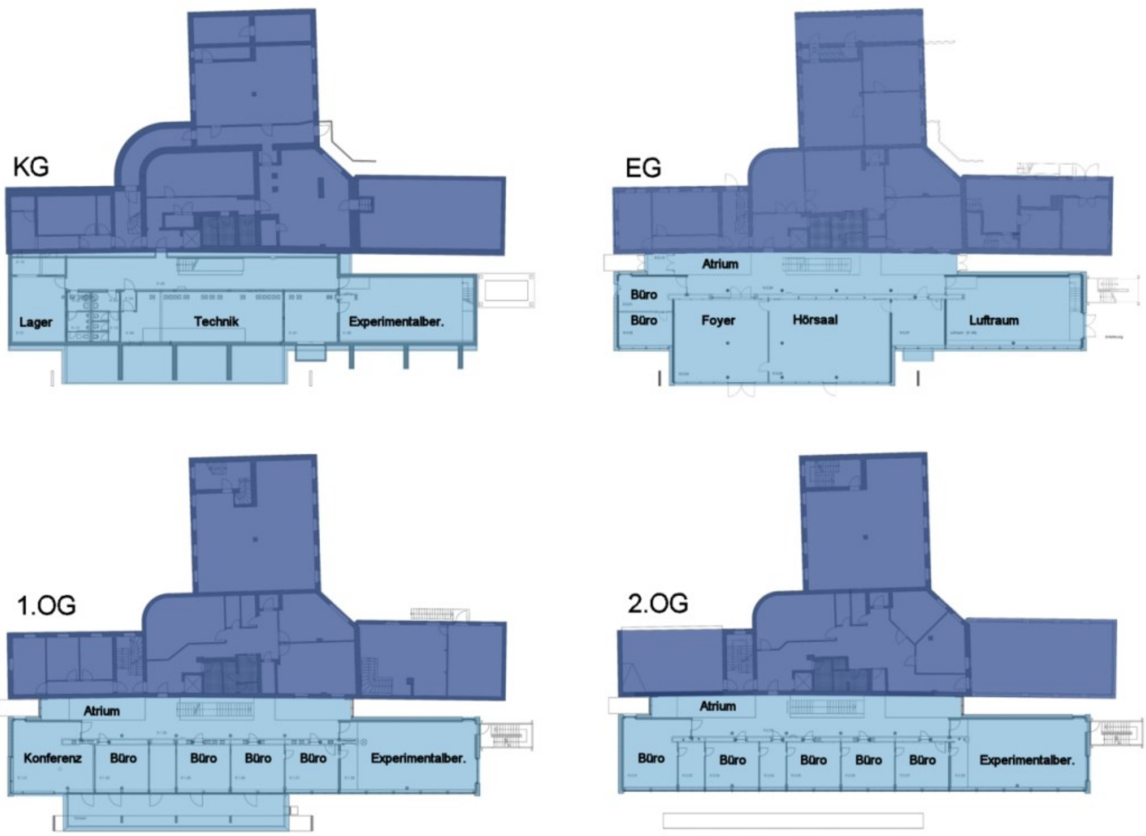


Figure 3: Zonal distribution of the spaces in ZUB building

Figure 4: Views of the Atrium (Western Entrance/Eastern Second floor)

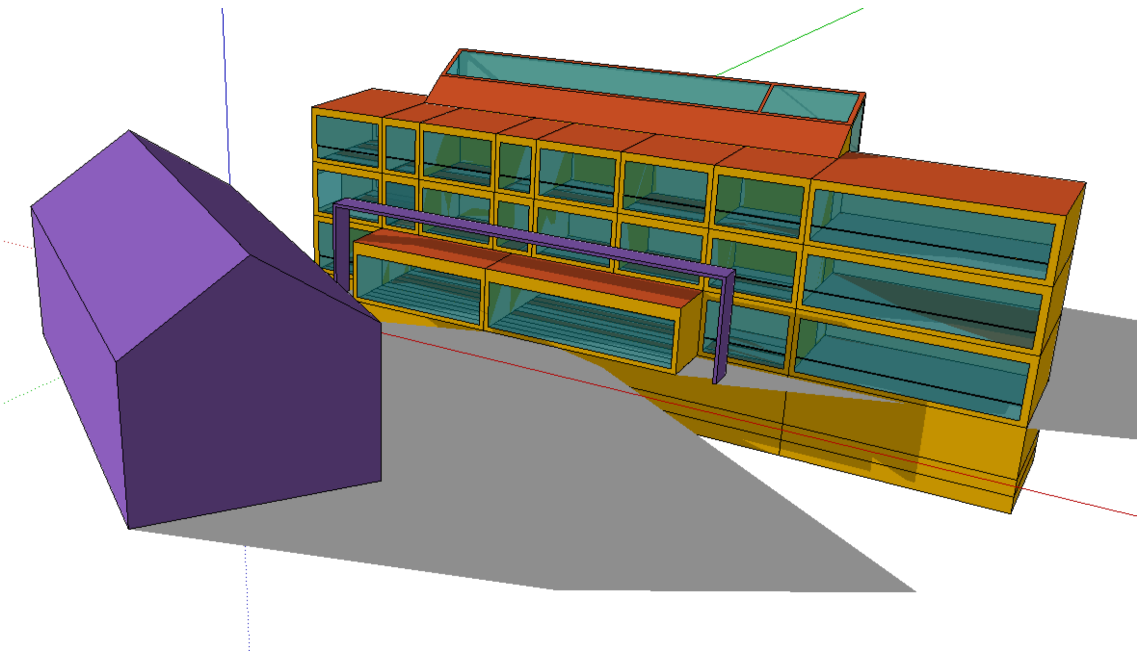


Figure 5 Complete building model of the ZUB

Table 3: ZUB building distribution / usage

Zone	Floor	Useful area (m^2)	H. (m)	Vol. (m^3)	% cond.	Occ. (pax)
Atrium	0	144	≈10	1384.82	0	N/A

Foyer	0	120.68	3.35	406.85	100	Max 50
Lecture Room	0	120.82	3.35	407.22	100	Max 50
Kitchen	0	-	3.35	-	100	N/A
Conference Room	1	58.6	3.00	176.37	100	Max 20
R102	1	28.2	3.00	84.6	100	3
R105	1	28.2	3.00	84.6	100	2
R106	1	28.2	3.00	84.6	100	2
R107	1	28.2	3.00	84.6	100	2
R201	2	44.5	3	133.5	100	1
R202	2	14.1	3	42.3	100	N/A
R203	2	28.2	3.00	84.6	100	2
R204	2	14.1	3.00	42.3	100	1
R205	2	28.2	3.00	84.6	100	2
R206	2	28.2	3.00	84.6	100	2
R207	3	28.2	3.00	84.6	100	3

Table 4: Building daily occupation profile of ZUB building [1]

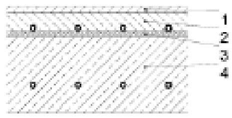
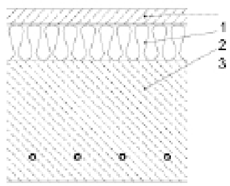
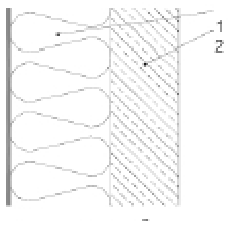
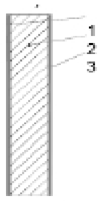
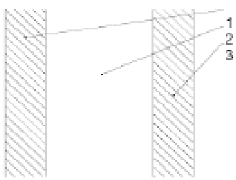
Hour	1	2	3	4	5	6	7	8	9	10	11	12
Mon-Fri	0	0	0	0	0	0	0	15	20	20	20	5
Weekend	0	0	0	0	0	0	0	0	0	0	0	0
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Mon-Fri	20	20	20	20	5	0	0	0	0	0	0	0
Weekend	0	0	0	0	0	0	0	0	0	0	0	0

[1] (Not occup.=0; partially occup.=1; occup.=2)

3 Building characteristics

3.1 Envelope elements and thermal characteristics

Table 5: Construction elements of ZUB building

Envelope Element	Material Description	λ W/mK	ρ kg/m^3	C J/kgK	Thickness m	U-Value W/m2K
1 Basement Ceiling 	1. Magnesia cement	0.9	2000	1000	0.02	0.98
	2. Cement	1.4	2000	1000	0.06	
	3. Insulation	0.035	30	1380	0.02	
	4. Reinforced concrete	2.1	2400	1050	0.25	
2 Basement Floor 	1. Cement	1.4	2000	1000	0.5	0.26
	2. Insulation	0.035	30	1380	0.12	
	3.Reinforced concrete	2.1	2400	1050	0.40	
3 External Walls 	1. Insulation	0.035	30	1380	0.3	0.11
	2. Reinforced concrete	2.1	2400	1050	0.2	
4 Internal walls 	1. Plaster Board	0.035	1200	840	0.01	2.08
	2. Limestone	0.7	1400	920	0.115	
	3. Plaster Board	0.035	1200	840	0.01	
5 Clay wall 	1. Clay	0.95	1800	900	0.135	1.4
	2. Air	2.15	1.2	1006	0.365	
	3. Clay	0.95	1800	900	0.135	

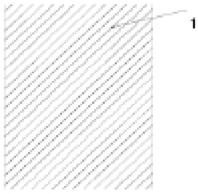
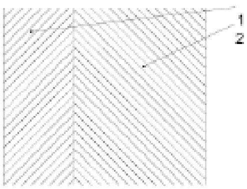
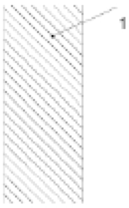
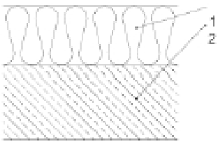
6 Firewall 	1. Brick	0.96	2000	920	0.45	1.37
7 Firewall Basement 	1. Brick 2. Limestone	0.96 0.7	2000 1400	920 920	0.45 0.24	0.93
8 Basement Walls 	1. Limestone	0.7	1400	92	0.24	1.67
9 External roof 	1. Insulation 2. Reinforced concrete	0.035 2.1	30 2400	1380 1050	0.2 0.25	0.17

Table 6: Windows description of ZUB building

Window Element	U-Value (W/m^2K)	U-Frame (W/m^2K)	g	SC	SSC
10 Offices	0.6	1.6 (20%frame)	0.42	0.483	0.392
11 Roof	0.68	1.1 (10%frame)	0.45	0.517	0.42
12 Lateral Walls	0.6	1.1 (10%frame)	0.42	0.483	0.392

4 Energy flow

In order to summarise the installed systems in the building the following table give an overview and some specialties of the building equipment.

Table 7: Installed systems

Systems	Specialties
building	high insulation level, high mass, external shading devises
heating	district heating, radiant slabs (ceiling and floor)
cooling	ground heat exchanger
AHU	heat exchanger, two possible directions
PV	electricity generation
DHW	none (only one tankless water heater for a rarely used shower)
control	external and internal sensors, actors

The ZUB building is equipped with radiant slabs sited in ceilings and floors for every room. These two systems can be operated independently in combination with the external air for renovations that comes from the main Air Handling Unit. Both systems share a common distribution system that delivers cooling from an active ground exchanger during warm periods and heating provided by the Kassel's University district heating ring during the cold season.

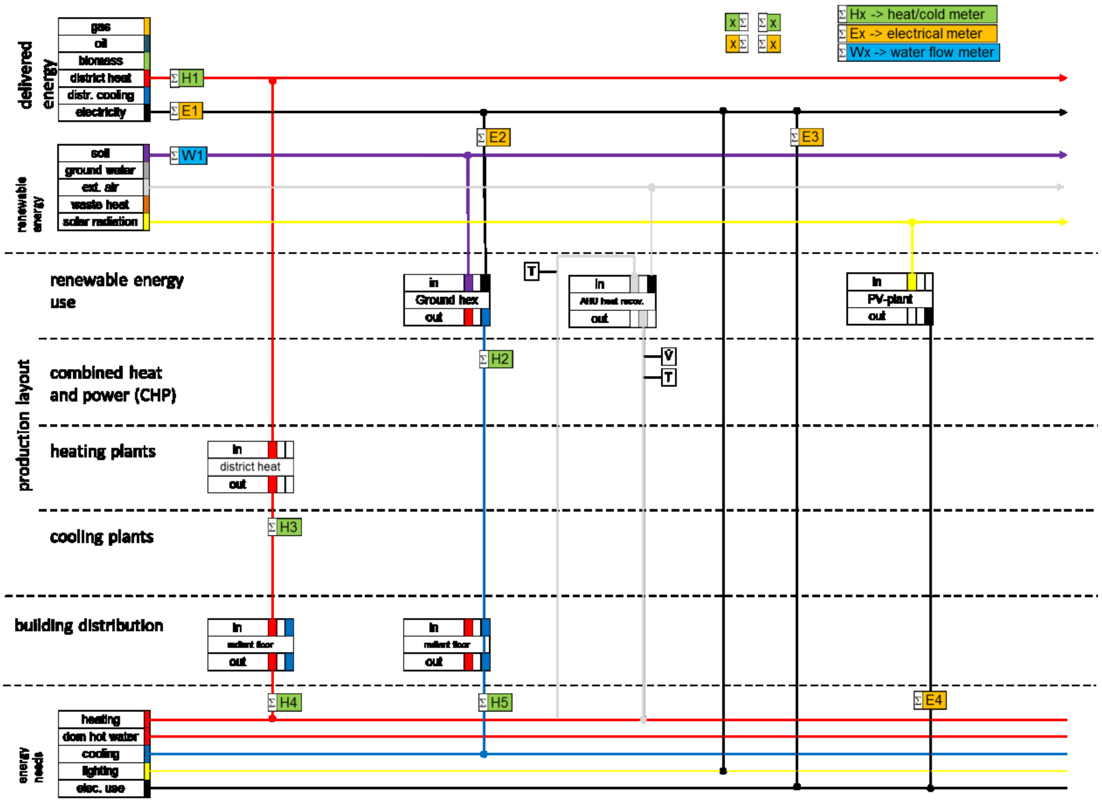


Figure 6: ZUB energy scheme

The geometrical distribution of the tubes DN22 polyethylene pipes in both slabs is different because of their main periods of use:

- Radiant floor is mostly thought to deliver heat, so its shape send the higher temperature loops near the window where the losses are important and the operative temperature decrease because of the windows, assuring comfort quality and the operative temperature programmed along the complete zone.
- Ceiling systems have loop distributions perpendicular to the windows. Summer heat is stored homogenously in all the room after the convection effects, so it is no needed a coldest part near the hottest wall. They are supposed to work the most in summer time.

As ventilation system the building has a central Air Handling Unit to treat mechanically the renovations with external air, recovering the heat contained in the wasted air. The air is taken from the ambient and conducted to a double sensible exchanger to increase/decrease the thermal level of the fresh air with the energy contained in the internal flow that will be expulsed to the ambient.

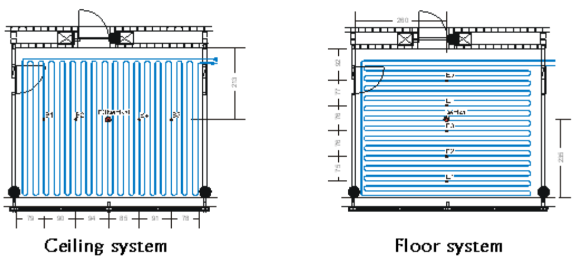


Figure 7: Physical configuration of the radiant slabs

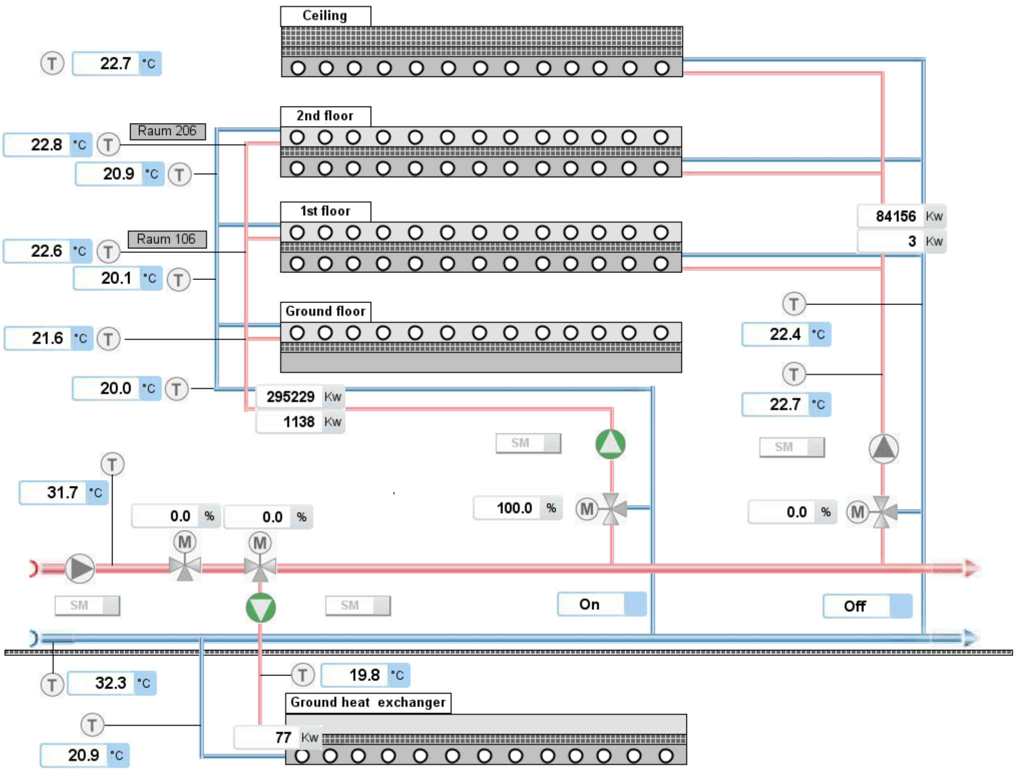


Figure 8: Radiant floors of ZUB building

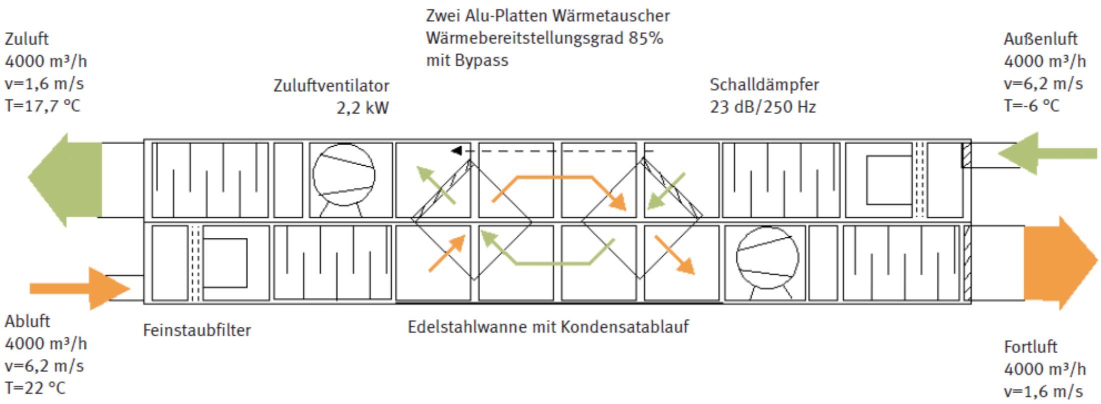


Figure 9: Nominal values of the AHU

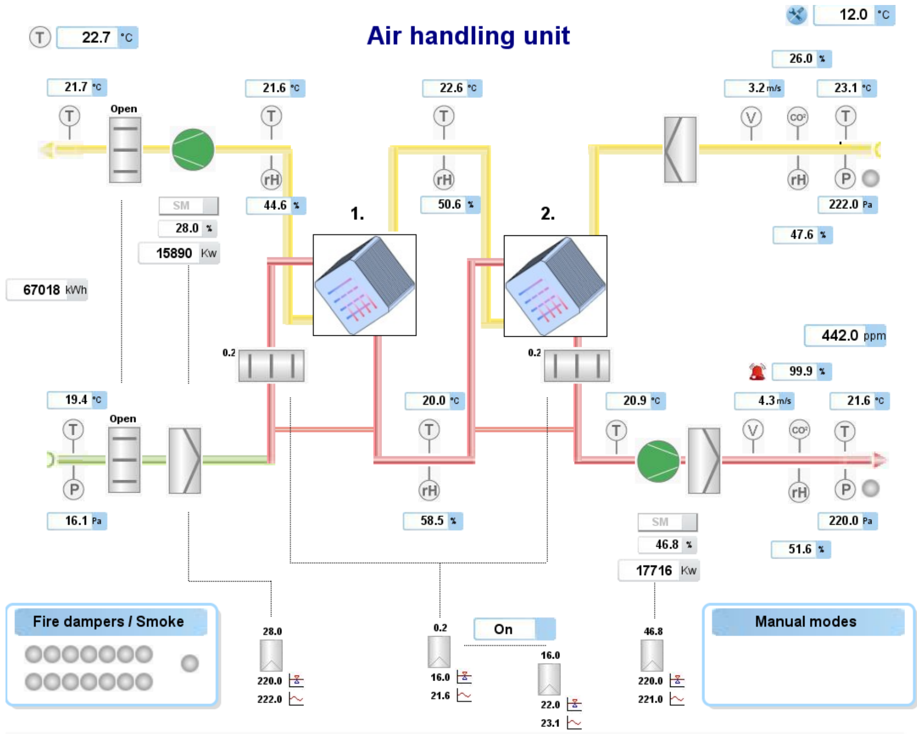


Figure 10: Air handling unit of ZUB building

As can be seeing in the following picture, the air is ducted inside the building in two different ways permitting the implementation of different control strategies depending on the season:

- Taking waste air from the offices and meeting rooms while the fresh treated air is driven to the atrium and from there distributed inside every zone.
- Waste air is taken by the atrium while the distribution will be handled by the diffusers installed in every room.

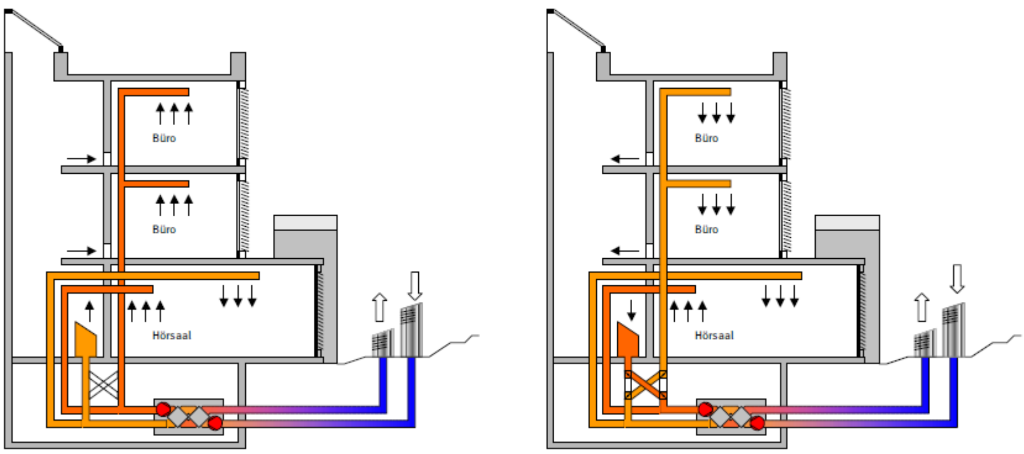


Figure 11: Mechanical Air Renovation

During winter time, the air from the offices, with higher thermal level than the atrium will be passed through the heat exchanger of the AHU to increase the level of the fresh air with higher yields, while in summer time, the coldest air that is in the lowest part of the atrium will be used to cool the fresh air before sending it into the building.

Figure 12: Air Diffuser (Room 207)

The distribution/collection of the air to/from the offices is done thanks to the use of the air diffuser (Figure 12) and prototype air ducts installed in every office. Figure 13 shows a photo and a diagram that explain the working mode of the prototype ducts that allow an increase of the ventilation rates when doors are closed.

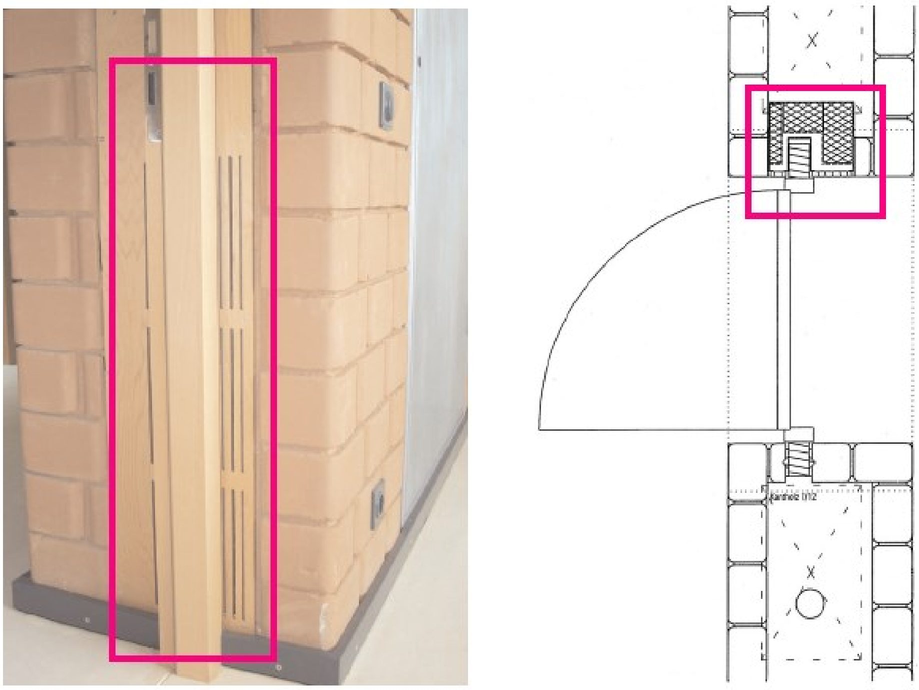


Figure 13: Prototype air ducts connect every office with the atrium

5 Energy supply and use

5.1 Electricity supply and consumption

The electrical consumes of the building during the year 2012 are described in the following table. Electricity is mainly used to illuminate the building, the offices, and to power the computers and electrical devices needed to work in an office building. The electrical consume of the Air Handling unit ventilators demanded 6.85% of the building consume during the year 2012 while the illumination and computers corresponded respectively 20.13% and 73.02 %.

Table 8: Electricity consumption of ZUB building

	Jan	Feb	Mar	Apr	May	Jun
kWh	7829	8345	7330	6127	4811	5610
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
kWh	4888	5650	6248	6792	8941	5692

Total (kWh): 78,263 kWh

5.2 Thermal energy supplied and consumption

Total thermal consumption during the year 2012 is monthly described in the following table.

Table 9: Thermal energy consumption of ZUB building (year 2012)

	Jan	Feb	Mar	Apr	May	Jun
kWh	7199	7649	1651	652	0	0
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
kWh	0	0	0	2193	5972	7304

Total (kWh): 32,623 kWh

6 Building Management System

The Centre for Sustainable Building (ZUB) has a wide amount of sensors installed that allows the evaluation of different demands and comfort conditions without the necessity of installing new measuring hardware.

Every office is equipped with control devices for dry air temperature, air pollution, position of the radiant systems valves and their sending and return temperatures. Some sensors are linked to occupancy and position of blinds, windows and doors.

The complete demand for each of the three floors is monitored with fluid energy meters and two different electrical meters that monitor the lighting consume and electrical consume of appliances. In order to allow more detailed monitoring and/or further experiments there are 3 test cells, one on each floor. i.e. 3 rooms of the building are better equipped with sensors.

The equipment of the test cells include the installation of the following sensors

- separate electrical and thermal counters
- energy meters for the ventilation system (hot wire sensors combined with air temperatures and humidities inside the distribution ducts, before and after the controlled zones
- a set of 3 more air temperature sensors that control the air stratification inside the zones
- 2 contact temperature sensors that deliver the thermal level of the radiant surfaces
- CO_2 and VOC sensors
- air humidity sensors for the controlled zone
- in some cases 3 added illuminance sensors to control the illumination quality
- measurement of the energy flows delivered by the radiant surfaces as well as their state of charged composed by
    - a set of 10 temperature sensors inside the thermal masses placed parallel to the surface
    - a set of 5 temperature sensors inside the thermal masses perpendicular to the surface
    - a flow energy meter placed inside the thermal masses

The complexity of the system allow the comparison of the behaviour of twin rooms placed one over the other under different control strategies applied as well as the correlation of the installed sensors in the non-intensively measured rooms with the data measured inside the test cells when all of them work under the same control conditions.

The following figure describes how is installed the building management system. Four different PLC's collect the signals delivered by the installed sensors. Each one of the controllers cover a different task:

- Blind PLC: controls the 80 relais correspondent to the 40 blind controllers existing in the building.
- Grundfunktion PLC: Collect the value of all the sensors installed in the basement of the building (mostly installed to control the general components that serve heating, cooling and ventilation) and control each installed equipment: AHU, radiant floor and ceiling tempering valves and pumps are controlled by it.
- Messprogram1 collects data and control every component installed in the ground and first floor.
- Messprogram2 collects data and control the components placed in the second floor and the thermal masses in between the office floors and the building roof.

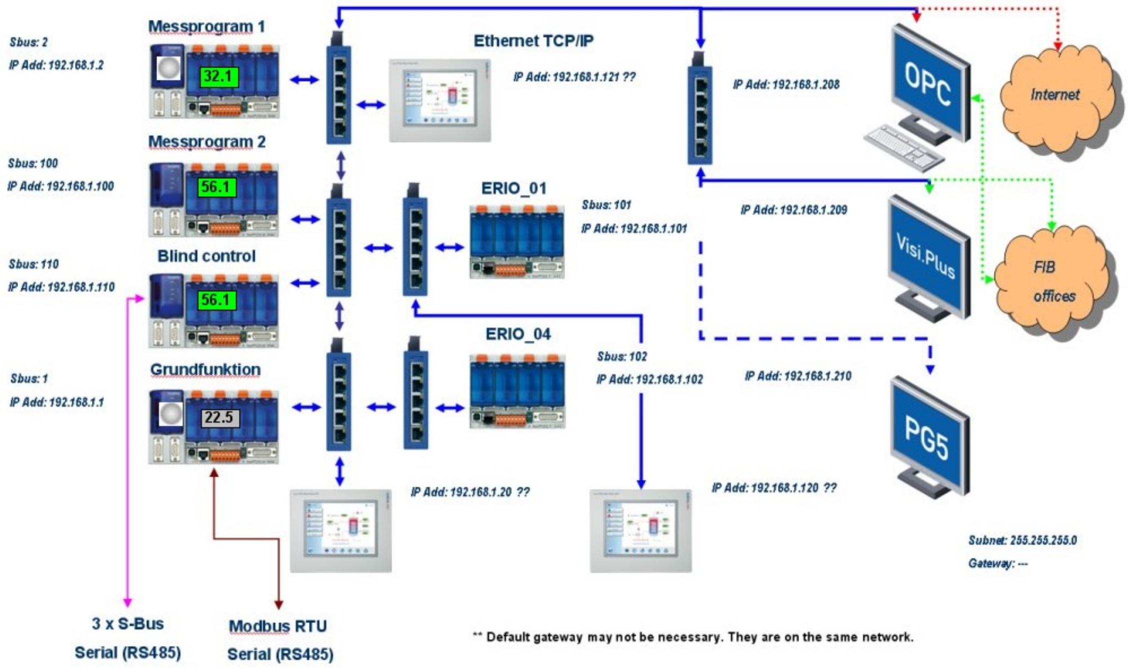


Figure 14: BMS scheme of ZUB building

6.1 Zonal monitoring network

Every office/room of this building is equipped with:

- Ambient temperature control/sensor to regulate the heating/cooling offer (PT1000)
- Air quality sensor (Sauter eg 0120)
- Luminance sensor to control the overall lighting levels
- Luminance sensor inside the lamps controlling the amount of light delivered when working
- Presence sensor that switch on/off the lights when someone is detected. (First on should be done manually)
- Radiant slab's 2-way valves controlled by zonal temperature
- Temperatures going inside the slabs
- Open advisor for doors and windows

There are also special rooms and auditoriums where the amount of sensors increases.

Two office rooms (106 & 206) have over the previously mentioned sensors:

- Three Pt1000 sensors at different heights inside the room to evaluate the stratification
- CO_2 sensor to measure that particles inside the room
- Relative humidity sensor
- Two air flow sensors (Hot wires) that measure how much air arrives in the tube before and after conditioning the office. (subtracting we obtain the office incoming air amount)
- Operative temperature sensor
- Two surface contact temperatures (Pt1000)

In the meeting rooms, there is a different distribution of the sensors comparing with the offices. Here the importance is marked on the quality of the air and the light that permits to follow the lessons/conferences with the maximum quality and minimum visual effort for the audience. Luminance, CO2, dry/operative temperature, humidity and air quality sensors are distributed along the meeting room to assure the comfort.

In every case the users/facility manager can change:

- Internal air setpoint temperatures (±2ºK difference with the predetermined setpoint programmed by the building manager)
- Position of the blinds to avoid glares and overheating in sunny days
- Artificial light
- Opening closing windows to renovate the air / generate free-cooling effects and increase natural ventilation
- CO_2, VOC maximum limits that increases/activate the ventilation effects

Table 10: Installed devices per zone of ZUB building

Devices installed per thermal zone														
Zone	Window Contacts	Door Contacts	Blind Motors	Selfcontroled lamps	AirTemperature	Operative Temp	Humidity Sensors	CO_2 Sensors	Air Quality	Illuminance	Occupancy Sensor	Water Temperatures	Water Flow mass	Air Speed and temp.
Atrium	-	2		1	3	-	3	-	-	3	3	4	2	4
R001	1	1	2	1	1	-	1	-	1	1	1	2	-	-
R002	1	2	3	1	1	-	-	-	1	1	1	2	-	-
R004	1	2	4	1	3	2	1		1	1	1	2	-	-
R005	1	1	2	1	5	2	1	1	1	2	1	4	2	4
R007	3	1	2	1	1	-	-	-	1	1	1	2	-	-
R101	1	1	3	1	1	-	-	-	1	2	1	2	-	-
R102	3	3	2	1	1	-	-	-	1	1	1	2	-	-
R105	3	3	2	1	1	-	-	-	1	1	1	2	-	-
R106	5	3	2	1	6	1	1	1	1	1	1	4	2	4
R107	3	1	2	1	1	-	-	-	1	1	1	2	-	-
R201	3	3	2	1	1	-	-	-	1	1	1	2	-	-
R202	1	3	1	1	1	-	-	-	1	1	1	2	-	-
R203	3	3	2	1	1	-	-	-	1	1	1	2	-	-

R204	2	2	1	1	1	-	-	-	1	1	1	2	-	-
R205	3	3	2	1	1	-	-	-	1	1	1	2	-	-
R206	5	3	2	1	6	1	1	1	1	1	1	4	2	4
R207	3	3	2	1	1	-	-	-	1	1	1	2	-	-
TOTAL	**42**	**41**	**36**	**18**	**36**	**6**	**8**	**3**	**17**	**22**	**20**	**44**	**8**	**16**

Meeting rooms have a different distribution of the sensors comparing with the offices. Here the importance is marked on the quality of the air and the light that permits to follow the lessons/conferences with the maximum quality and minimum visual effort for the audience. Luminance, CO_2, dry/operative temperature, humidity and air quality sensors are distributed along the meeting room to assure the comfort.

6.2 Control strategies

6.2.1 Moveable shading control

External shading systems are nowadays controlled manually but there is no appreciable difficulties to install a relays based control that permits the variation of the slaps angles and the total longitudinal movement of the venetian blind.

Internal temperature probes and internal /external luminance and radiation sensors permits to close the blinds depending on the intensity of the sun while the optimal light conditions are kept.

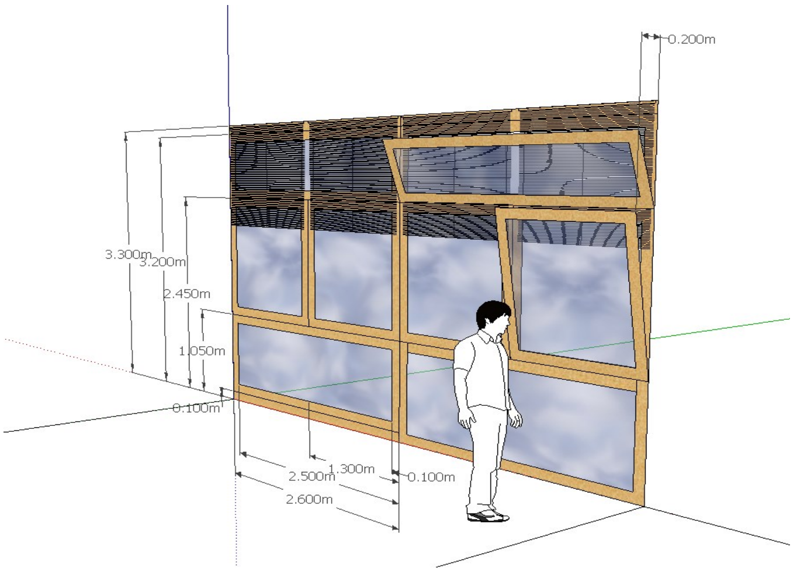


Figure 15: Blind and window schema for each one of the ZUB Offices

Presence sensors advise the control about the needed of keeping the working conditions inside the offices.

There are two offices in the building where the shading systems can move in two independent positions depending on the height of the window we consider. Approximately the first meter of the venetian blind and the resting 130 cm can move with different tilted angles.

All slats of the blind have a longitudinal turning movement along their own axes to create different degrees of shadowing for the same vertical position.

The complete blind can go up and down to cover approximately 2.2 meter of the windows, so leaving without sun coverage the inferior meter of the windows.

Nowadays there is not an automatic control strategy to position the slaps in the optimal place for the internal loads depending on the heating/cooling period.

6.2.2 Lighting system

Lighting control is combined to the presence and illumination sensors to deliver the optimal light depending on the internal conditions.

Nowadays, the user must connect the lighting system, and it will increase the luminance intensity (electrical consume) measuring the conditions inside the zone.

6.2.3 Heating and cooling system

For the definition of the heating controls should be explained first that there are two variable set points in the system.

The first set point is on the overall sending temperature to the slabs that works as defined in the following figure, depending on the occupancy.

The second set point is the internal temperature demanded by the people that work inside each zone. A basic set point of 21 is settled but the user can change it ± 2 degrees (19-23ºC).

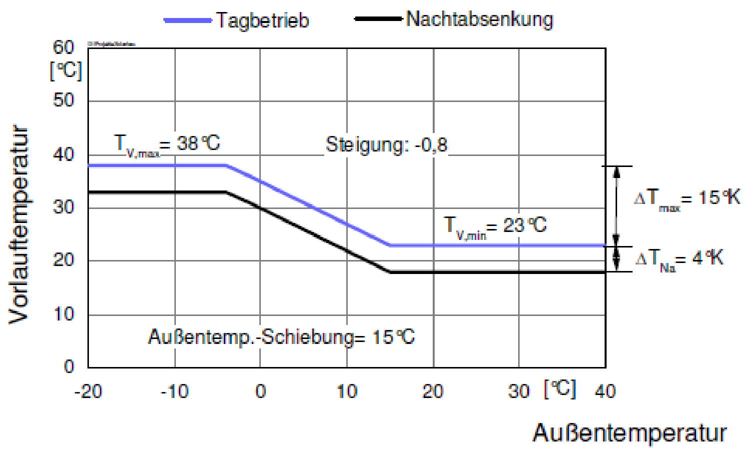


Figure 16: Heating programmed sent temperature as a function of the external ones

6.2.4 Ventilation control

The unique ventilation system installed and controlled in the building is the AHU that move the air through an air exchanger that assure the recovery in the renovations.

Every office has their own three windows that are controlled manually as described in the figure 18. Also there are 5 windows on the top of the atrium that can be opened to create chimney effects in the building increasing the natural ventilation by the temperature difference between rooms and top-atrium.

7 Historical data: existing data base

Currently there is a MS SQL database in order to store all the data from the BMS including weather station and weather forecast data. MS SQL Server is a high performance relational database management system available for the Microsoft operating systems. Its primary query languages are T-SQL and ANSI SQL so as to manage information stored (insert, delete update, execute etc). The figure bellow represents the entity relational scheme of ZUB building monitoring system, which is the same than the existing scheme in TUC building. For further information, Appendix B: Technical University of Crete, can be consulted.

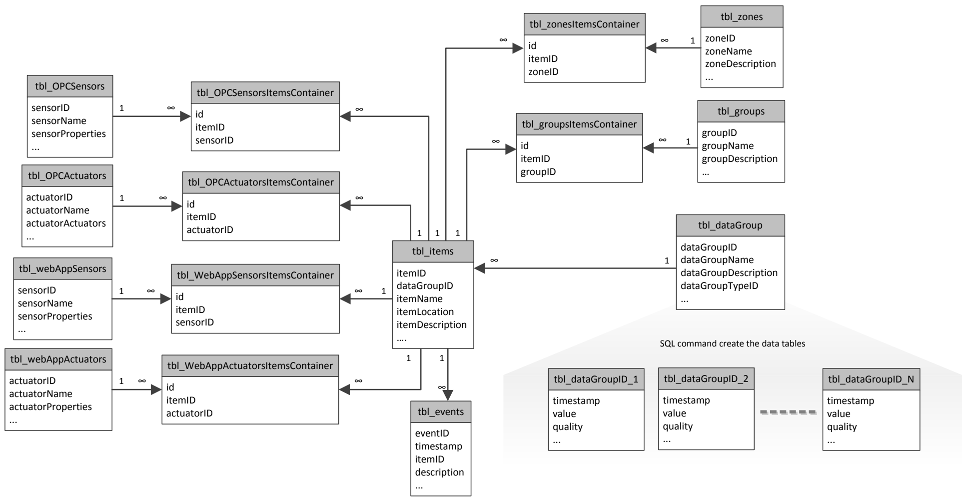


Figure 17: ZUB building monitoring relational database scheme

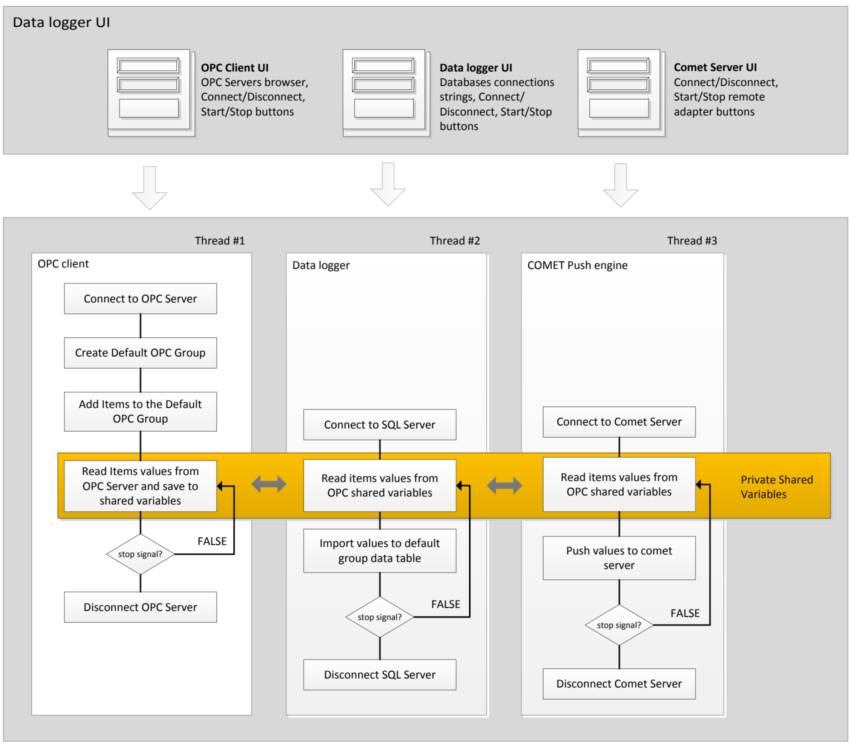


Figure 18: Multi-threaded datalogging software of ZUB building

8 External data sources: weather data

A Vaisala WXT520 weather station delivers through a web service the data related to the air conditions and precipitations while two Kipp&Zonnen pyranometers deliver the horizontal radiations through the building management system with a time step of 1 minute. Values from 2001 are available.

Table 11: Outdoor ambient parameters of ZUB building

Outdoor ambient parameters			
Concept	**No.**	**Explanation**	**Unit**
Outdoor ambient param.	1	Global Radiation on Horizontal	W/m^2
	2	Diffuse Radiation on Horizontal	W/m^2
	3	Wind Speed	m/s
	4	Wind Direction	degree
	5	Rainfall	mm
	6	Rain Duration	s
	7	Rain Intensity	mm/h
	8	Barometric Pressure	hPa
	9	Air temperature	ºC
	10	Relative humidity	%RH