D6.1 Appendix Summary Sheet

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D6.1 Appendix B: Technical University of Crete: Short Description
This document describes the demonstration building TUC.
Keywords: TUC, offices, Crete, demonstration building

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Appendix B: Technical University of Crete. Chania (Greece)

TUC building is located at the Technical University Campus situated at Kounoupidiana in the Akrotiri peninsula. The area is at the suburbs of Chania, thinly built-up, with an open view towards the north. The distance of the area from the sea is nearly 2.97 km from south and 2.02 km from north. Figure 1 shows satellite pictures of the area with the building marked.

Figure 1: TUC building's site

1.1 General building information

The elevation of the area above the sea level is 146 m, the latitude is 35˚31'36.58" and the longitude 24˚04'13.01". The building is a two storey dwelling with a basement and a total surface area of 450 m^2. The overall construction is currently used for the University's technical services' offices. It has a North-North-West orientation with large openings and an atrium.

Table 1: General information of TUC building

Name	Technical University of Crete	Envelopment area	-
Address	Technical University of Crete Campus	Glazed area	-
City / Post code	Chania / 73100	From factor (S/V)	-
Country	Greece	Heated Area (m^2)	
Contact Person	Rovas Dimitrios	Heated Volume (m^3)	-
e-mail of contact person	rovas@dpem.tuc.gr	Cooled Area (m^2)	-
Location (coordinates)	Latitude: 35˚31'36.58" Longitude: 24˚04'13.01"	Cooled Volume (m^3)	-
Orientation	North-North-West	Heating degree days (15.5ºC)	510
Altitude (m)	146	Cooling degree days (15.5ºC)	1680
Year of	2003	Average power	-

construction		consumption (kWh/m²a)	
Typology of building	Office Building	Average thermal consumption (kWh/m²a)	31.37
Floors	2	Heating system	Oil Boiler, Radiators Split Units (DX Heating)
Built area	-	Cooling system	Split Units (DX Cooling)
Net usable area	-	DHW system	n.a.

The region is characterized by long-hot summers and cool/cold-humid winters and long periods of sunlight at the bigger duration of year, typical of a Mediterranean climate. The heating period starts in October and ends in April and cooling period starts in May and ends in September.

Table 2: Climate values for Chania

	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	10.7	13.4	9.1	62	74	16	0	-	-	-	-	3
Feb	9.6	13.0	8.0	37	70	11	0	-	-	-	-	4
Mar	11.4	14.6	9.7	37	67	11	0	-	-	-	-	6
Apr	15.1	18.7	11.7	23	63	9	0	-	-	-	-	9
May	19.6	23.2	16.5	23	59	8	0	-	-	-	-	10
Jun	24.6	28.3	20.5	14	53	4	0	-	-	-	-	10
Jul	27.3	30.4	23.0	6	47	2	0	-	-	-	-	10
Aug	27.6	32.0	24.0	7	47	3	0	-	-	-	-	8
Sep	23.9	27.6	20.1	15	56	4	0	-	-	-	-	7
Oct	19.1	22.9	16.9	51	67	8	0	-	-	-	-	5
Nov	14.5	17.8	12.8	56	73	12	0	-	-	-	-	3
Dec	10.9	14.0	9.8	71	75	15	0	-	-	-	-	3
Total	17.9	21.4	15.2	33.5	63	9	0	-	-	-	-	7

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 Table 2

Several views of the building can be seen from

Figure 2 to Figure 4 [2].

Figure 2: Depiction of the main entrance of the building

Figure 3: Depiction of the south-west (left) and south-east (right) side

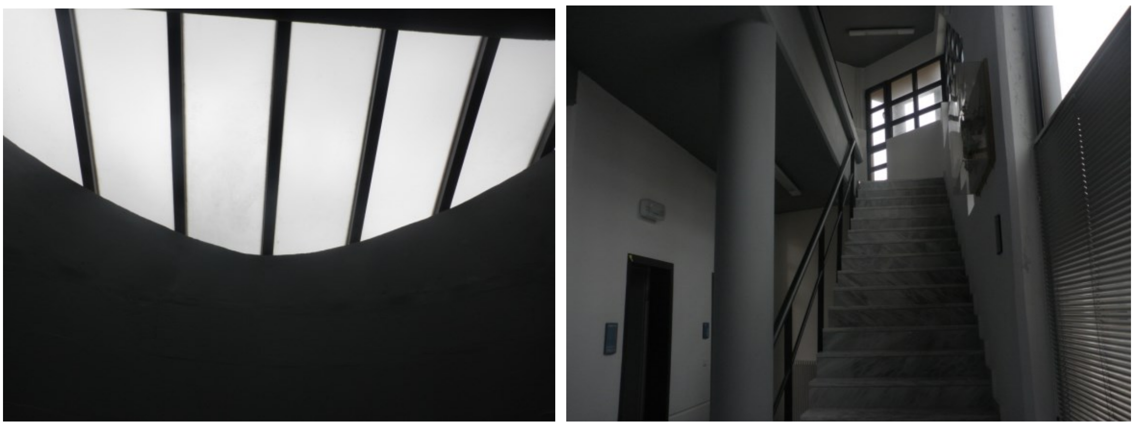

Figure 4: Roof opening (atrium) and the indoor stairs

2 Building use: distribution and occupancy

The building has two floors and a basement with a total surface area of 450 m^2. Its use is hosting the office of the Technical and Building Services Department of the University. The building has a North-North-West orientation with large openings and an atrium.

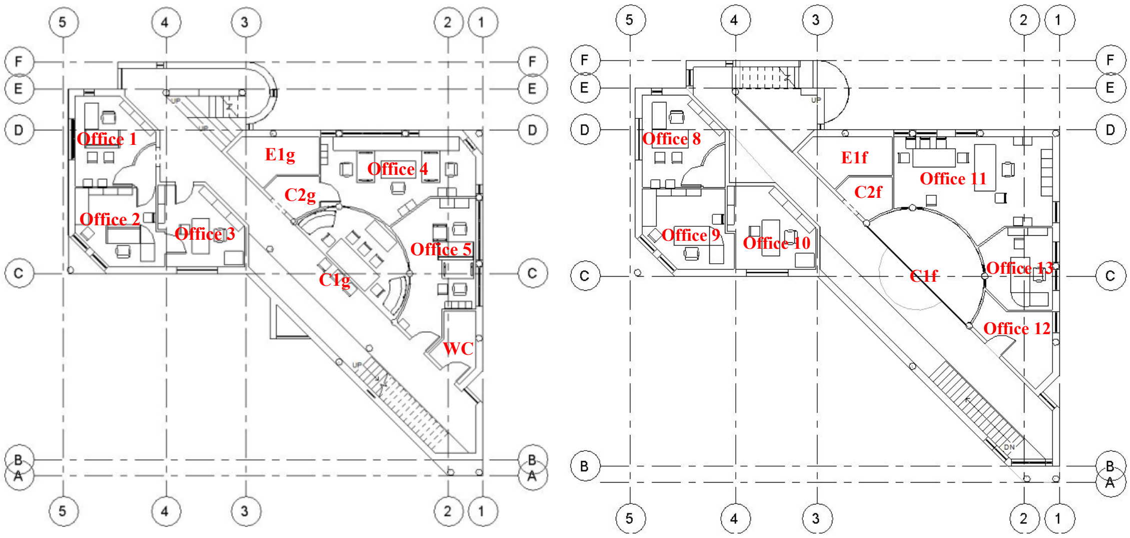

Figure 5: Ground Floor (left) and First Floor (right) Plan views

Solar gains through the atrium are particularly important, especially during the summer months when the sun is at an angle conducive to overheating the space below the atrium and the adjacent offices.

The external walls are constructed by concrete, brick and stone wool as insulation material with the exception of some specific parts in the front and back of the building that are constructed by concrete only. Some of the internal partitions are brick, some concrete and others added later on to separate the space are constructed by gypsum plastering. The U-values of the external, internal walls and windows are quite high which reveals the thermal attitude of the building. Hence, the building has a significant amount of thermal losses due to its construction materials.

With reference to HVAC of the building, heating is achieved through a central system using a campus-wide oil boiler and hot water radiators in each room. An AC-unit is positioned in each office to cool the zone during summer but it is also used as a supplementary heating system whenever the central system does not cover the heating needs of each space during winter. Data regarding the heating and cooling function of each type of split unit in each zone such as availability schedule, air flow rates, EER, COP, capacity along with data regarding the boiler (fuel type, thermal efficiency, water temperature), the radiators located in each zone (average water temperature, water mass flow rate, capacity, surfaces and fractions of radiant energy to surfaces) and the connection of the boiler with the radiators in each zone (branches, splitter, mixer) are presented in the following sections.

The ventilation and infiltration are based on window openings and cracks, expressing the airtightness of the building. A low airtightness is assumed for TUC building due to its construction and its exposure to winds.

To summarize, the low insulation standards combined with a solar atrium contribute to overheating during the summer months along with moderate (because of the mild climate) heating needs during the winter. Concerning the efficiency of the building, in addition to thermal-comfort problems for the building users, the energy consumption is quite high, at 130kWh/m^{2}a based on energy audits and simulation results.

Table 3: TUC building distribution / usage

Zone	Floor	Useful area (m^2)	H. (m)	Vol. (m^3)	% cond.	Occ. (pax)	TAS loops	Cond. services
Office 1	0	11	3.55	39.05	100%	1	-	RADIATORS SPLIT UNITS
Office 2	0	12	3.55	42.6	100%	1	-	RADIATORS SPLIT UNITS
Office 3	0	12	3.55	42.6	100%	1	-	RADIATORS SPLIT UNITS
Office 4	0	21	3.55	74.55	100%	1	-	RADIATORS SPLIT UNITS
Office 5	0	18	3.55	63.9	100%	1	-	RADIATORS SPLIT UNITS
Office 8	1	11	3.1	34.1	100%	1	-	RADIATORS SPLIT UNITS
Office 9	1	12	3.1	37.2	100%	1	-	RADIATORS SPLIT UNITS
Office 10	1	12	3.1	37.2	100%	1	-	RADIATORS SPLIT UNITS
Office 11	1	25	3.55	88.75	100%	1	-	RADIATORS SPLIT UNITS
Office 12	1	8	3.55	28.4	0%	1	-	-
Office 13	1	10	3.55	35.5	100%	1	-	RADIATORS SPLIT UNITS
C1g (corridor)	0	60	3.55	2130		0	-	RADIATORS
C1f (corridor)	1	60	3.55	2130		0	-	RADIATORS
C2g (corridor)	0	3	3.55	10.65	0%	0	-	-
C2f (corridor)	1	3	2.65	7.95	0%	0	-	-
WC	0	5	3.55	17.75	100%	0	-	RADIATORS
E1g (elevator)	0	6	3.55	21.3	0%	0	-	-

E1f (elevator)	1	6	3.55	21.3	0%	0	-	-

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

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Mon-Fri	0	0	0	0	0	0	0	0	1	1	1	1
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	1	1	1	0	0	0	0	0	0	0	0	0
Weekend	0	0	0	0	0	0	0	0	0	0	0	0

Table 5: Building yearly occupation profile of TUC building

Week	1	2	3	4	5	6	7	8	9	10	11	12	13
Mon-Fri	1	1	1	1	1	1	1	1	1	1	1	1	1
Weekend	0	0	0	0	0	0	0	0	0	0	0	0	0
Week	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Mon-Fri	1	1	1	1	1	1	1	1	1	1	1	1	1
Weekend	0	0	0	0	0	0	0	0	0	0	0	0	0
Week	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
Mon-Fri	1	1	1	1	1	1	1	1	1	1	1	1	1
Weekend	0	0	0	0	0	0	0	0	0	0	0	0	0
Week	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**
Mon-Fri	1	1	1	1	1	1	1	1	1	1	1	1	1
Weekend	0	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

The characteristics of the construction materials are described in detail by Table 6 while each layers construction is described by Table 7. Table 8 provides information on thermal, solar, visible and infra-red properties of the glazing of the building.

The external walls are constructed by concrete, brick and stone wool as insulation material with the exception of some specific parts in the front and back of the building that are constructed by concrete only. Some of the internal partitions are brick, some concrete and others added later on to separate the space are constructed by gypsum plastering. The U-values of the external, internal walls and windows are quite high which reveals the thermal attitude of the building. The building has a significant amount of thermal losses due to its construction materials and heat gains during summer due to the roof glazing.

Table 6: Thermal properties of construction materials [2]

	Thermal Bulk Properties			Surface Properties		
Material	**Conductivity (W/mK)**	**Specific Heat (J/kg K)**	**Density (kg/m^3)**	**Thermal Absorptance**	**Solar Absorptance**	**Visible Absorptance**
Coating	0.85	1085	1900	0.9	0.7	0.7
Cast concrete (dense)	1.4	840	2100	0.9	0.6	0.6
MW Stone Wool	0.038	840	40	0.9	0.6	0.6
Brick	0.72	840	1920	0.9	0.6	0.6
Gypsum plastering	0.4	1000	1000	0.9	0.5	0.5
Aerated concrete slab	0.16	840	500	0.9	0.6	0.6
Expanded Polystyrene	0.035	1400	25	0.9	0.6	0.6
Asphalt	0.7	1000	2100	0.9	0.85	0.9
Gravel	0.36	840	1840	0.9	0.29	0.29
Marble (white)	2.77	802	2600	0.9	0.58	0.58

Table 7: Description and layers U-values [2]

Layer	Layer bedding	U-value

		(W/m^2K)
External walls	0.02m coating, 0.19m concrete, 0.03m stone wool, 0.09m brick and 0.02m coating	1.026
External walls	0.02m coating, 0.31m concrete and 0.02m coating	4.3
Internal partitions	0.02m coating, 0.2m concrete, 0.02m coating	5.65
Internal walls-round partitions	0.05m gypsum plastering, 0.05m gypsum plastering	4
Roof	0.1m concrete, density 500kgr/m^3, double asphaltpane 0.08m, extruded polysterine 0.04m, gravel 0.2m	0.41
Floor	white marble 0.03m and 0.3m concrete	4.44
External windows	double clear 3mm/6mm air (aluminum frames)	3.159
Internal windows	double clear 3mm/6mm air (aluminum frames)	3.159

Table 8: Windows glazing characteristics [2]

Generic clear glass	
Thermal Properties	
Thickness (mm)	3
Conductivity (W/m K)	0.9
Solar Properties	
Solar transmittance	0.837
Outside solar reflectance	0.075
Inside solar reflectance	0.075
Visible Properties	
Visible transmittance	0.898
Outside visible reflectance	0.081
Inside visible reflectance	0.081
Infra-red Properties	

Infra-red transmittance	0
Outside emissivity	0.84
Inside emissivity	0.84

The shading of the windows is attained through shading devices such as blinds with medium reflectivity slats (see Figure 6). The position of the shading devices is from the inside of the window. The operation of the blinds is manually controlled by occupants (working hours only). It is assumed that employees control the operation of the blinds according to the solar radiation while they are working.

The shading of the windows is attained through shading devices such as blinds with medium reflectivity slats (see Figure 6). The position of the shading devices is from the inside of the window. The operation of the blinds is manually controlled by occupants (working hours only). It is assumed that employees control the operation of the blinds according to the solar radiation while they are working.

Figure 6: Shading devices

Figure 7 depicts the dimensions of windows with blinds and the dimensions of windows with no shading device, using red color, at the façade of the building.

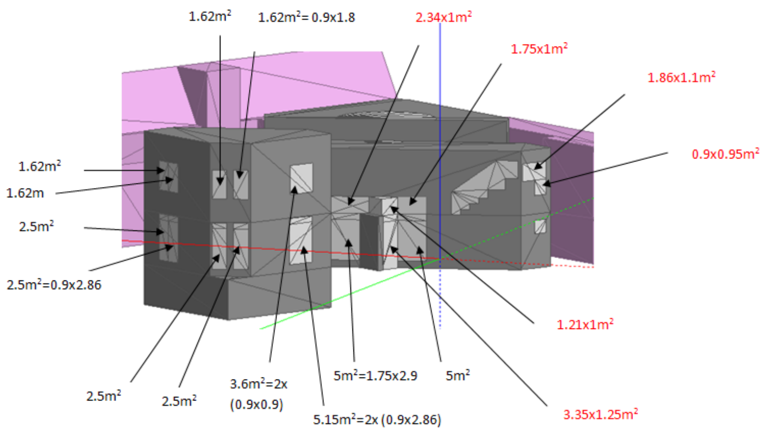

Figure 7: Dimensions of windows with blinds (black color) and of windows without shading devices (red color)-façade view

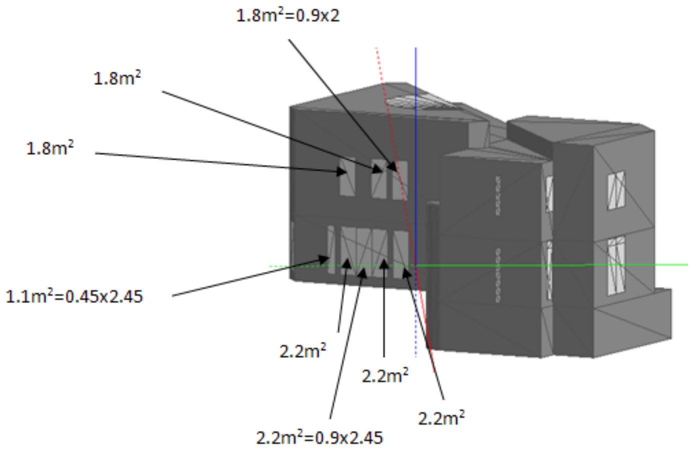

Figure 8: Dimensions of windows with blinds-left side view

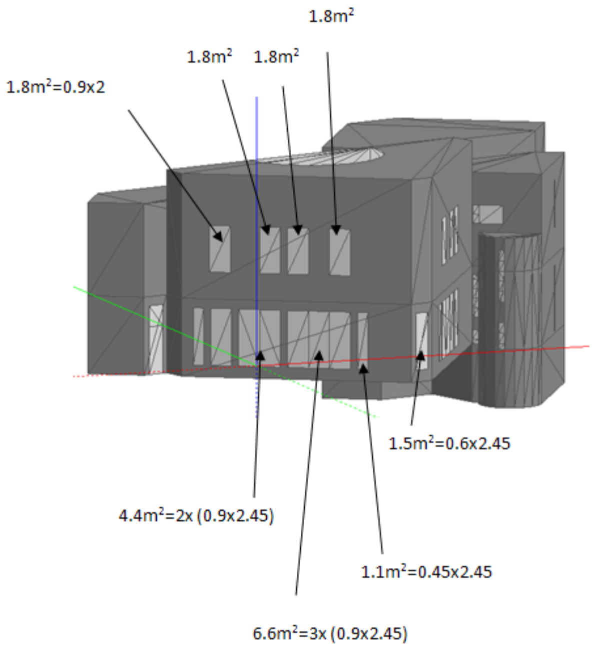

Figure 9: Dimensions of windows with blinds-right side view

4 Energy flow

The heating system of the building is a central system with an oil boiler and hot water radiators in each zone. The efficiency of the boiler is estimated at 0.8. The thermal bodies are depicted in Figure 11. The technical characteristics of the radiators such as dimensions, capacity can be seen in Table 9.

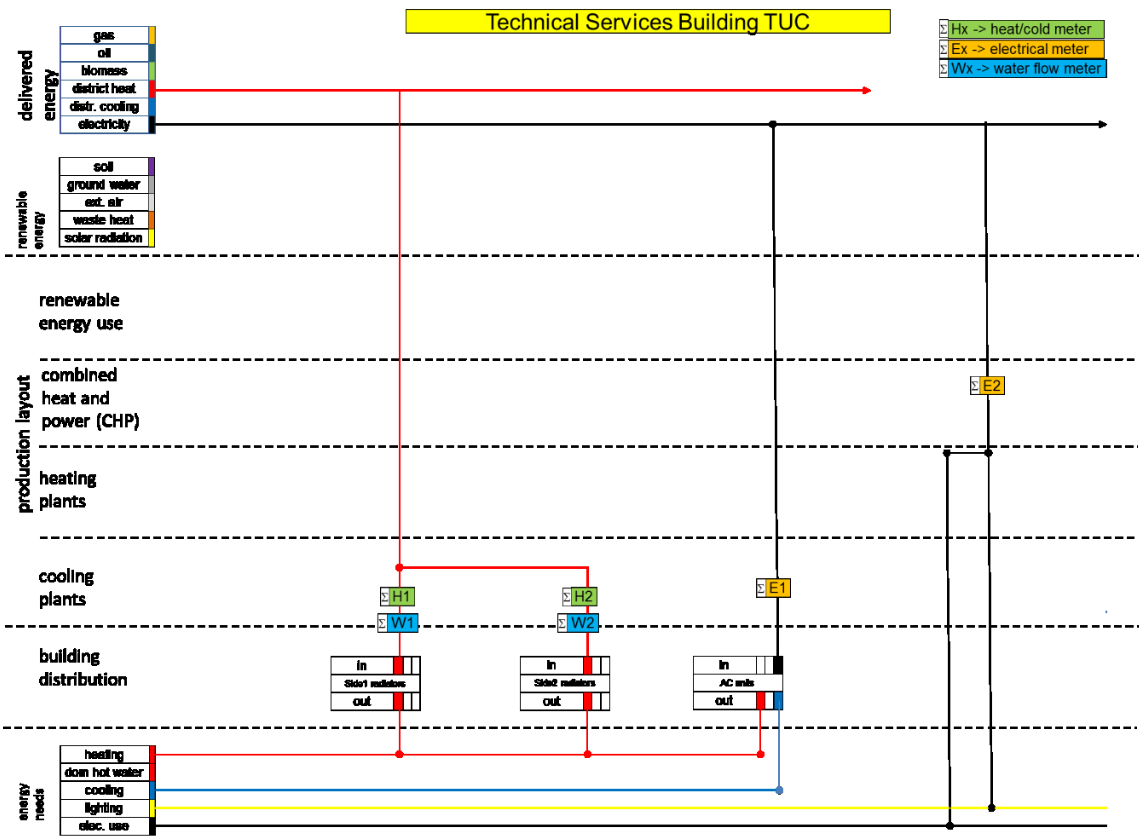

Figure 10: Energy flow

During winter the heating system is available according to the work time schedule. The thermal heat pump is activated only when the capacity of the radiators is not sufficient to reach the desired (set) temperature level within a zone. That means that whenever the employees do not feel comfortable, they are turning on the split-type unit even if the radiators are heating the zone.

Figure 11: Radiators-Thermal bodies of TUC building

Table 9: Technical characteristics of the radiators in each zone

Zone	Slices	Columns	Length (mm)	h_2 (mm)	h_1 (mm)	Capacity (kW)
Office 1	10	3	380	905	995	1.488
Office 2	10	3	380	905	995	1.488
Office 3	10	3	380	905	995	1.488
Office 4	10	3	380	905	995	1.488
Office 4	29	2	1160	655	745	2.326
Office 4	23	2	920	655	745	1.860
Office 5	18	3	684	905	995	2.523
Office 8	10	3	380	905	995	1.488
Office 9	10	3	380	905	995	1.488
Office 10	10	3	380	905	995	1.488
Office 11	10	3	380	505	595	0.942
Office 11	10	3	380	905	995	1.488
Office 13	12	4	456	905	995	2.395
WC	10	2	380	905	995	1.035

C1g	8	3	304	905	995	1.186
C1g	22	2	836	905	995	2.245
C1f	10	3	380	905	995	1.488
C1f	24	2	912	905	995	2.453
C1f	14	2	532	355	445	0.870
C1g	8	3	304	905	995	1.186

The oil boiler serves three buildings. The connection between the central boiler and TUC building is achieved through underground pipes in two central points (see Figure 12, red arrows) and then from these points hot water is distributed from the pipes to the radiators of each zone. Due to the fact that the building does not own the boiler, no thermostat can act on its operation which means that the availability schedule of the boiler is controlled by one person in charge who decides whether the heating should be on and for how long.

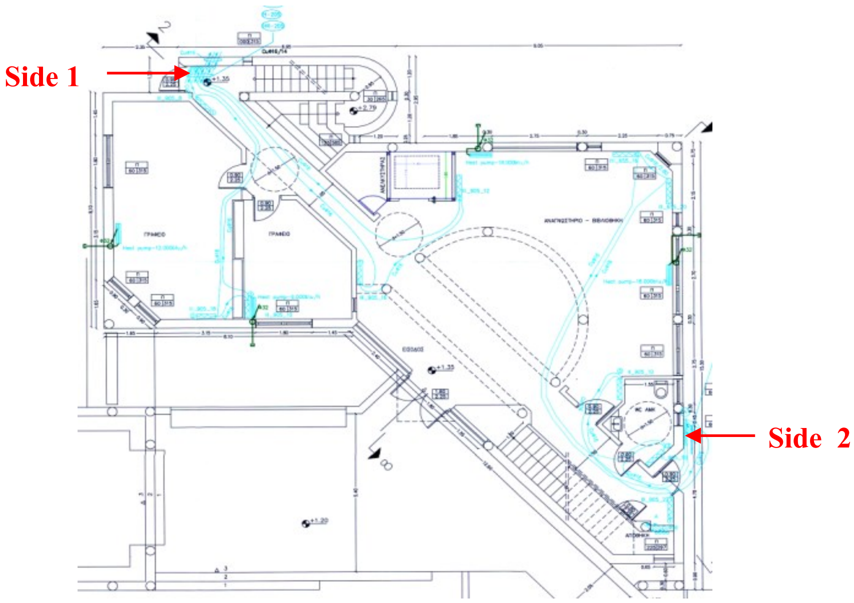

Figure 12: Heating system central points – Side 1 and Side 2

According to real measurements, during winter, the central heating system serving all campus buildings is opened every day at (about) 05:30 to pre-heat the buildings and is closed around 11:30 – 12:00, depending on the outside conditions; while the valves controlling the lines inside each building are always open. In Figure 13, the radiator lines serving the zones and the corresponding flow valves are presented (marked with *T1*, *T2*, etc.)

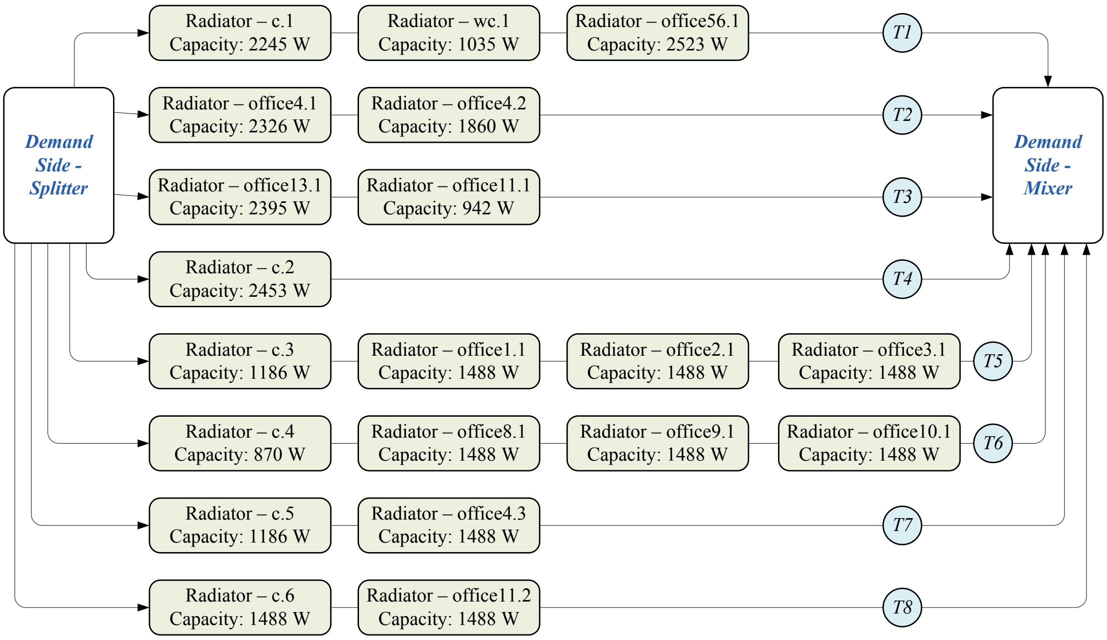

Figure 13: Central heating system branches and the corresponding flow valves

The cooling of the building is achieved by split units. The EER, COP and the capacity of the system vary depending of the model of the split unit. The type and characteristics of each split unit are shown in Table 10. The cooling of the zone is again available according to the work time schedule during the summer period while; the cooling system operational schedule and its setpoint at each zone are manually determined by occupants.

Table 10: Technical characteristics of the cooling system in each zone [2]

		Cooling characteristics			Heating characteristics		
Zone	Split unit type	EER	Cooling capacity (kW)	Rated air flow rate (m^3/s)	COP	Heating capacity (kW)	Rated air flow rate (m^3/s)
Office 1	Haier HSU-09 HC03/R2	3.82	2.6	0.153	3.66	3.45	0.153
Office 2	MITSUBISHI MSH-AXV12WV	2.41	3.5	0.131	3.03	4	0.141
Office 3	MITSUBISHI MSH-AXV12WV	2.41	3.5	0.131	3.03	4	0.141
Office 4	MITSUBISHI GA50VB	2.81	5	0.178	3.23	5.3	0.178
Office 5-6	MITSUBISHI MCFH-A24WV	2.45	6	0.206	2.5	6.8	0.206

Office 8	Haier HSU-09 HC03/R2	3.82	2.6	0.153	3.66	3.45	0.153
Office 9	MITSUBISHI MSH-AXV12WV	2.41	3.5	0.131	3.03	4	0.141
Office 10	MITSUBISHI MSH-AXV12WV	2.41	3.5	0.131	3.03	4	0.141
Office 11	MITSUBISHI GA50VB	2.81	5	0.178	3.23	5.3	0.178
Office 13	MITSUBISHI GA50VB	2.81	5	0.178	3.23	5.3	0.178

Artificial lights are located in each office providing sufficient lighting when natural cannot reach the desirable lux levels. The type of lighting tubes is TL-D 36 fluorescent of 25mm diameter and 1.5m length.

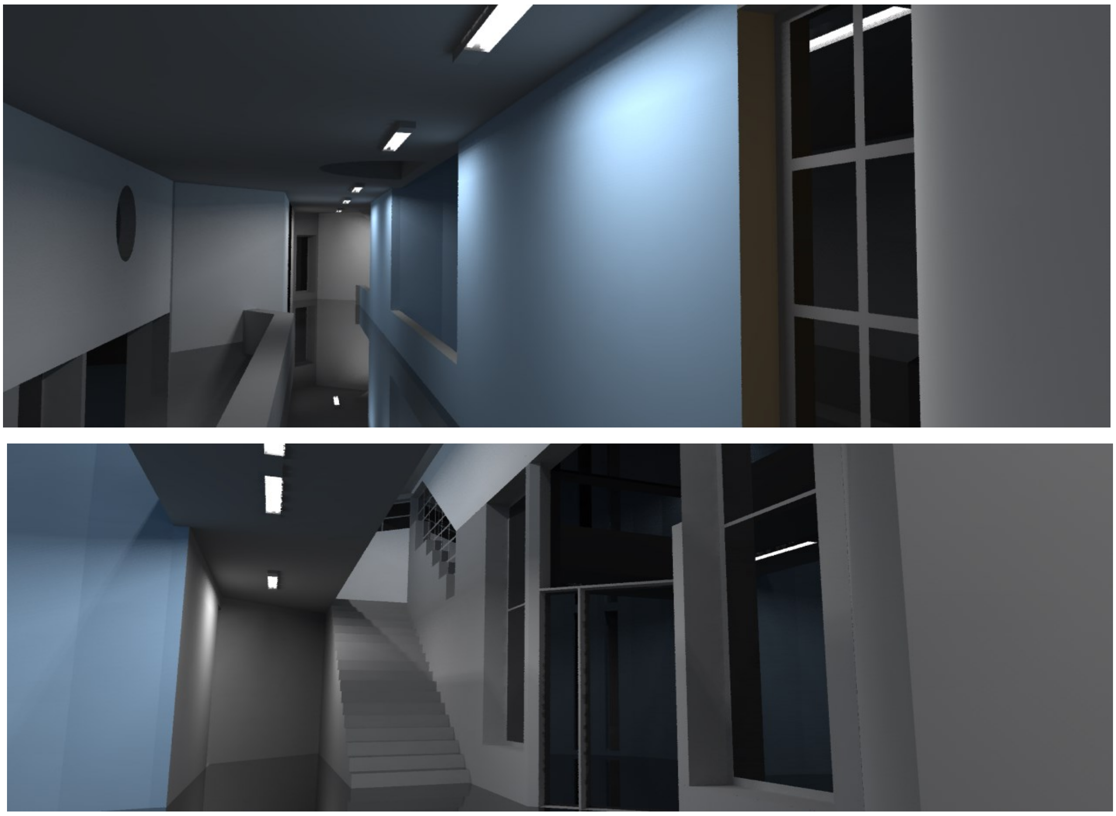

Figure 14: Operating lighting tubes in each floor corridor – Radiance rendering

The power per tube is 36 Watt and the voltage 230V. There is also a smaller type of lighting tubes TL-D 18 placed in the corridor of the ground and first floor, 4 tubes in each zone. The luminaire type is surface mount with radiant fraction of 0.72 and visible fraction 0.18. The number of lighting tubes and their efficiency can be seen in Table 11. The lighting system operational pattern is manually determined by occupants.

Table 11: Artificial Lighting in each zone [2]

Zone	Surface (m^2)	Lighting tubes	Total power demand (W)	W/m^2
Ground floor-corridor	63	6+4	288	4.57
1st floor-corridor	63	6+4	288	4.57
WC	5	1	36	7.20
Office 1	11	4	144	13.09
Office 2	12	4	144	12.00
Office 3	12	8	288	24.00
Office 4	21	8	288	13.71
Office 5	18	10	360	20.00
Office 8	11	4	144	13.09
Office 9	12	4	144	12.00
Office 10	12	8	288	24.00
Office 11	25	14	504	20.16
Office 12 (equipment room)	8	2	72	9.00
Office 13	10	6	216	21.6

The internal gains due to the operation of office equipment and computers can be seen in the following table. It is assumed that computers are operating during the work-time schedule except the one positioned in office 11 that is always on according to information provided by the user, the rest are off when the building is closed. Concerning office equipment (office 12) such us printers, it is assumed that they are always in sleep mode because of the small frequency of operation.

Table 12: Electrical Equipment in each zone [2]

Zone	Surface (m^2)	Office Equipment	Computer Gains (W/m^2)	Equipment Gains (W/m^2)
Office 1	11	1 PC (100 Watt)	9.09	-
Office 2	12	1 PC (100 Watt), 1 printer (15 Watt, sleep mode)	8.33	1.25
Office 3	12	1 PC (100 Watt), 1 printer (15 Watt, sleep	8.33	1.25

		mode)		
Office 4	21	1 PC (100 Watt), 1 printer (15 Watt, sleep mode)	4.76	0.71
Office 5	18	2 PC (200 Watt)	11.11	-
Office 8	11	1 PC (100 Watt), 1 printer (15 Watt, sleep mode)	9.09	1.36
Office 9	12	1 PC (100 Watt), 1 printer (15 Watt, sleep mode)	8.33	1.25
Office 10	12	1 PC (100 Watt)	8.33	-
Office 11	25	1 PC (100 Watt)	5	-
Office 12	8	1 plotter (HP designjet 800ps- 15 Watt sleeping mode, 150 Watt max),OKI C7300 (45 Watt sleep mode), Samsung SF-560 R (12 Watt, sleep mode), refrigerator Goldstar GR-1410 GS (30 Watt)	-	12.75
Office 13	10	1 PC (100 Watt)	10	-

5 Energy use

The energy consumption results presented in this section are stemming from a simulation-based energy auditing, where a thermal simulation model is used, acting as surrogate of real building, including not only its geometry and construction materials but also its use and the operation of its HVAC and lighting system.

5.1 Electricity consumption

Table 13: Electricity consumption of TUC building

	Jan	Feb	Mar	Apr	May	Jun
Heating kWh	191	212	118	0	0	0
Cooling kWh	0	0	0	0	0	949
	Jul	Aug	Sep	Oct	Nov	Dec
Heating kWh	0	0	0	0	41	163
Cooling kWh	2037	1680	933	0	0	0

Total (kWh): 6324

5.2 Fuel consumption

Table 14: Oil consumption of TUC building

	Jan	Feb	Mar	Apr	May	Jun
kWh	1723	1623	1085	0	0	0
	Jul	Aug	Sep	Oct	Nov	Dec
kWh	0	0	0	16	616	1383

Total (kWh): 6446

The heating of the building is achieved primarily by the radiators and secondly by the heat pump. During April and May the building has no heating needs and the central heating system is not operating while for the rest of the winter months the heating pump supplements the central heating system. The warmest months in Chania are July and August comparing to June and September. The annual electricity consumption of the cooling system is less from the oil consumption of heating system. This is due to the fact that the heated area of the building contains the central corridors of the building while the cooling area comprises only the offices.

6 Building Management System

6.1 Monitoring network

The TUC building data-logger is a software component developed for storing historical data to external data bases. This is also a component of the TUC building BMS framework and using the building connector, can access building values which are then written to one or more databases connected to the system. One of the design considerations was ensuring high availability of the data logging system to ensure minimum loss of data points for the evaluation. The architecture presented schematically in Figure 15 below, comprises of two-data logging virtual machines. Each of these machines is connected to the information network and receives via the building connector the data values. Restarting one of the two data-logging machines (for maintenance or repair purposes) automatically switches the data logging to the other machines. High availability is applied at two levels: at the physical machine layer, where two VM servers are concurrently running, and the physical machine is automatically (transparently) transported to the other machine in case either VM server experiences a physical or component failure.

At the application level, the databases running on the two data logging VMs are constantly kept up to date using database mirroring technologies. In addition, log shipping is used to update a third database running on another machine (to off-load) some of the transactional load, while keeping an active backup. Finally, a backup solution takes a snapshot of the database every 15 minutes so that a copy of the recorded data is kept off the building site.

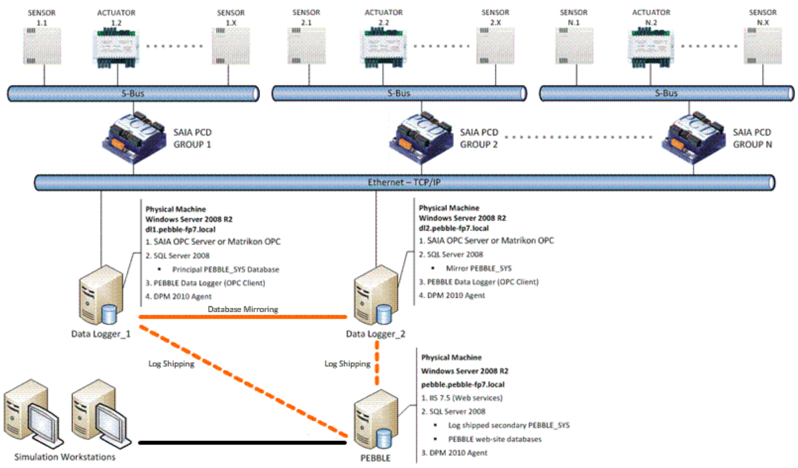

Figure 15: TUC Data Logging System

Table 15: Installed devices per zone of TUC building

Devices installed per thermal zone								
Zone	Ambient temperature sensors	Radiance temperature sensors	Humidity sensors	Pressence sensors	Contact sensors	A/C energy meters	Lighting sensors	CO_2 sensors

Office 1	1	1	1	1	2	1	1	0
Office 2	1	1	1	1	3	1	1	0
Office 3	1	1	1	1	2	1	1	1
Office 4	1	1	1	1	4	1	2	0
Office 5-6	1	1	1	1	3	1	1	1
Office 8	1	1	1	1	2	1	2	0
Office 9	1	1	1	1	3	1	1	0
Office 10	1	1	1	1	2	1	1	0
Office 11	1	1	1	1	5	1	2	1
Office 13	1	1	1	1	3	1	1	0
Corridor 1A	1	0	0	2	1	0	1	0
Corridor 2A	3	1	1	0	1	0	0	0
Corridor 1B	1	0	0	1	1	0	0	0
Corridor 2B	0	0	0	0	1	0	0	0
Basement	1	0	0	0	0	0	0	0
TOTAL	**16**	**11**	**11**	**13**	**33**	**10**	**14**	**3**

6.2 Energy generation monitoring and control

For the heating system, two representative screenshots, one for the control of the central valve feeding the building lines and one for the valve controlling one line are shown in Figure 16 and Figure 17 respectively. Here, information on the input and returning temperature of the water are available, along with a set of an installed controller parameters for the adjustment of the system.

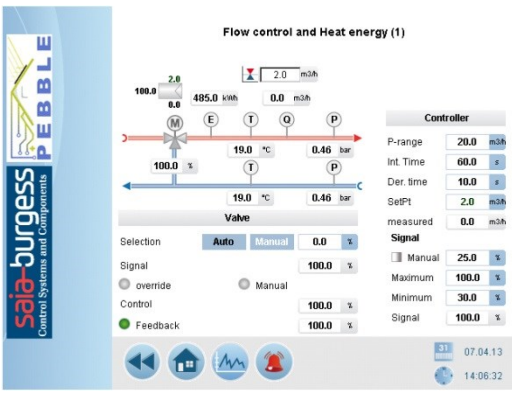

Figure 16: Central flow control

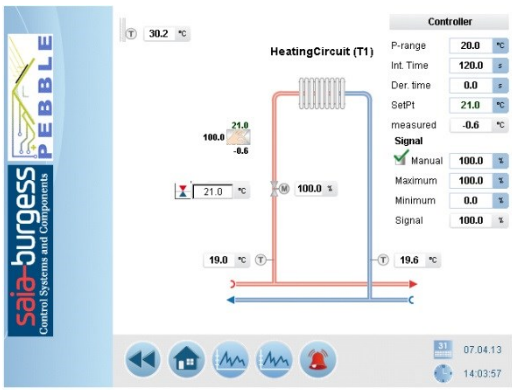

Figure 17 Line flow control

6.3 Energy use monitoring and control

In TUC building, the BMS devices presented in Table 16, have been installed. Here, Saia Energy Meters are connected to the PLC sending telegrams using the S-Bus protocol; EnOcean sensors communicate to the transceiver via EnOcean telegrams, and the transceiver is connected to the PLC using the S-Bus protocol. At the same time, a second PLC, is used for the connection of the CSEM sensors, an instruction list code was developed for the translation of the WiseMAC protocol and the connection to the PLCs; a KNX module is installed in the PLC and the HVAC control modules are communicating using EIB telegrams. Yet another PLC is in charge of controlling the heating system: analogue signals are used for the control of the thermo-electric valves, and the M-Bus protocol for reading values from the energy flow meters.

Table 16: BMS installed devices and power balance of TUC building

Device	Model	Manufacturer	Power (W)	Voltage (V)
KNX to IR Split A/C units management	ZN1CL - IRSC	ZENNIO	0,28W	29V DC
KNX power supply 160mA	ZPS160MPA	ZENNIO	4,64W	29V DC
KNX to Ethernet Interface	N 148/22 KNX/IP	SIEMENS	1,65W	29V DC
PLC building gateway	PCD1.M2120	SAIA BURGESS	12W	24V DC
PLC heating circuits controller	PCD1.M2120	SAIA BURGESS	12W	24V DC
PLC hot water flow controller	PCD1.M2120	SAIA BURGESS	12W	24V DC
Electonic valve actuator	SAX61.03	SIEMENS	3,75W	24V DC
Heating energy meter	UH50-C45Q-GR06-E	SIEMENS	?	230V AC
Thermal actuator	STP21	SIEMENS	2,5W	230V AC
Power supply	Q.PS-AD2-2402F	SAIA BURGESS	?	230V AC
EnOcean Transceiver	EOR-700EVC	SENSORTEC	1,2W	24V DC
EnOcean contact sensor	SRW01	THERMOKON	-	-
EnOcean temperature & humidity sensor	SR04P	THERMOKON	-	-
EnOcean presence &	SR-MDS Solar	THERMOKON	-	-

lighting sensor				
Single phase energy meter 230VAC 50Hz	ALD1	SAIA BURGESS	0,4W	230V AC
Three phase energy meter	ALE3	SAIA BURGESS	1,2W	400V AC
Weather station	OMC-410 MultiMetProbe	OBSERVATOR	?	30V DC

6.3.1 Electrical meters

One-phase electrical meters are located in the main electrical cabinet of the building and currently measure the power consumption of each air-condition unit. Also three-phase energy meters are found in the same cabinet to measure the total electric power consumption of the building. The energy meters of Saia-Burgess model ALE3 are coming with an integrated S-Bus interface which allows direct reading of all relevant data, such as energy (total and partial), current and voltage for every phase and power for every phase.

Figure 18: Three-phase energy meter model ALE3 with S-Bus interface

Figure 19: One-phase energy meter model ALD1 with S-Bus interface

The measured and calculated parameters of the three-phase energy meter, model ALE3 are shown in the following table of variables:

Symbol	Magnitude	Symbol	Magnitude
V_1	Phase voltage L1 (V)	I_1	Current L1(A)
V_2	Phase voltage L2 (V)	I_2	Current L2 (A)
V_3	Phase voltage L3 (V)	I_3	Current L3 (A)
C_1	Consumption L1 (kWh)	P_1	Power L1 (kW)
C_2	Consumption L2 (kWh)	P_2	Power L2 (kW)
C_3	Consumption L3 (kWh)	P_3	Power L3 (kW)
-	Tarif I Total / Partial	-	Tarif II Total / Partial

The measured and calculated parametres of the one-phase energy meter, model ALD1 are shown in the following table of variables:

Symbol	Magnitude	Symbol	Magnitude
P_1	Phase voltage (V)	I_1	Current (A)
C_1	Consumption (kWh)	P_1	Power (kW)
-	Tarif Total	-	Tarif Partial

6.3.2 Thermal energy meters

For hot water needs, a campus-wide heating system is utilized. The building receives hot water from two inlets on two sides of the building, shown in Figure 20. From these sides hot water is distributed from the pipes to the radiators of each zone.

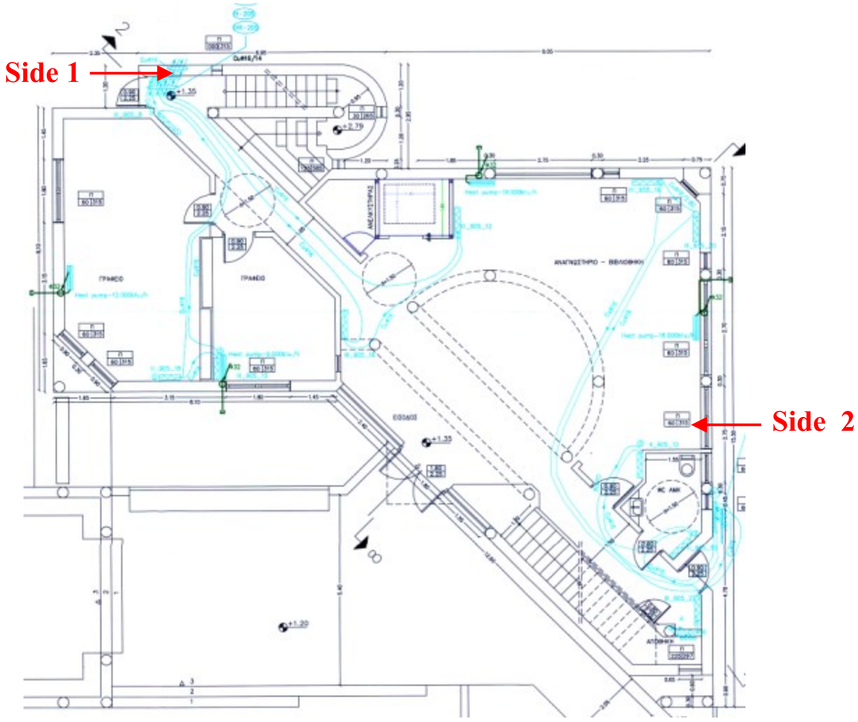

Figure 20: Heating system central points, Side 1 and Side 2

On each side, a thermal energy meter is installed, measuring temperature and flow rate of the hot water supply. The quantity of thermal energy transferred to the building over a defined period of time is proportional to the temperature difference between the flow and return and volume of water that has passed through. The water volume and the temperature difference between flow and return are multiplied and its product integrated. The result is the consumed quantity of the thermal energy. The heat meters installed are made by SIEMENS (model UH50) and have an integrated M-Bus module for the remote readout of the measurements from the PLCs. The values made available are shown in Table 17 below.

Figure 21: Heat energy meter of SIEMENS, model UH50

Table 17: Measurements obtained by each thermal energy meter

Symbol	Magnitude	Symbol	Magnitude
TD	Difference temperature (°C)	P	Power (kW)
E	Energy (kWh)	RT	Return temperature (°C)
Q	Flow (m^3/h)	Ot	Operating time (h)
FT	Forward temperature (°C)	E_p	Energy of previous year (kWh)
Mt	Missing time (h)	Q_p	Flow of previous year (m^3/h)

6.3.3 Thermal distribution control

The controllable elements of each AC unit are the operation schedule (on/off operation) and the set point temperature. Furthermore, the users of the building are able to communicate their preferences to the system through simple interface: a temperature sensor (see Figure 22) has been properly enhanced to transmit user climate preferences through the embedded dimmer. This way, when the dimmer is turned to the right, users require more heating in the room, while when turned to the left, users require more cooling.

Figure 22: User preference interface device

Regarding the heating system, the thermoelectric hot water valves installed on each of the water loops allow independent control of hot water flow in each loop. Each loop consists of thermal bodies (radiators) connected in series by pipes. In order to isolate the operation of each thermal body, a manual radiator valve is located at the inlet node of each radiator.

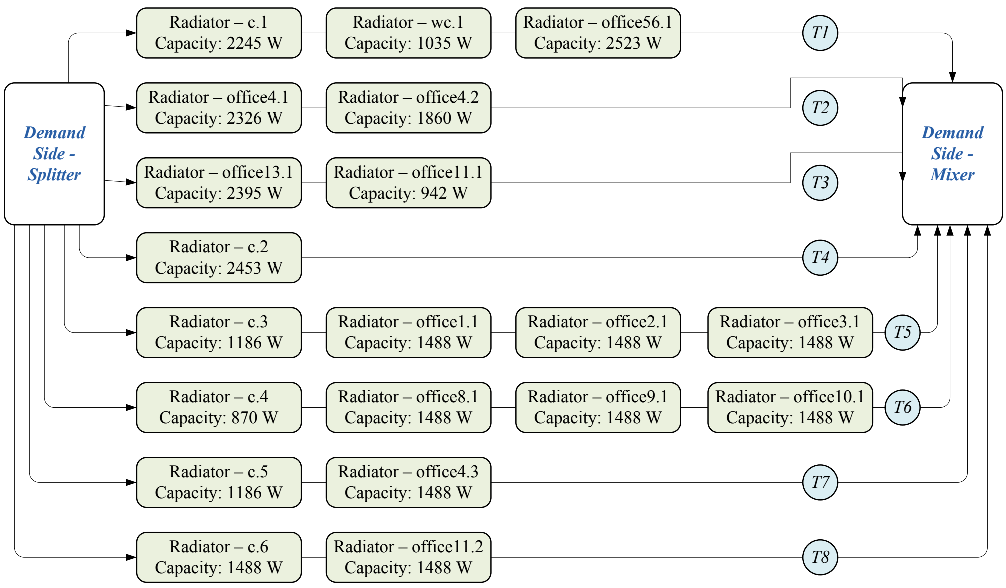

Figure 23: Central heating system branches and the corresponding flow valves

In cases where rule control design or more advanced control design approaches (to provide control decisions regarding the controllable actuating elements) are adopted, in building sensor measurements along with historical weather data and weather predictions are prerequisites. For real-time sensor measurements of the building, temperature, humidity, illumination and occupancy sensors are installed at each office while a contact sensor is installed on each opening (window or door). Historical weather data are provided by the TUC weather station, while weather predictions are gathered from a publicly available weather service (http://www.tutiempo.net). In some cases, historical weather data and weather predictions are properly merged in a weather file, to produce an accurate representation of the external conditions on the site area.

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 TUC building monitoring system.

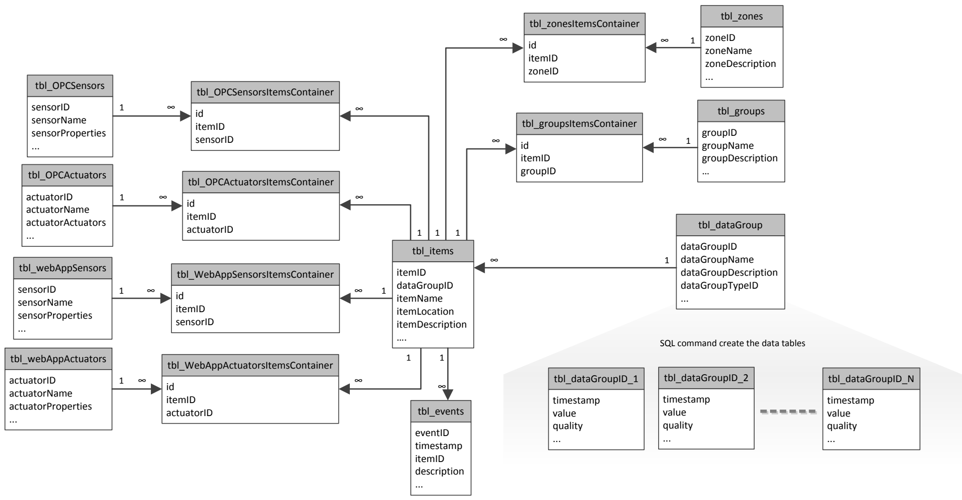

Figure 24: TUC building monitoring relational database scheme

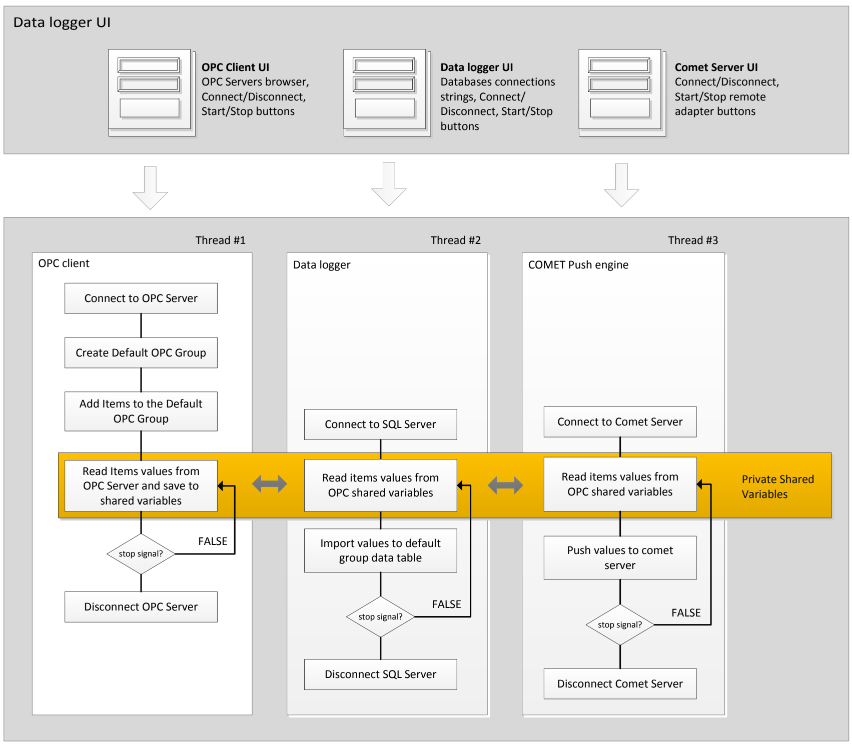

Figure 25: Multi-threaded datalogging software of TUC building

7.1 Existing historical variables

Table 18: Consumed energy parameters of TUC building

Consumed Energy				
Concept	**Application**		**Measurement[2]**	**Monitoring point and location**
Electricity	Heating	Y	E	Defined on the table bellow
	Cooling	Y	E	Defined on the table bellow
	DHW	N	-	
	Ventilation	N	-	
	Lighting	N	-	
	Appliances	Y	E	
District energy	District heating	Y	HC	Defined on the table bellow
	District cooling	N	-	

Table 19: Delivered energy parameters of TUC building

Delivered energy				
Concept	**No.**		**Explanation**	**Unit**
First floor		dp_122	Office 10 A/C total energy consumption	KWh
		dp_124	Office 10 A/C power	KW
		dp_119	Office 13 A/C total energy consumption	KWh
		dp_121	Office 13 A/C power	KW
		dp_126	Office 11 A/C total energy consumption	KWh
		dp_125	Office 11 A/C power	KW
		dp_80	Office 08 A/C total energy consumption	KWh
		dp_82	Office 08 A/C power	KW
		dp_70	Office 09 A/C total energy consumption	KWh
		dp_71	Office 09 A/C power	KW
Ground floor		dp_114	Office 05 A/C total energy consumption	KWh
		dp_115	Office 05 A/C power	KW
		dp_116	Office 03 A/C total energy consumption	KWh
		dp_118	Office 03 A/C power	KW
		dp_107	Office 01 A/C total energy consumption	KWh
		dp_130	Office 01 A/C power	KW

[2] Electricity meter (E), Fuel meter (F), Water meter (W), Hot/cold water meter (HC), None (N)

		dp_102	Office 02 A/C total energy consumption	KWh
		dp_100	Office 02 A/C power	KW
		dp_89	Office 04 A/C total energy consumption	KWh
		dp_91	Office 04 A/C power	KW
Side 1	1	dp_183	Inlet temperature of side 1	°C
	2	dp_182	Outlet temperature of side 1	°C
	3	dp_184	Inlet pressure of side 1	bar
	4	dp_185	Outlet pressure of side 1	bar
	5	dp_180	Energy of side 1	KWh
	6	dp_181	Power of side 1	KW
	7	dp_179	Flow of side 1	m^3/h
Side 2	8	dp_190	Inlet temperature of side 2	°C
	9	dp_189	Outlet temperature of side 2	°C
	10	dp_191	Inlet pressure of side 2	bar
	11	dp_192	Outlet pressure of side 2	bar
	12	dp_187	Energy of side 2	KWh
	13	dp_188	Power of side 2	KW
	14	dp_186	Flow of side 2	m^3/h
T1 circuit	15	dp_193	Outlet temperature of circuit 1	°C
T2 circuit	16	dp_194	Outlet temperature of circuit 2	°C
T3 circuit	17	dp_195	Outlet temperature of circuit 3	°C
T4 circuit	18	dp_196	Outlet temperature of circuit 4	°C
T5 circuit	19	dp_197	Outlet temperature of circuit 5	°C
T6 circuit	20	dp_198	Outlet temperature of circuit 6	°C
T7 circuit	21	dp_199	Outlet temperature of circuit 7	°C
T8 circuit	22	dp_200	Outlet temperature of circuit 8	°C
T9 circuit	23	dp_201	Outlet temperature of circuit 9	°C

Table 20: Indoor ambient parameters of TUC building

Indoor ambient parameters				
Concept	**Measurement**		**Quantity**	**Monitoring point and location**
Indoor conditions	Temperature	Y	16	Defined on the tables bellow
	Relative humidity	Y	11	Defined on the tables bellow

	Illumination level	Y	14	Defined on the tables bellow
	CO_2 concentration	N	-	
	Occupancy	Y	13	Defined on the tables bellow
	Window status	Y	33	Defined on the tables bellow

Table 21: Zone temperature sensors of TUC building

	Floor	Area	Associated thermal system
dp_44	2	Office 10	A/C O10 and T6
dp_166	2	Office 13	A/C O13 and T3
dp_59	1	Office 5-6	A/C O5-6 and T1
dp_52	1	Office 3	A/C O3 and T5
dp_64	1	Corridor 1	T1, T5, T7
dp_37	2	Office 11	A/C O11 and T3,T8
dp_65	2	Corridor 2	T6, T8, T4
dp_110	1	Office 1	A/C O1 and T5
dp_145	1	Office 2	A/C O2 and T5
dp_93	1	Office 4	A/C O4 and T2, T7
dp_85	2	Office 8	A/C O8 and T6
dp_76	2	Office 9	A/C O9 and T6

Table 22: Zone humidity sensors of TUC building

	Floor	Area	Associated thermal system
dp_45	2	Office 10	A/C O10 and T6
dp_167	2	Office 13	A/C O13 and T3
dp_60	1	Office 5-6	A/C O5-6 and T1
dp_53	1	Office 3	A/C O3 and T5
dp_38	2	Office 11	A/C O11 and
dp_111	1	Office 1	A/C O1 and T5
dp_146	1	Office 2	A/C O2 and T5
dp_94	1	Office 4	A/C O4 and T2, T7
dp_86	2	Office 8	A/C O8 and T6
dp_77	2	Office 9	A/C O9 and T6

Table 23: Zone illumination sensors of TUC building

	Floor	Area
dp_47	2	Office 10
dp_61	1	Office 5-6
dp_54	1	Office 3
dp_40	2	Office 11
dp_113	1	Office 1
dp_147	1	Office 2
dp_95	1	Office 4
dp_88	2	Office 8
dp_78	2	Office 9

Table 24: Zone presence sensors of TUC building

	Floor	Area
dp_46	2	Office 10
dp_62	1	Office 5-6
dp_55	1	Office 3
dp_39	2	Office 11
dp_112	1	Office 1
dp_148	1	Office 2
dp_96	1	Office 4
dp_87	2	Office 8
dp_79	2	Office 9

Table 25: Zone contact sensors of TUC building

	Floor	Area	Type
dp_43	2	Office 10	Window
dp_42	2	Office 10	Door
dp_49	2	Office 13	Window
dp_?	2	Office 13	Window
dp_48	2	Office 13	Door
dp_56	1	Office 5-6	Door
dp_57	1	Office 5-6	Window
dp_58	1	Office 5-6	Window

dp_50	1	Office 3	Door
dp_51	1	Office 3	Window
dp_63	1	Corridor 1	Door
dp_67	1	Corridor 1	Door
dp_36	2	Office 11	Door
dp_127	2	Office 11	Window
dp_128	2	Office 11	Window
dp_129	2	Office 11	Window
dp_41	2	Office 11	Window
dp_66	2	Corridor 2	Window
dp_69	2	Corridor 2	Window
dp_109	1	Office 1	Door
dp_?	1	Office 1	Window
dp_103	1	Office 2	Door
dp_104	1	Office 2	Window
dp_105	1	Office 2	Window
dp_92	1	Office 4	Door
dp_97	1	Office 4	Window
dp_98	1	Office 4	Window
dp_99	1	Office 4	Window
dp_83	2	Office 8	Door
dp_84		Office 8	Window
dp_73	2	Office 9	Door
dp_74	2	Office 9	Window
dp_75	2	Office 9	Window

8 External data sources: weather data

There are two external connections providing values to the TUC building: one is a weather station installed at the top of the building; and a second is weather forecast data. The weather station is connected to an RS-232/Ethernet connector, and the messages are then obtained via a telnet connection from the BMS. These data are stored in the same location as the sensor data. In addition the weather forecast information becomes available by polling at regular intervals the tutiempo.net web-site, and storing these forecasts in the SQL database.

Table 26: Outdoor ambient parameters of TUC building

Outdoor ambient parameters				
Concept	**No.**	**Data point**	**Explanation**	**Unit**
Outdoor ambient param.	1	dp_29	Ambient temperature	°C
	2	dp_32	Relative humidity	%
	3	dp_34	Wind speed	m/s
	4	dp_35	Wind direction	°
	5	solar_rdiation	Global radiation	W/m^2
	6	dp_33	Rain rate	mm
	7	b_pressure	Barometric pressure	hPa

Table 27: Forecast ambient parameters of TUC building

Forecast ambient parameters				
Concept	**No.**	**Data point**	**Explanation**	**Unit**
Forecast ambient param.	1	temperature	Temperature	°C
	2	humidity	Relative humidity	%
	3	windSpeed	Wind speed	m/s
	4	windDirection	Wind direction	°

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[1] CARTIF and DALKIA. BaaS Deliverable 1.1: Definition of Theoretical Case Studies including Key Performance Indicators. September 2012.

[2] A. Dröscher, H. Schranzhofer, J. Santiago, A. Constantin, R. Streblow, D. Müller, N. Exizidou, G. Giannakis, D. Rovas. PEBBLE Deliverable 2.1: Integrated Thermal Simulation Models for the Three Buildings. 2010.