Physical Inspection metering and evaluation of HVAC systems efficiency in tertiary buildings

HARMONAC

IT Case Study 1:
Office – Water system

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CASE STUDY
ATC: Office building with Water system

This case study examines a 10 floor office building built between 1969 and 1972. The A/C system of the office spaces is an all-water, two-pipe, fan coil type. No mechanical ventilation is provided. The main plant comprises a cogeneration unit. The cold generators for the system are one Trane RTWB 214 (screw) and an absorption unit, Broad BDH 20, installed in June 2008. Condenser heat rejection is achieved with underground water.
The building has an online electrical consumption metering system that was installed within the EU funded Policity project, in which Politecnico di Torino is also involved; aim of the project is the detailed analysis of electrical energy consumption of buildings.

Building Description

Country & City	Italy, Turin
Building Sector /Main Activity	Office
Net Area[m²]	6840

Installed Plant

Parameter	Installed electrical load / kW	Floor area served / m^2 GIA	Installed capacity W/m^2 GIA	Annual consumption kWh	Average annual power W/m^2	Annual use kWh/m^2	Average annual power (% FLE)
Total Chillers nominal cooling capacity (cooling output)	630.0	4'840.0	130.2				
Total Chillers	100.0	4'840.0	20.7	66'400.0	1.6	13.7	7.6
Total CW pumps[a]	82.0	4'840.0	16.9		-	-	-
Total fans			-		-	-	-
Total humidifiers			-		-	-	-
Total boilers	4.9	6'440.0	0.8	-	-	-	-
Total HW pumps	57.9	6'440.0	9.0	113'200.0	2.0	17.6	22.3
Total HVAC electrical	246.8	6'440.0	38.3		-	-	-
Total Building Elec kWh		6'440.0		1'260'700.0	22.3	195.8	
Total Boilers/Heat kWh		6'440.0	-		-	-	-
Total Building Gas/Heat kWh		6'440.0			-	-	

Energy savings

ECO CODE	DESCRIPTION	ACTION	Saving
E2.4	Correct excessive envelope air leakage	partially windows substitution	-0.6-4% of HVAC consumption in summer -1.5-7.3% of heat consumption in winter
E2.6	Apply night time over ventilation	users or automatic devices	1.5-5% of summer HVAC consumption
E3.1	Upgrade insulation of flat roofs externally	roof insulation	-0.6 on summer HVAC consumption
E3.7	Locate and minimize the effect of thermal bridges	already applied, insulation of overhangs	11.5% on heating energy in winter
E3.9	Use double or triple glaze replacement	partially applied, spot measurements	24.17% on heating energy in winter
P2.12	Consider the possibility of using waste heat for absorption system	applied with CHP, measured by BMS	Value dramatically different between simulation and measurement

Overview of building and system

This case study examines a 10 floor office building built between 1969 and 1972, which hosts the headquarters of ATC, the public housing agency of the Province of Torino. The A/C system of the office spaces (Zone 1: roughly 12000 m^3) is an all-water, two-pipe, fan coil type. While no mechanical ventilation is provided to the office spaces, two distinct AHU's serve the Canteen (Zone 2) and the Auditorium (Zone 3). The building is presently undergoing a thorough refurbishment including interventions on the building envelope, fan coil substitution, and the installation of a new absorption water chiller. The lighting system in the building is standard, without any type of PIR control.

HVAC system

The system is centralized. The main plant comprises a cogeneration unit, consisting of a gas fired IC engine providing 960 kW of electric output and 1168 kW of thermal output, and three gas fired hot water boilers, two of which rated at 2600 kW and one rated at 895 kW. The hot water produced by the central plant is used both for the ATC office building and for a district heating network serving the nearby "Arquata" quarter (505 apartments, 80000 m^3 heated volume). The circuit is hydraulically disconnected, by two heat exchangers. One heat exchanger, rated at 1000 kW, serves the ATC building, while the other one, rated at 3000 kW, serves the Arquata district heating network. The hot water on the primary circuit is circulated by 2 x 15 kW pumps. The secondary circuits of the ATC building comprise a main collector. From the collector the hot water is circulated by 11 pumps, serving distinct zones (more detail in **HVACs' system components** section).

The pumps for the horizontal circulation for district heating are 3 x 15 kW; in each building served, a sub station exists with dedicated pumping devices.

The cold generators for the system are one Trane RTWB 214 (screw) rated at 400 kW cooling capacity, with a maximum electrical consumption of 91 kW. The absorption Broad BDH 20 unit was installed in June 2008, rated at 195 kW cooling, with a maximum electrical consumption of 1.8 kW; thermal input to the absorption chiller is given by heat recovered from the cogeneration plant. The chilled water produced by these generators is distributed by 4 x 1.5 W fixed speed pumps. Condenser heat rejection is achieved with underground water.

The building has an online electrical consumption metering system that was installed within the EU funded Policity project, in which Politecnico di Torino is also involved; aim of the project is the detailed analysis of electrical energy consumption of buildings.

This means that the metering currently available is:
- Main electrical incomer
- Global electrical consumption of the central cooling plant
- CHP electrical production

- Electric chiller consumption
- Absorption chiller Thermal production

To obtain the overall performance of the A/C system, additional metering was installed to allow disaggregation of the cooling plant global consumption.

The system has a BMS operated via the BacNet protocol. This enables data to be stored on the outstations for items such as external temperature and RH, internal temperature and RH, etc. This data are available since March 2008.

Summary of building and systems

The following table summarises the main aspects of the building (based on EPA-NR and WP2):

Building Description

Building Sector /Main Activity	Office
Net Area[m²]	6840
Max number Occupants	390
N° Zones	3

Zone Description

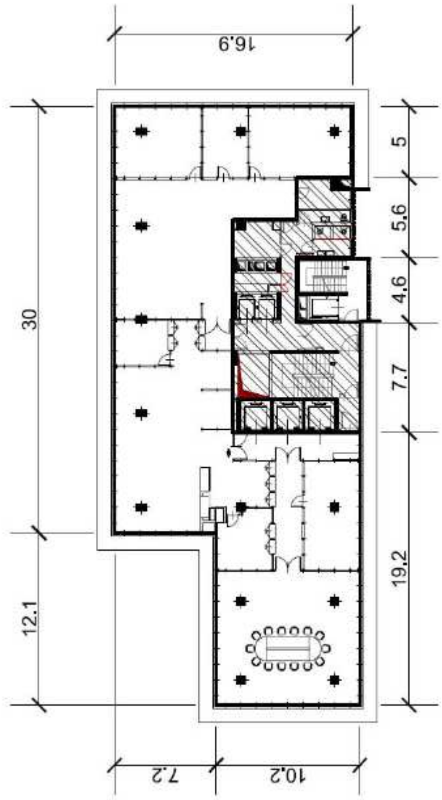
Zone ID	Activity Type	Net Area	N° Occupants
1	Office	6440 (net)	300
2	Canteen	80 (net)	10
3	Conference Hall	315 (net)	80

Heating/Cooling Production		**Normalised/ m² GIA**	**Notes**
Conditioned net Area (cooling)	**4840** [m²]		not all the area are conditioned
Chillers nominal cooling capacity	**630** [kW]	**130.2** W/m²	195 abs. + 400 el.
Chillers nominal electrical demand	**100** [kW]	**20.7** W/m²	
Chillers chilled water circulation pumps nominal electric demand	**82** [kW]	**16.9** W/m²	
COP	**4.35**		
Operation Hours	**760**	-	estimate
Conditioned net Area (heating)	**6440** [m²]		Zone 1,2 (3 on demand)
Boilers nominal heating capacity	**7195** [kW]	Not Applicable	2 gas boilers (2600 each) + 1 gas boiler (895) + 1 CHP unit (1100) The building serves also as a central heating station for District Heating
Nominal Efficiency	**95**[%]	-	
Operation Hours	**1680**	-	depending on climatic conditions

Measured annual performance

		Normalised/ m^2 GIA	Notes
Total Building Electrical Consumption	**1260.7** [MWh]	**195.8** kWh/m^2	
• HVAC Equipment	**74.1** [MWh]	**15.3** kWh/m^2	Data referred to electric chiller and chilled water pumps
Total Building Gas Consumption	**15723** [MWh]	The kWh/m^2 value has not meaning because the gas is used to heat the nearby quarter	
HVACs' system components			
Main Chillers and Chilled Water circulation pumps	**74.1** [MWh]	**15.3** kWh/m^2	Data referred to electric chiller
Main Chillers Chilled Water circulation pumps	**3.8** [MWh]	**0.8** kWh/m^2	
CHP system Gas consumption	**1370** [MWh]	The kWh/m^2 value has not meaning because the gas is used to heat the nearby quarter	

Case study details - Building Description



General building data

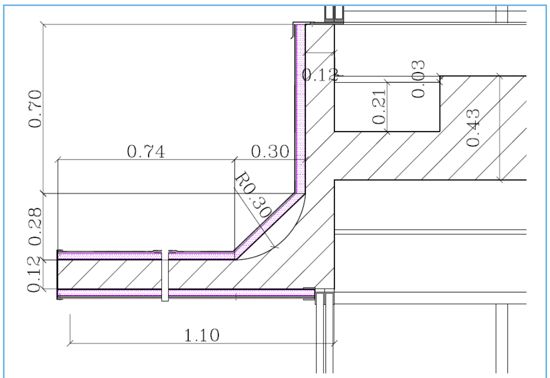
Country/City	Italy – Turin
Latitude/Longitude[°]	45°4'41"16 N-07°40'33"96 E
Elevation [m]	240
Cooling Degree Days	2617
Building Sector/Main Activity	Office
Total net floor area [m²]	6440
Ceiling height [m²]	3,3
Number of floors	9

Case study details - Constructions details

Envelope – Heat Transfer Coefficient [W/m².K]	
External wall (predominant)	**0.74**
Floor (predominant)	**1.2**
Intermediated floor (predominant)	**1.1**
Roof (predominant)	**1.0**

Windows	
U- value (predominant) [W/m².K]	**1.75 - 3.58**
Window type	**4 glass – 2 glass**
Window gas	**Argon – air**
Solar Factor	
Solar Protection Devices	
Window Overhangs	**External**
Shading Device	**interior Shade**

Construction details pictures



Main Wall pictures

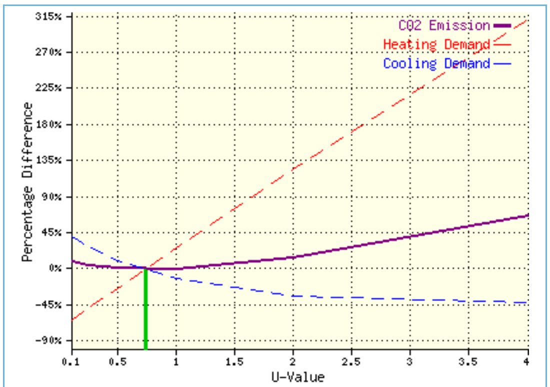
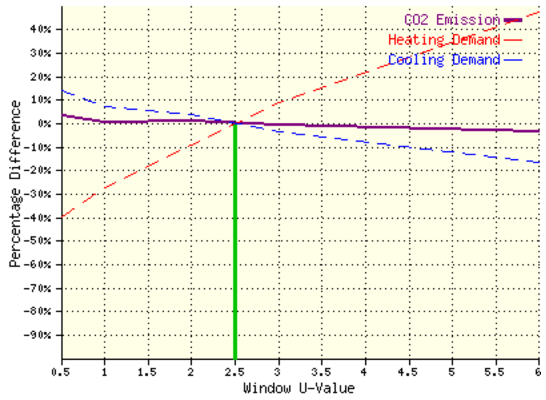
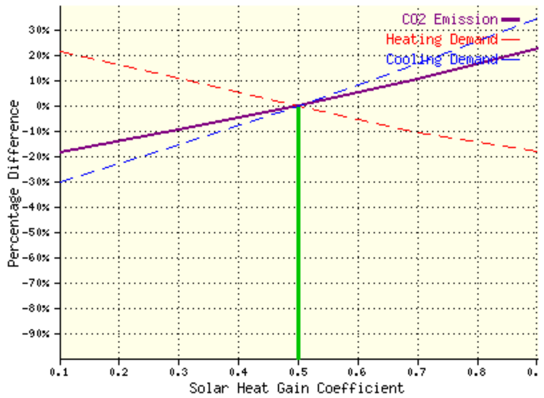


Figure – Windows pictures



overhangs pictures

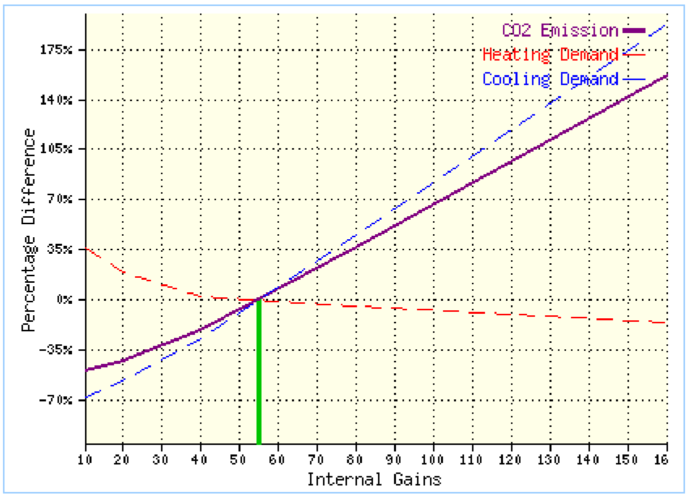


Internal gains and operation schedules per zone

Zone ID:	**1**	
Activity type	**Office**	
Equipment electric loads/Schedules	**Design**	**Measure/observe - Winter/Summer (average)**
Office equipment [W/m²]	16	
Working schedule	Mon-Fri 9:00-18:00 Sat 9:00-13:00	
Permanent/variable occupancy	-	300 (mean)
Cleaning staff schedule	-	variable
Lighting [W/m²]	23	22
Type of lighting	Fluorescent tubes	-
Lighting control	manual on/off	-

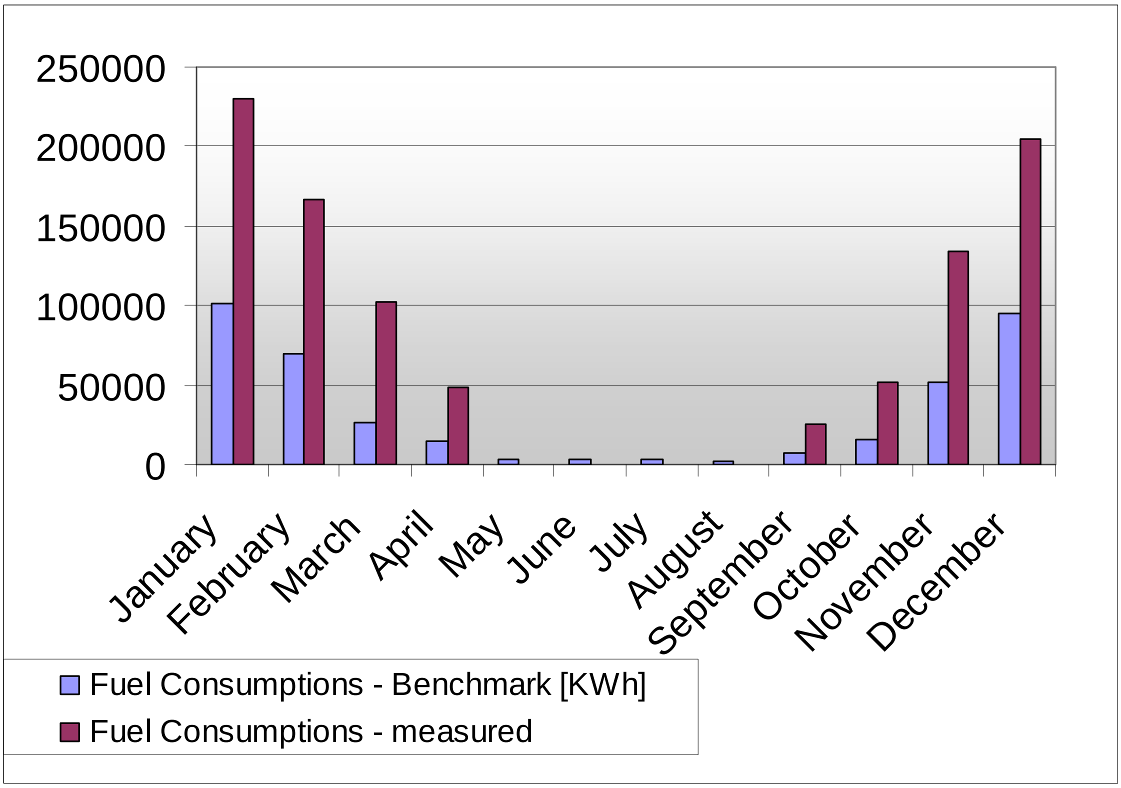
Lighting schedule	**Winter** **30% 8:00-15:00** **100% 15:00-18:00** **Summer** **30% 8:00-18:00**

The building, due to its construction, has high levels of natural light. Automatic lighting control would permit high savings on electric consumption associated to electric light system. At present conditions, lights are shut off manually, with low effectiveness on control.

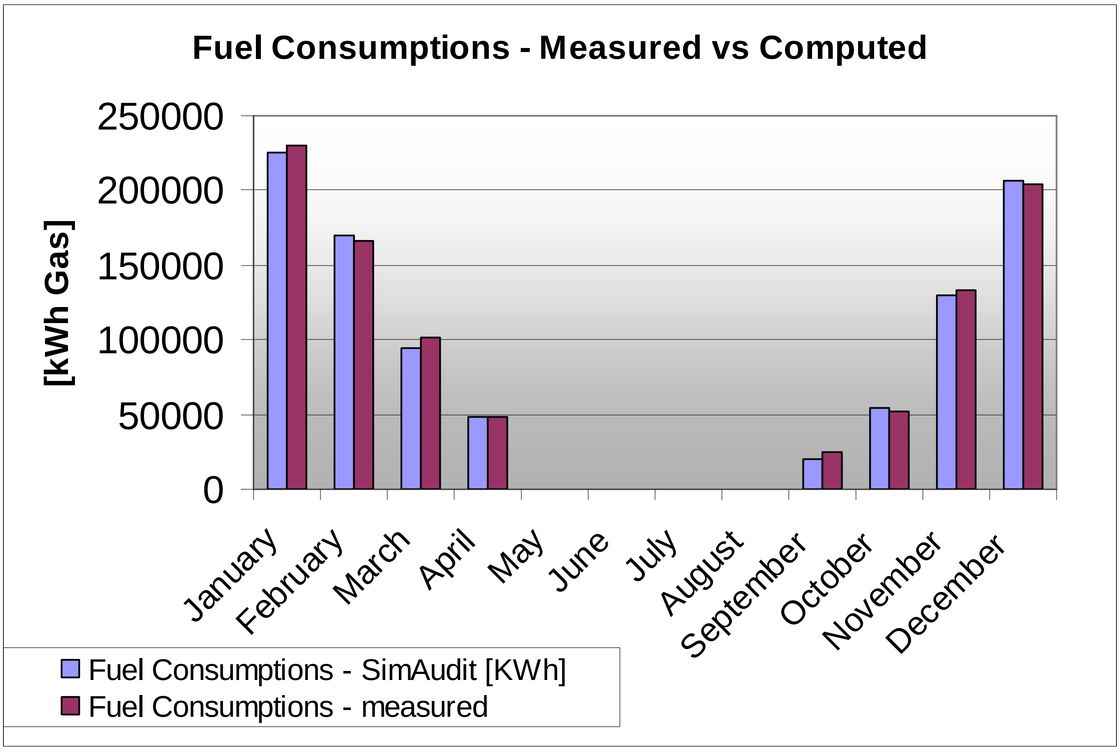


Monitoring observations for internal gains

Benchmark and Simaudit tools were used on the case study, to simulate energy consumption of the building. The first run on benchmark shows underestimate values (almost at 50%). Second run on Simaudit, changing the more sensitive variables on the model (air exchange, internal temperature), shows good results.



Benchmark Simulation



SimAudit Simulation

In the table below are presented some parameters, input of the simulation in benchmark

1.2.1. Global Heat Transfer Coefficient

h_{in} = 8 [W/m²/K]

h_{out} = 20 [W/m²-K]

1.2.2. Frontages Characteristics

$U_{opaque,frontages}$ = 0,62 [W/m²-K]

Type_Opaque_frontages$ MEDIUM : 250000 J/m²-K

$U_{windows}$ = 2,5 [W/m²-K]

$SF_{windows,0}$ = 0,5 [-]

1.2.3. Structure Characteristics

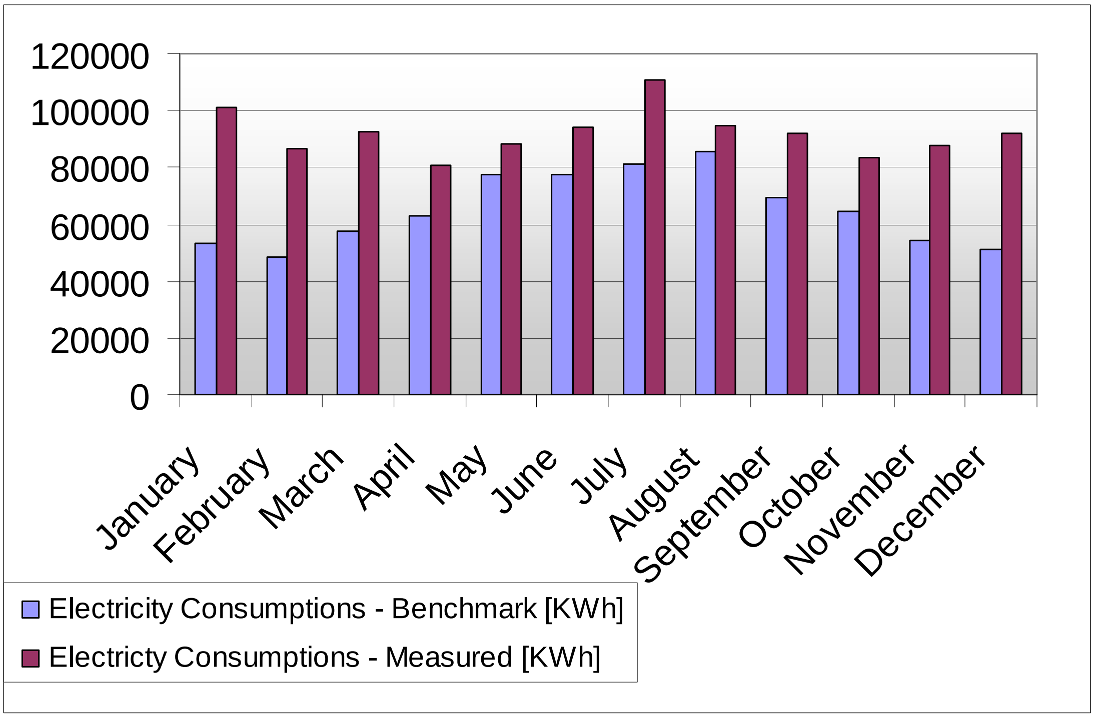
U_{floor} = 1,6 [W/m²-K]

$U_{ceiling}$ = 1,6 [W/m²-K]

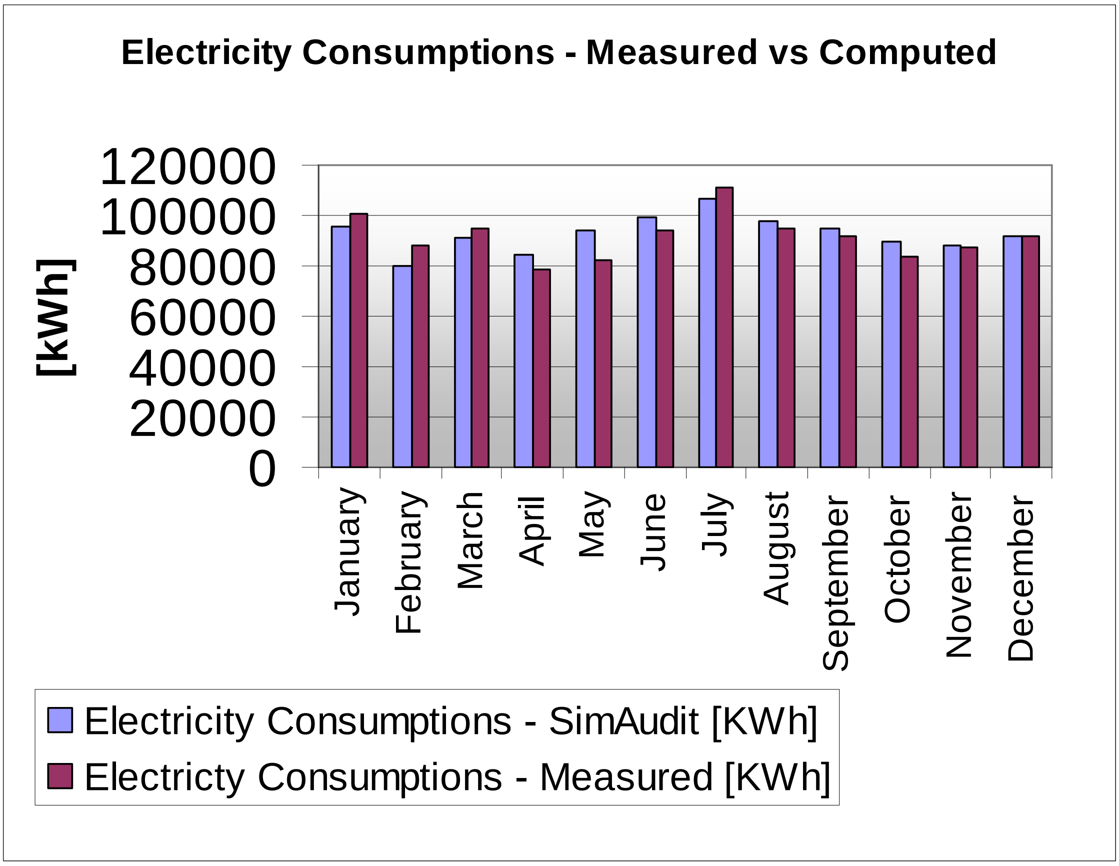
U_{roof} = 0,8 [W/m²-K]

$C_{int,walls\backslash A,int,walls}$ = 150000 [J/m²-K]

Diagram from Benchmark and SimAudit tool on electricity consumption.



Benchmark Simulation



SimAudit Simulation

Environment parameters

Description of the environment design conditions, Heating/cooling loads, design temperatures (from UNI EN 10349).

Outdoor Environment Parameters	Design	Measure/observe - Winter/Summer (average)
Outdoor air temperature [°C] Winter/Summer	-8 / 30.7	min -3 / max 36.4 avg: 6.1/ 25.3
Outdoor Relative Humidity [%] Winter/Summer	85% / 46%	77/ 61.6
Max. Solar Radiation [W/m^2]		max 1119 (10.06.2008) avg : 63.6 / 203.1 (on 24h)

Zone ID:	**1**
Activity type	**Office**

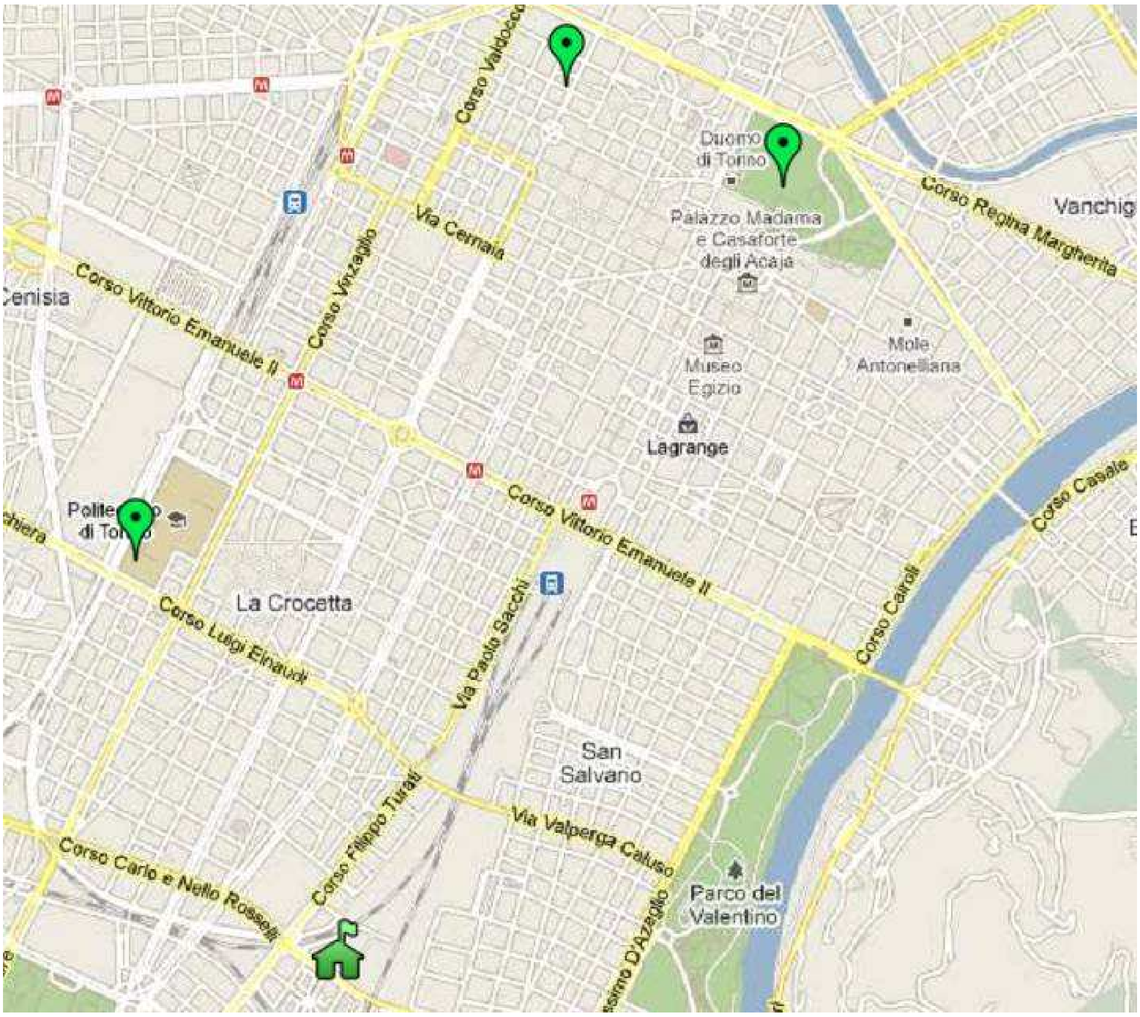
Indoor Environment Parameters per zone	Design	Measure/observe - Winter/Summer (average)
Ventilation Rate [ach]	2	
Indoor air Temperature [°C] – Winter/Summer (air temperature)	20/N.A.	21/22-26

Monitoring observations for environmental parameters

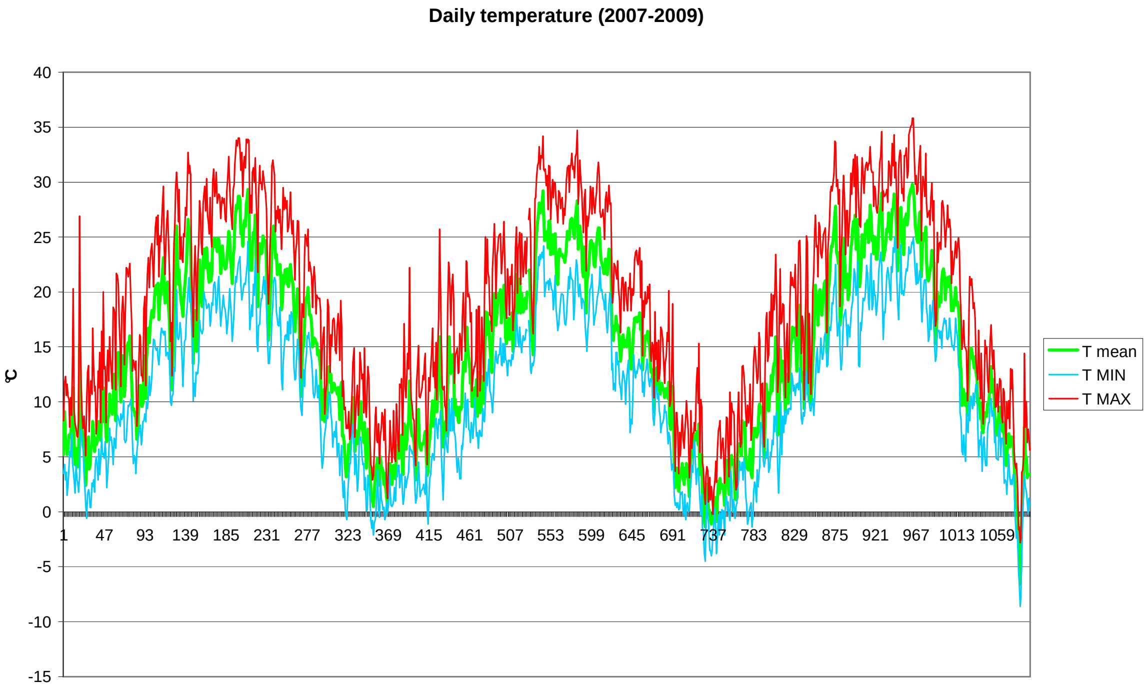
The meteo data for Torino were provided by three different sources:

1. meteo station installed on the roof of the building
2. meteo data provided by NEMEST project (station installed on Politecnico di Torino)
3. meteo data provided by ARPA Piemonte, the regional environmental protection agency

For the consumption and statistical analysis ARPA data were used. These data, in fact, showed statistical robustness, provided by 3 meteo stations in a 3 km radius from the case study location.



The green house represents ATC building, while the three green pointers represent the 3 meteo stations.



Carpet plots of external temperature are provided for different years (2008, 2009). Air enthalpy was calculated with the formula below (Ashrae 2009, Fundamentals) from external temperature, relative humidity and air pressure:

$$h = 1.006t + W(2501 + 1.86t)$$

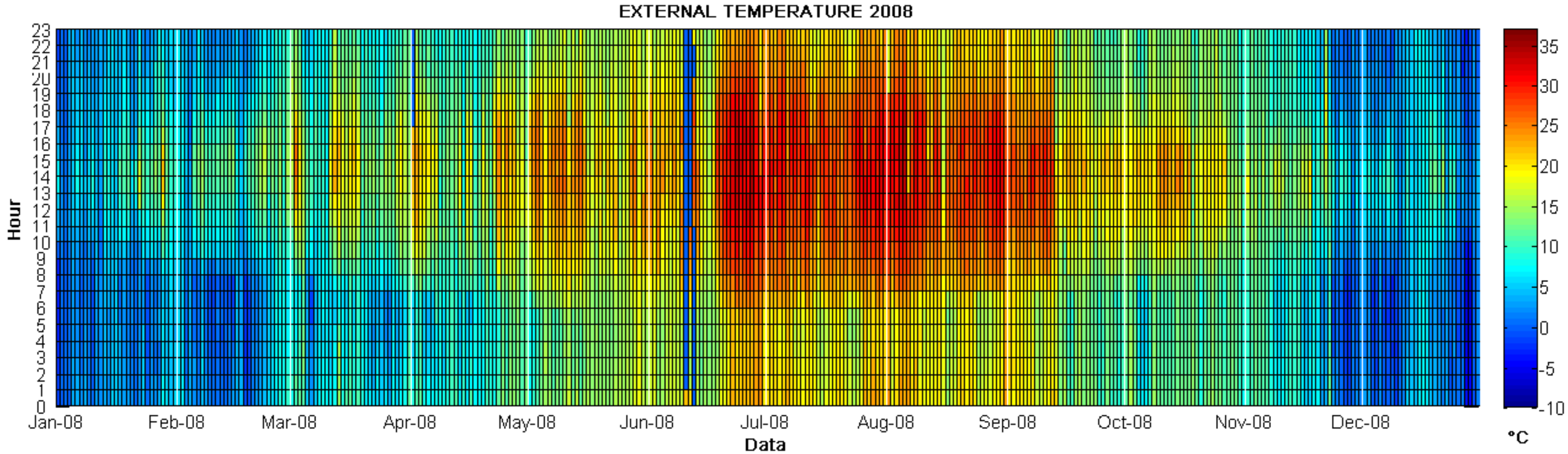
$$W = 0.621945\frac{p_w}{p - p_w}$$

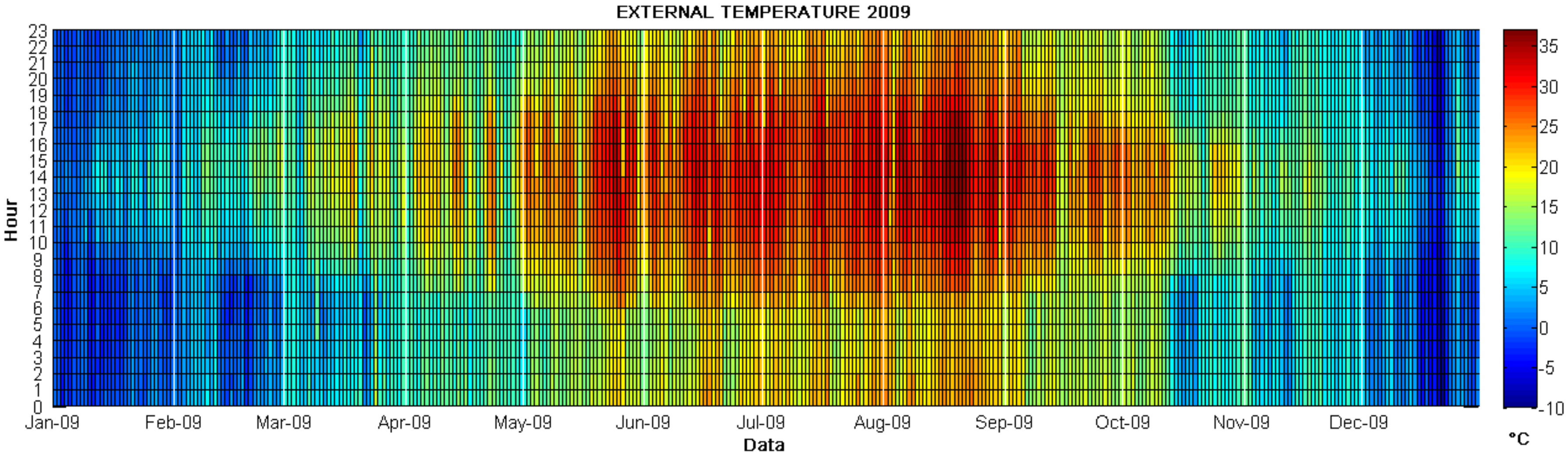
$$p_w = RH \cdot p_{ws}$$

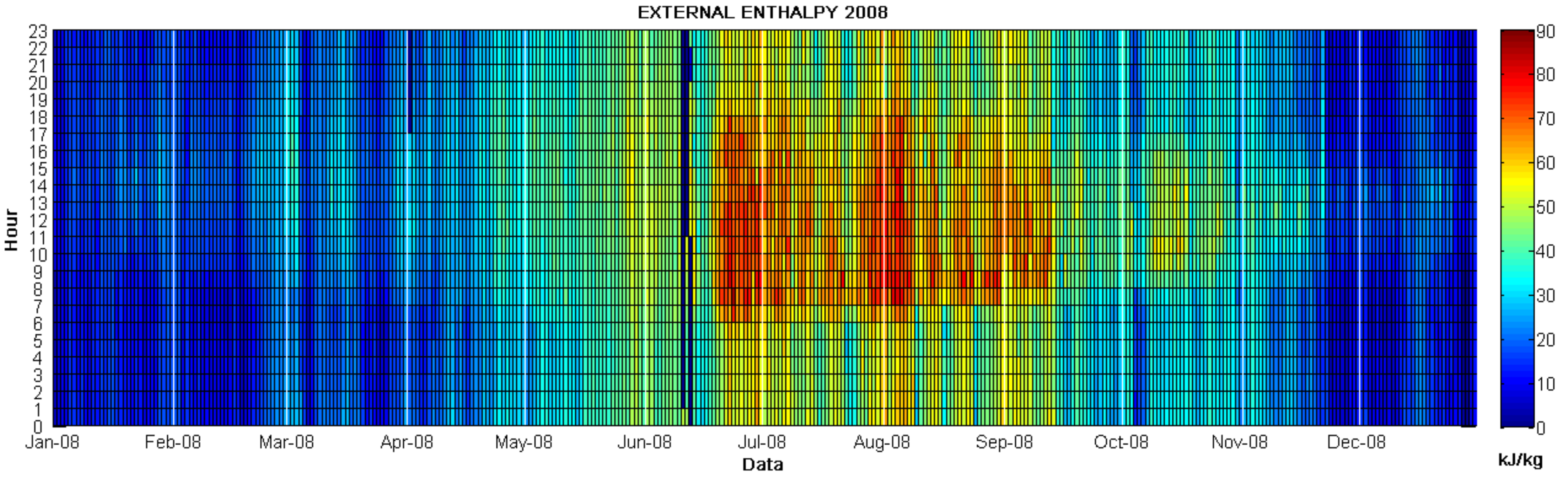
$$\ln(p_{ws}) = \frac{C8}{T} + C9 + C10T + C11T^2 + C12T^3 + C13\ln T$$

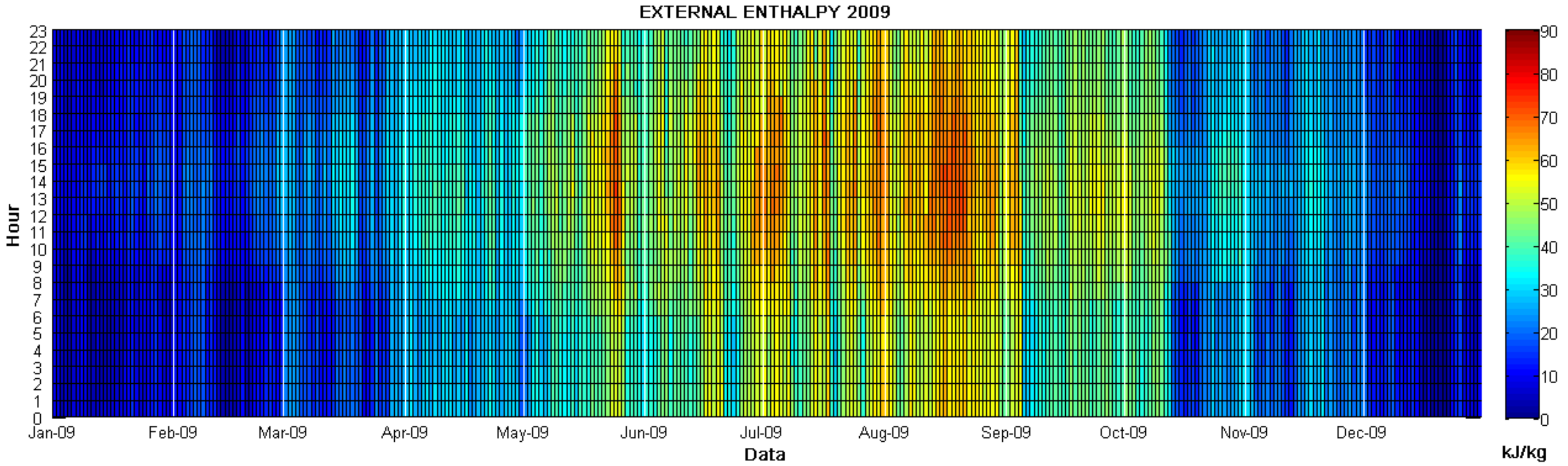
With:

h	=	air enthalpy
t	=	ait temperature (°C)
Pw	=	vapour pressure
Pws	=	saturated vapour pressure
RH	=	relative humidity
C9-C13	=	constants

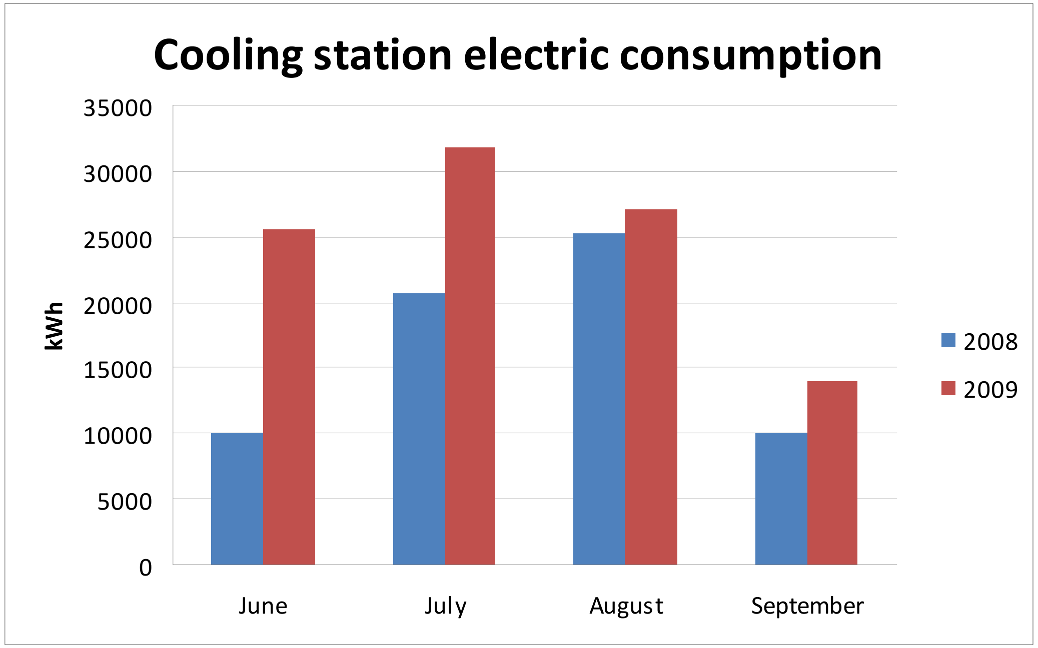

EXTERNAL TEMPERATURE 2008
Hour
Data
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
°C


EXTERNAL TEMPERATURE 2009
Hour
Data
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
°C


EXTERNAL ENTHALPY 2008
Hour
Data
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
kJ/kg

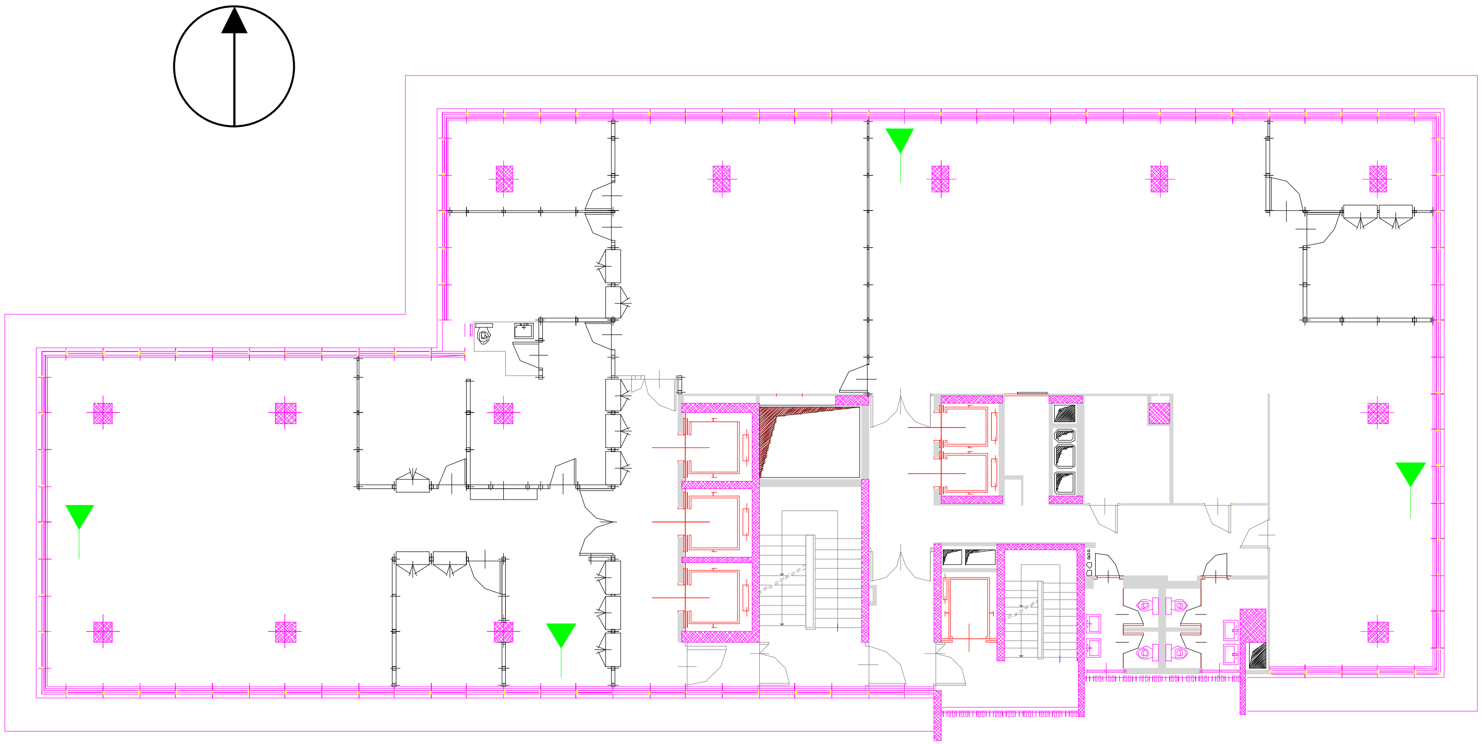

EXTERNAL ENTHALPY 2009
Hour
Data
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
kJ/kg

As seen in the graphs, 2009 season was characterized by external air temperature higher that 2008 season. This implies, on a first analysis, a higher load for the cooling system. Nevertheless is interesting that air enthalpy on 2009 season is lower than in 2008 season; this implies that for those system with mechanical ventilation, probably 2008 season was characterized by higher consumption.
The system analyzed does not provide mechanical ventilation: the 2009 season had a higher cooling load than 2008. This difference was due to external conditions, but also to a different system operation strategy (explained in the **Energy consumption data** section).

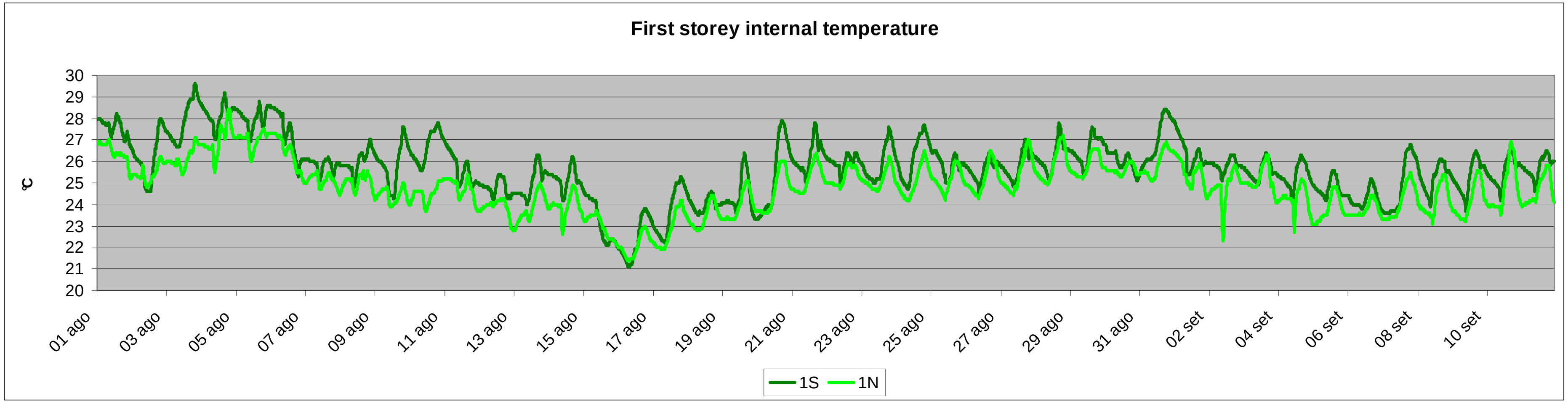


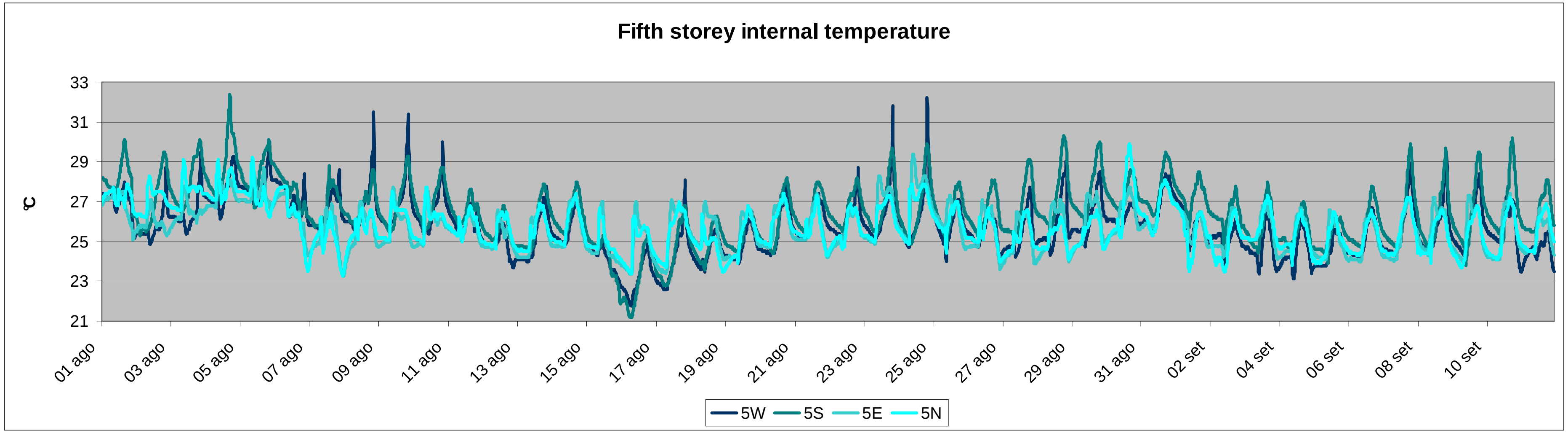
Internal temperature logging

Survey on occupants was made on a statistical basis. Four persons per storey were interviewed about complaints. Reason for complaints was in general temperature control in south part of the building.
The control system allows different temperature control in different zones; temperature logging was installed on August 2008 to check occupants' complaints. Loggers was installed on first, fifth and ninth storey. In the image below, the scheme of logger installation (green flags) on **storey number 5** is shown. Analogous installation was provided on storey 1 and 9.

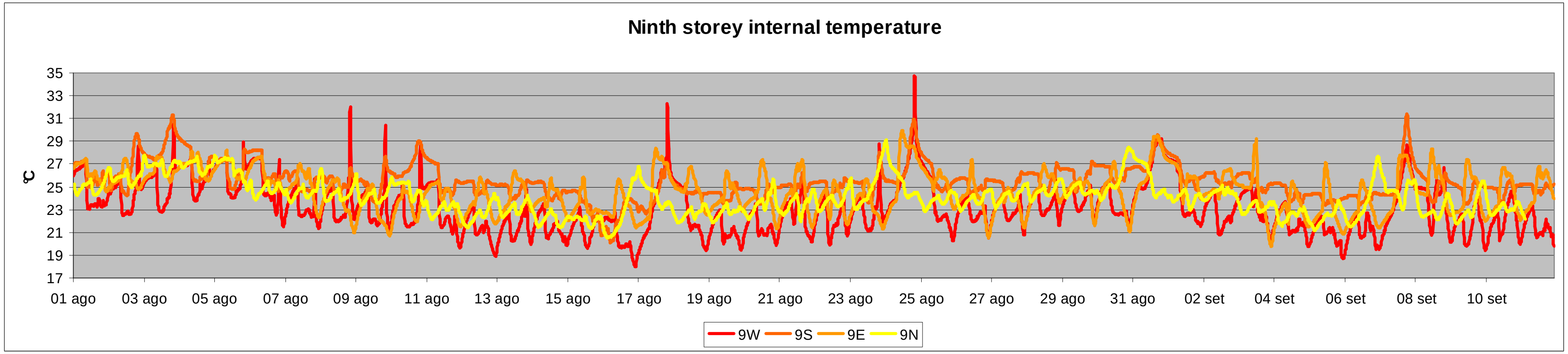


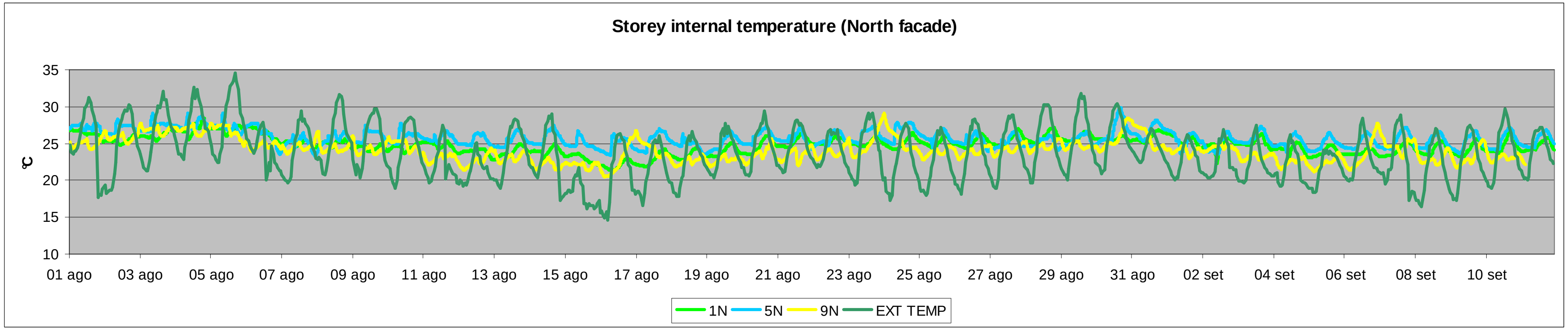
The installation cover the four different orientation. Data are provided in the graphs below.





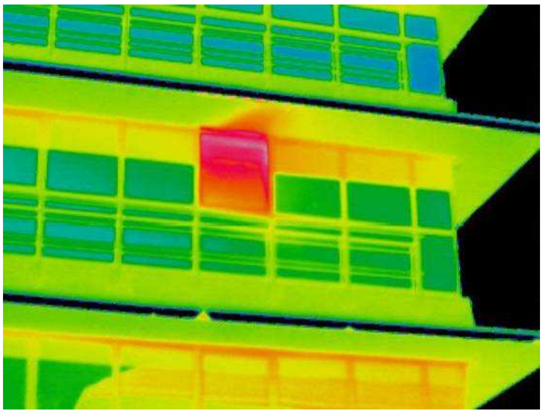
It can be noticed that temperature varies a lot between different parts of the building, depending on time of the day and solar irradiance. Some check in control system has to be made.

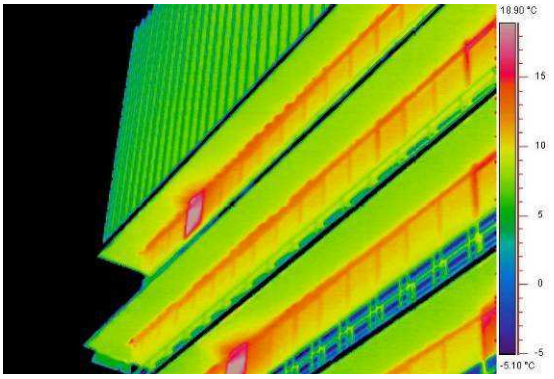




As seen in the graph the internal temperature varies from 20 to 29 °C. The ninth storey has in general temperatures lower than the other storeys; this is due to the relatively low set point of this storey, used as meeting room. With a better definition of system controls, zone set-point and users training, it will be possible to obtain better internal comfort and energy savings (it is clear that the ninth floor is over cooled, considering the external temperature).

User's behaviours





These thermographic pictures were shot in winter 2008 during work time; the sun light acts as a disturbance on the output of the instrument: the indicated temperatures are therefore affected by major errors, and should be used for qualitative analyses only. The thermographic pictures show some windows opened during winter season. The heat losses are clearly visible. Better control of zone temperature could avoid inconvenient windows openings.

HVACs' system components

The system is centralized. The main plant comprises a cogeneration unit, consisting of a gas fired IC engine providing 960 kW of electric output and 1168 kW of thermal output, and three gas fired hot water boilers, two of which rated at 2600 kW and one rated at 895 kW. The hot water produced by the central plant is used both for the ATC office building and for a district heating network serving the nearby "Arquata" quarter (505 apartments, 80'000 m^3 heated volume). The circuit is hydraulically disconnected by two heat exchangers. One heat exchanger, rated at 1000 kW, serves the ATC building, while the other one, rated at 3000 kW, serves the Arquata district heating network. The hot water on the primary circuit is circulated by 2 x 15 kW pumps. The secondary circuit of the ATC building comprises a main collector. From the collector the hot water is circulated by 11 pumps, serving distinct zones:

- 2 X KSB Rio 50-100 D rated at 0,45 kW each (meeting room)
- 2 X KSB Etabloc 80-160 rated at 2,2 kW each (conference room)
- 4 X KSB Etabloc 50-250 rated at 4 kW each (fan coils)
- 3 X KSB Etabloc 50-200 rated at 2,2 kW each (radiators)

The pumps for the horizontal circulation for district heating are 3 x KSB Etaline HDX 150-200 rated at 15 kW; each condominium served has a sub station with dedicated pumping devices.

Two cold generators are present. The first is a Trane RTWB 214 (screw) rated at 400 kW cooling capacity, with a maximum electrical input of 91 kW. The second is an absorption Broad BDH 20 unit that was installed in June 2008, rated at 195 kW cooling, with a maximum electrical consumption of 1.8 kW; thermal input to the absorption chiller is given by heat recovered from the cogeneration plant. The condensing circuits of the two units are connected to underground well. Water from the well is pumped by submersed pumps:

- 2 X KSB UPA 150 S 65/7 rated at 15 kW each
- 2 X KSB UPA 150 S 65/9 rated at 18.5 kW each

Finally, one pump KSB Trieline 100-170 rated at 3 kW serves the condensing circuits, while four pumps KSB 80-210 (3 kW each) feed the evaporators.

The building has an electrical consumption metering system that was installed within the EU funded Policity project, in which POLITO is also involved; aim of the project is the detailed analysis of electrical energy consumption of buildings.

This means that the metering currently available is:
- Main electrical incomer
- Global electrical consumption of the central cooling plant
- CHP electrical production

- Electric chiller consumption
- Total cooling production (absorption + electric chiller)

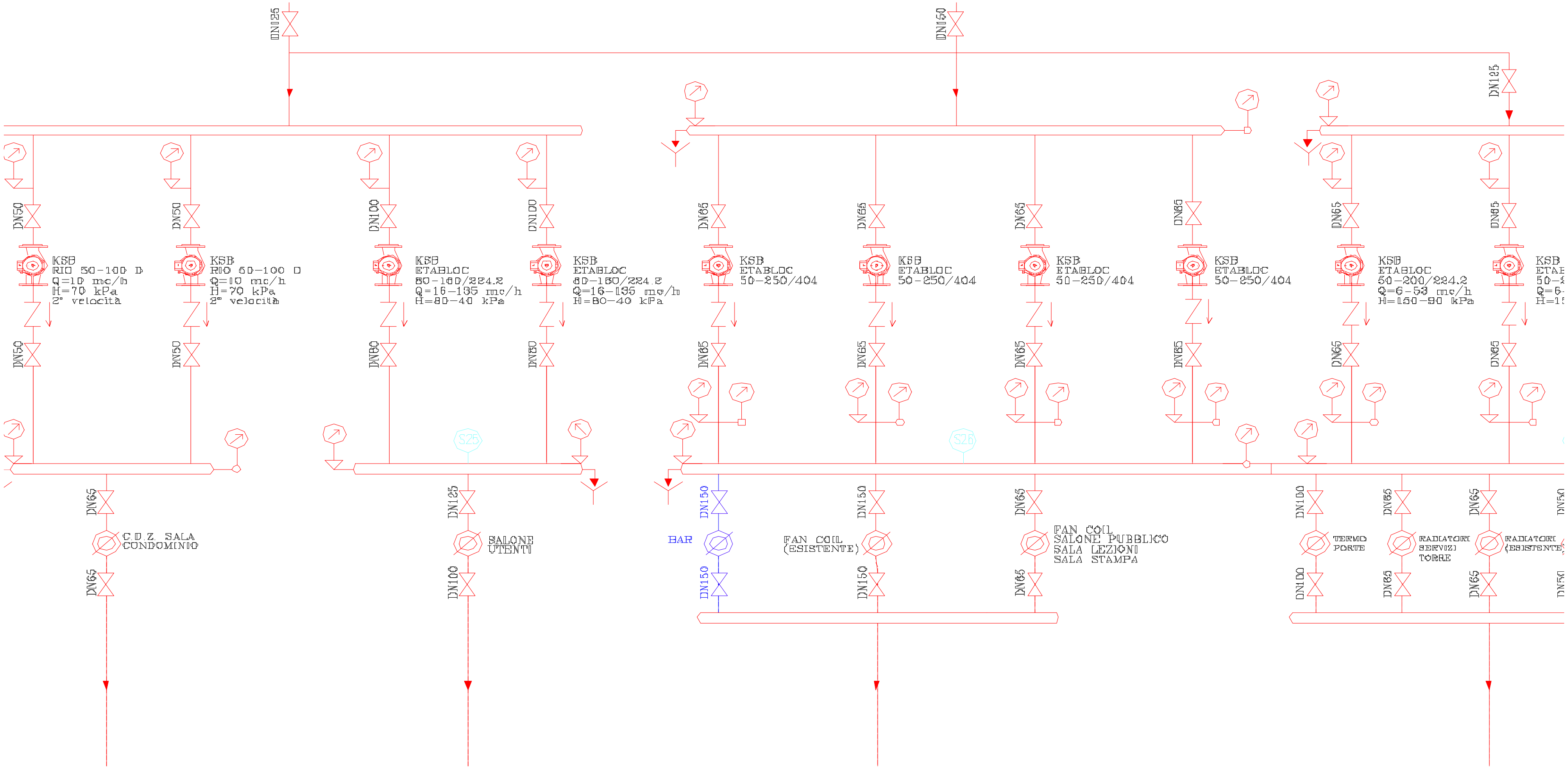
The system has a BMS operated via the BacNet protocol. This enables data to be stored on the outstations for items such as external temperature and RH, internal temperature and RH, etc. This data are available since March 2008.

The Case Study considers each of the components of the system individually in the following order and which of the zones are served with each system:

- Heating systems
- Cooling systems
- Heat rejection and pumps
- CHP system

All water system

In the scheme below a particular of the water distribution system. Each sub system has a duplicated pump.



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Heat Generator Boiler and Pumps

Boiler Identification (X2)

Manufacture/Model	Viessman / Vitomax 200
Year	2004
Equipment Type	condensing boiler
Fuel Type	Natural gas

Performance Data

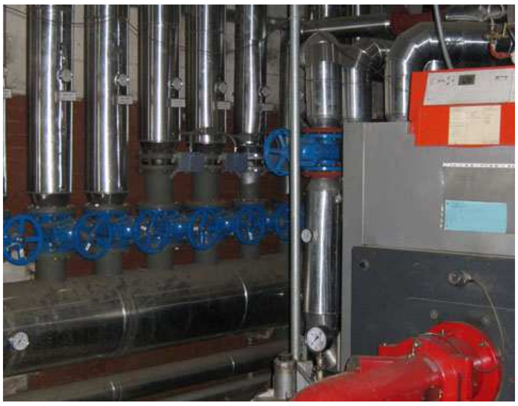
Nominal Heating Capacity [kW]	2600
Installed Heating Capacity /m² GIA	N.A.
Nominal Efficiency [%]	90
Water outlet temperature [°C]	90
Water inlet temperature[°C]	65

Electrical data

Power supply [V/Ph/Hz]	400/3/50
Start-up amps [A]	

Auxiliary Equipment

Pumps Electric Demand [kW]	
Other	/

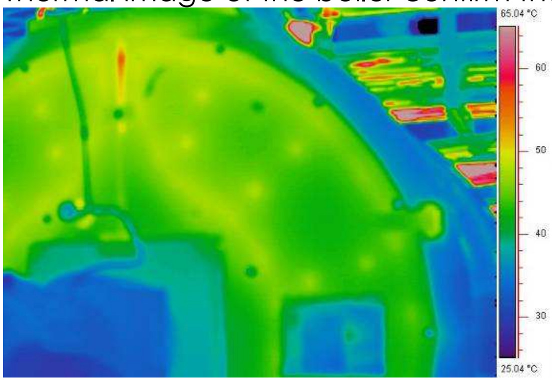


HARMONAC

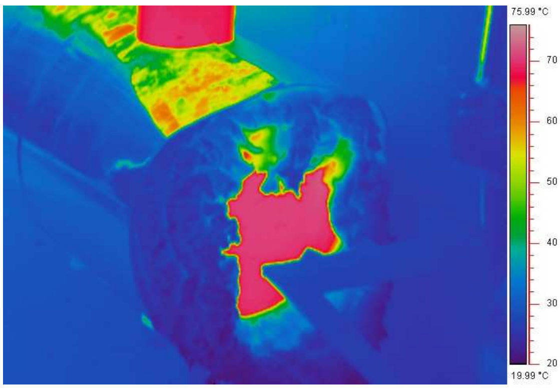
Monitoring observations

Inspection	
Maintenance status	Satisfactory
Previous inspection/maintenance Reports	Yes Data of last: monthly
Operation time estimated [h]	10000 (since installation)
Operating mode	Automatic
Dirtiness of burner	No
Thermal Insulation (Visual)	Satisfactory (except for some pipes)
Fuel leaks	No
Water leaks	No
Pressure status	Satisfactory
Sensors calibration records	No
Meter readings data	overall monthly gas consumption

Thermal image of the boiler confirm the good state of the shell.

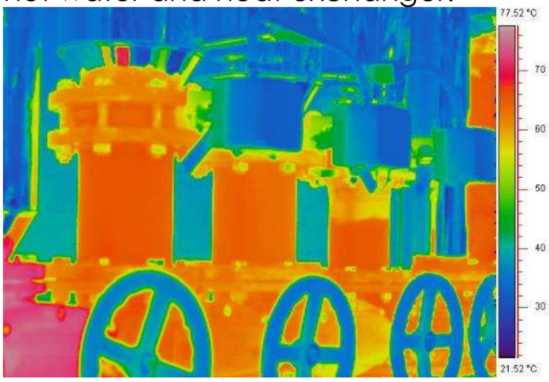


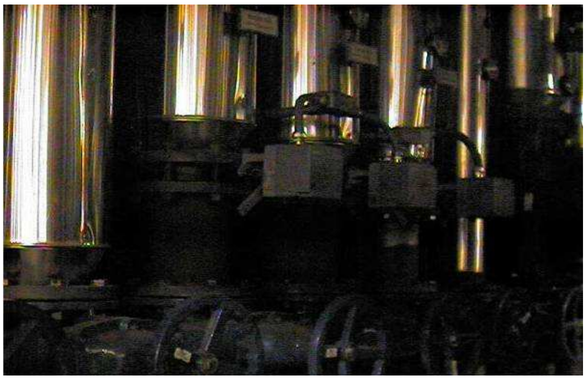
Damaged insulation of hot water collector

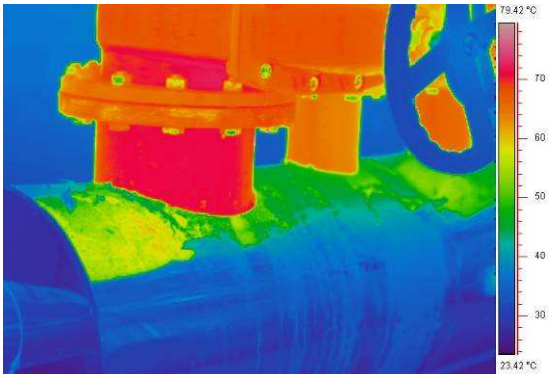


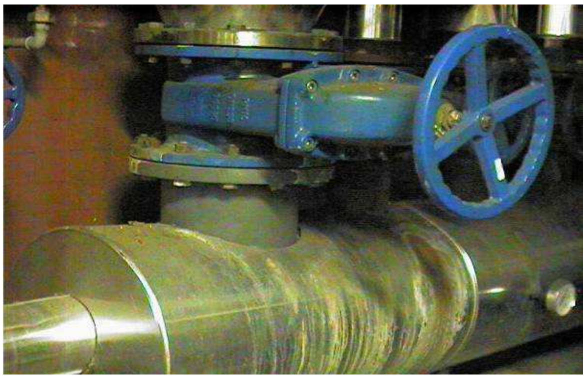
Some hot water circuit show excessive pressure loss

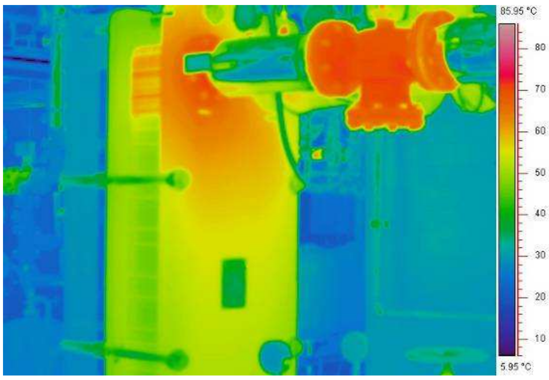
Some pipes of the primary and secondary circuits show insufficient insulation, especially close to motorized valves. Photos below show the main collector of hot water and heat exchanger.

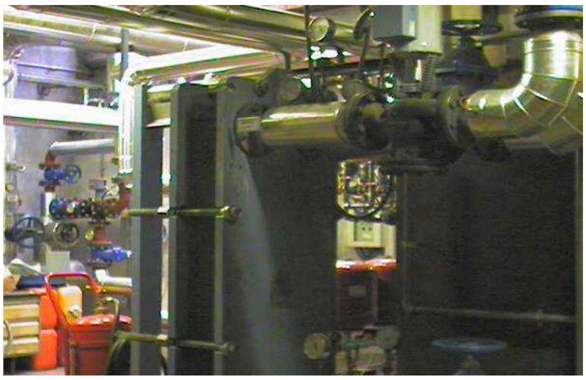












Heat Generator CHP

CHP Identification	
Manufacture/Model	Deutz
Year	2006
Equipment Type	CHP
Fuel Type	NG
Performance Data	
Nominal Heating Capacity [kW]	1168
Installed Heating Capacity /m² GIA	181.4
Nominal Efficiency [%]	
Water outlet temperature [°C]	90
Water inlet temperature[°C]	75

Auxiliary Equipment	
Fan Electrical Demand [kW]	5

Monitoring observations

Inspection	
Maintenance status	Satisfactory
Previous inspection/maintenance Reports	Yes Data of last: March 2009
Operation time estimated [h]	4794 (year)
Operating mode	Automatic
Fuel leaks	No
Water leaks	No
Pressure status	Satisfactory
Sensors calibration records	No
Meter readings data	Yes

Field measurements	
Electricity production [kWh]	380'000 (monthly average)
Fossil fuels consumption [kWh]	980'000 (monthly average)
Electric voltage [V]	380

Cold Generator

Chiller Identification	
Manufacture/Model	Trane RTWB 214
Year	2004
System Type	Water
Compressor Type	Screw
Fuel Type	el.energy
Performance Data	
Nominal Cooling Capacity [kW]	400
Installed Cooling Capacity W/m² GIA	82.6
Nominal Electric Power [kW]	91
COP/EER (Eurovent)	4.4
SEER	
Refrigerant Gas	R134a
Electrical data	
Power supply [V/Ph/Hz]	380/3/50
Start-up amps [A]	332

Auxiliary Equipment	
Fan Electrical Demand [kW]	N.I.
Pumps Electric Demand [kW]	2 X 3

temperature probe on cooling water return

HARMONAC

Monitoring observations

Inspection	
Maintenance status	**Satisfactory**
Previous inspection/maintenance Reports	**No**
Operation time estimated [h]	**760**
Operating mode	**automatic**
Thermal Insulation (Visual)	**Satisfactory**
Vibration eliminators	**Satisfactory**
Worn couplings	**Satisfactory**
Equipment cleanliness	**Satisfactory**
Compressor oil level	**Satisfactory**
Compressor oil pressure	**Satisfactory**
Refrigerant temperature	**Satisfactory**
Refrigerant pressure	**Satisfactory**
Chilled water systems leaks	**Yes (minor)**
Sensors calibration records	**No**
Refrigerant leaks	**No**
Location of the equipment	**Indoor**

Field measurements	
Electricity consumption [kWh]	73'200 (2008)
Electric voltage [V]	381
Electric current [A]	320


Water leaks pictures


Expansion valves

Cold Generator

Chiller Identification	
Manufacture/Model	Broad BDH 20
Year	2008
System Type	Absorption
Performance Data	
Nominal Cooling Capacity [kW]	195
Installed Cooling Capacity W/m^2 GIA	40.3
Nominal Electric Power [kW]	1.8
COP	0.78
Solution	LiBr
Electrical data	
Power supply [V/Ph/Hz]	380/3/50
Start-up amps [A]	5

Auxiliary Equipment	
Fan Electrical Demand [kW]	N.I.
Pumps Electric Demand [kW]	2 X 3

Monitoring observations

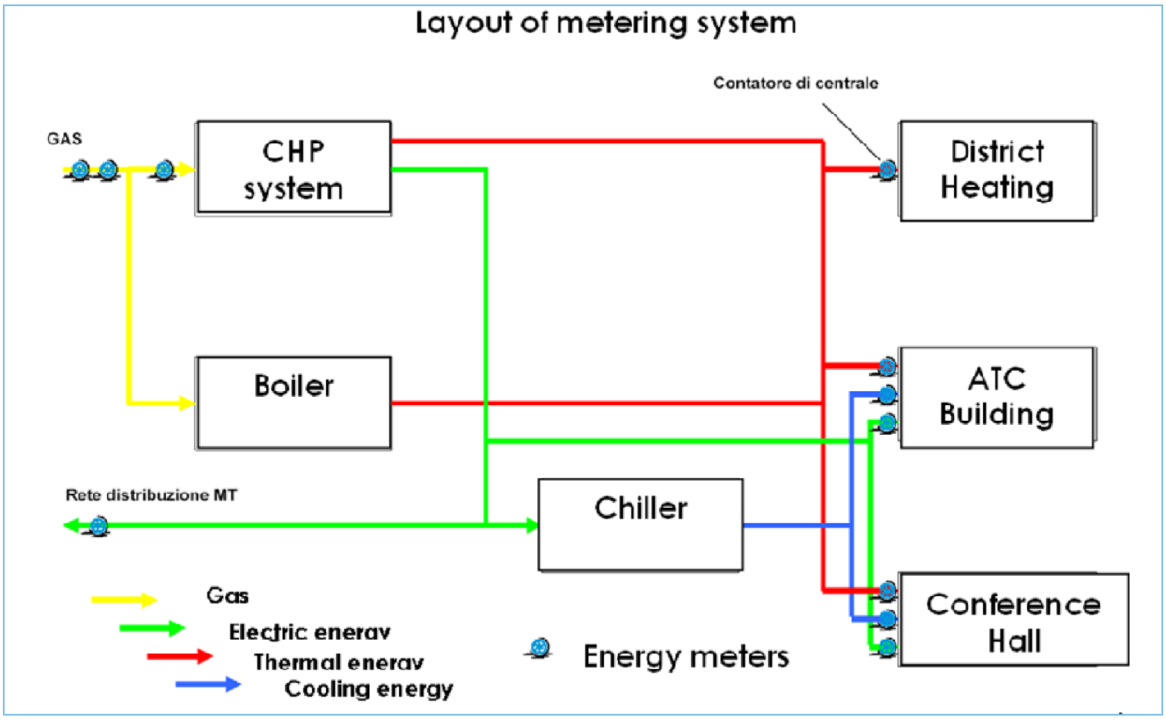
Inspection	
Maintenance status	**Satisfactory**
Previous inspection/maintenance Reports	**No**
Operation time estimated [h]	**700**
Operating mode	**automatic**
Thermal Insulation (Visual)	**Satisfactory**
Vibration eliminators	**Satisfactory**
Worn couplings	**Satisfactory**
Equipment cleanliness	**Satisfactory**
Compressor oil level	**N.A.**
Compressor oil pressure	**N.A.**
Refrigerant temperature	**Satisfactory**
Refrigerant pressure	**Satisfactory**
Chilled water systems leaks	**No**
Sensors calibration records	**No**
Refrigerant leaks	**No**
Location of the equipment	**Indoor**

Field measurements	
Electricity consumption [kWh]	N.A.
Electric voltage [V]	381
Electric current [A]	3

Energy consumption data

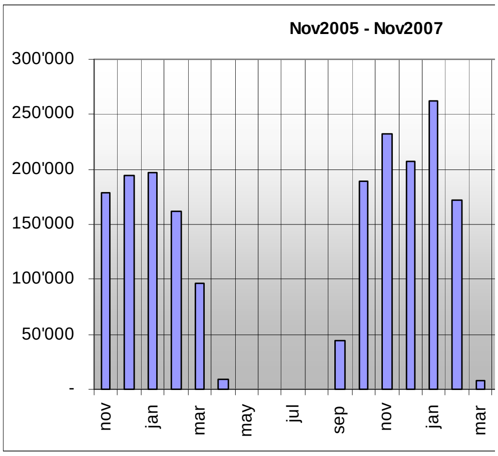
Metering information

This section shows how the metering was arranged in the Case Study. The meters monitored the energy consumption of the various parts of the HVAC system, along with other building related consumptions and data, at 15 minute intervals. The metering is carried out in accordance to Policity project. In the framework of the Policity project sensors was installed and readings stored in the last two years. The information available is summarized in the table below:

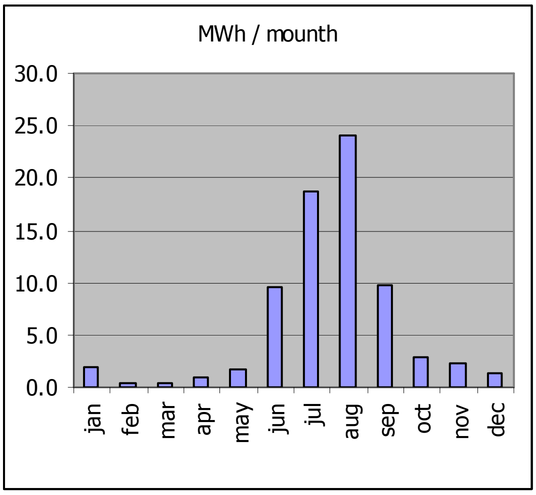


Monitoring observations

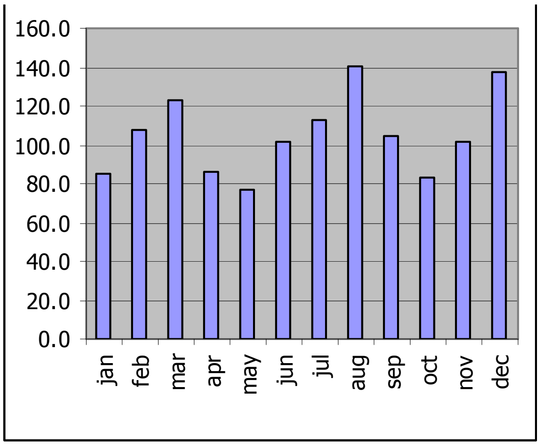
Heating [kWh]



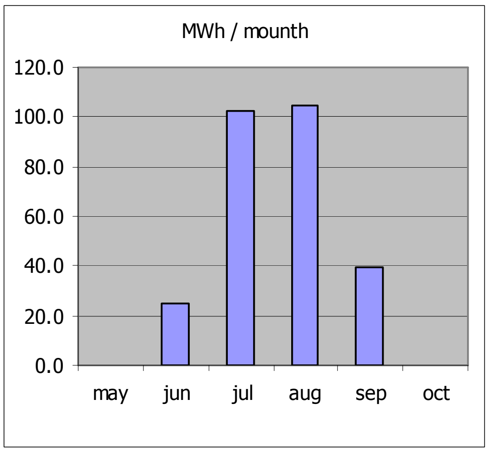
Cooling el. consumption [MWh]



Electricity [MWh/month]

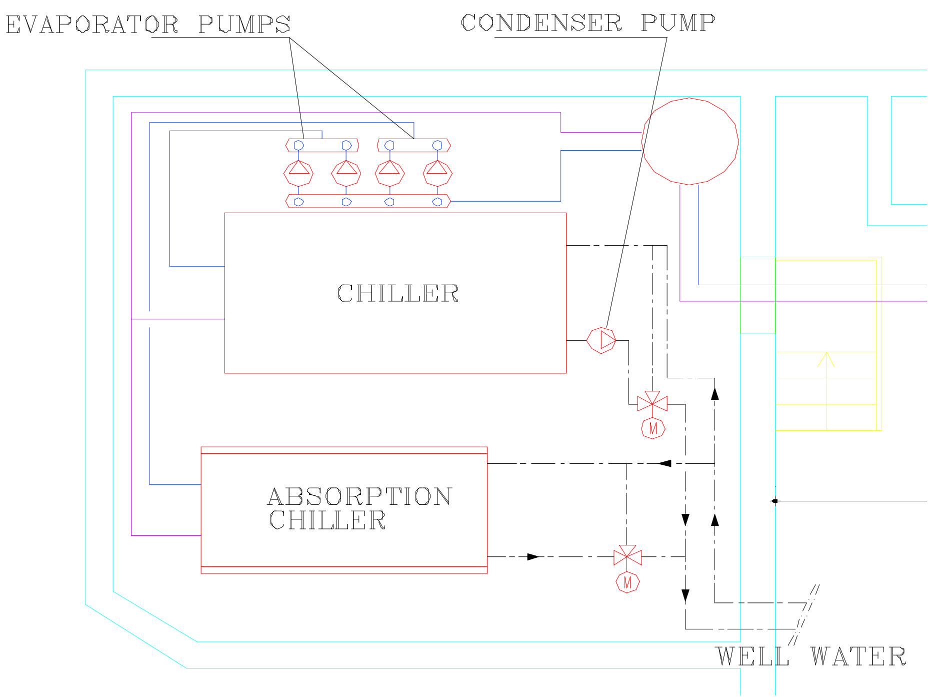


Cooling power [MWh/month]

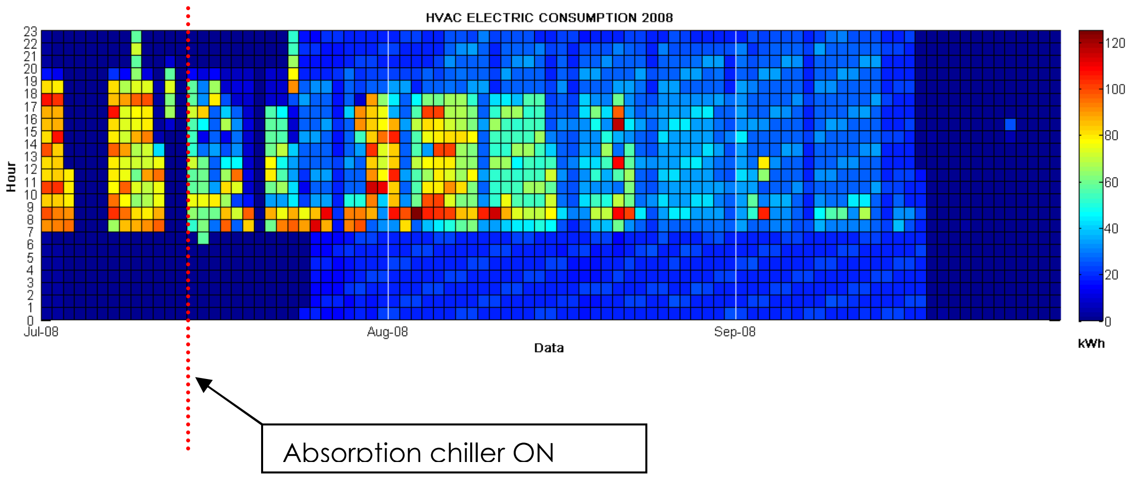


Monitoring cooling station

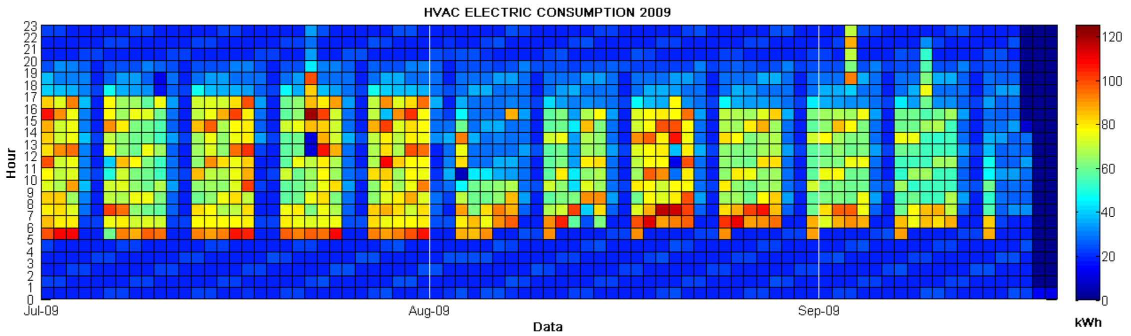
Consumption analysis was focused on electric consumption of cooling station. This consumption comprises one electric chiller, one absorption chiller, one pump for the condensing circuits (3 kW), and four pumps for evaporators circuit (3 kW each). In the image below the schematic plant view of cooling station is shown.



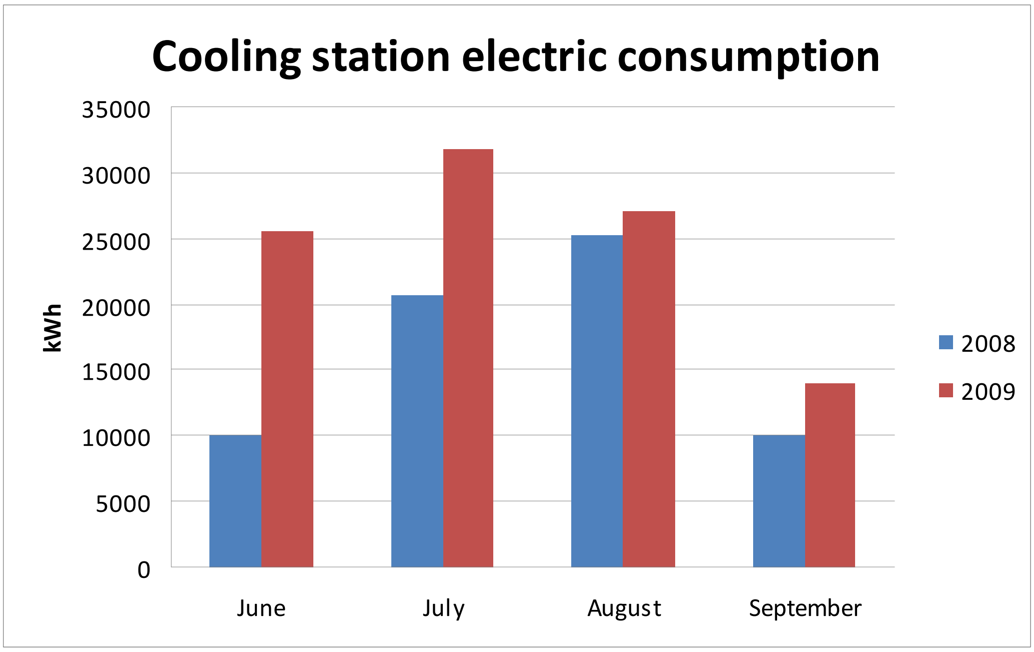
The analysis of electrical consumption over 2008 summer season shows a distributed load (due to circulation pumps) with some peaks of consumption (due to the electric chiller operation). At the end of the season, the fact that the electric chiller was almost always off is particularly appreciable. The absorption chiller was sufficient to provide cooling power. The operation schedule was five days per week (with some exceptions on Saturday) from 6:00 to 18:00. By the middle of July the peak consumption was deeply reduced; in fact on the 15 July the absorption chiller was operative, as seen in the graph below. The new schedule of the electric chiller seems from 7:00 to 17:00.



During the 2009 summer season a similar operation strategy for the cooling station was expected. The 2009 season was characterized by mean temperatures higher than 2008, as seen in the **Environment parameters** section. The graph of hourly consumption shows higher loads during the whole day; moreover the time schedule appears to be changed. From the graph we can identify this schedule: Mon-Fri 4:00-16:00. The operation hours during the day were increased (12 hours, instead of the 10 hours of 2008).

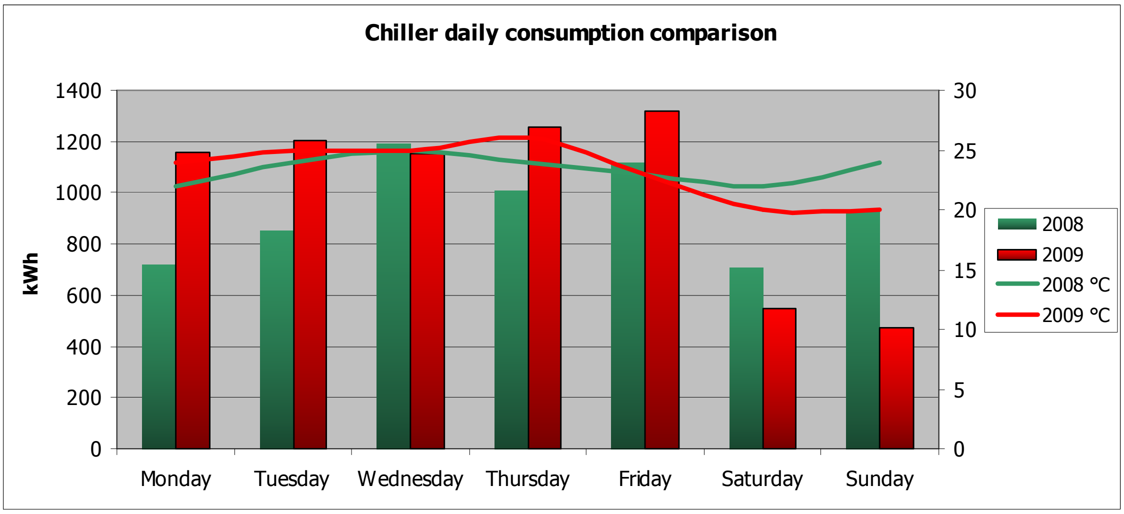


The climatic conditions are always the major cause for higher consumption, nevertheless in this case study the higher consumption was due to different schedule. The difference between 2008 and 2009 season was high, <u>almost 50 % more on the overall summer season.</u>

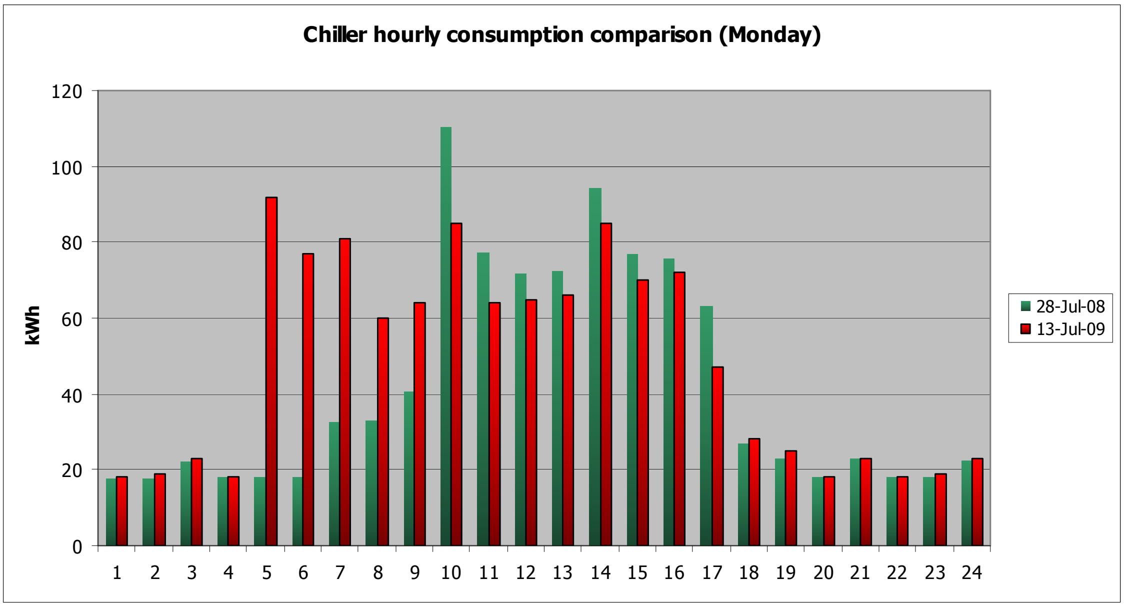


To analyze the cooling station electrical consumption, two weeks with similar average external temperature were chosen. In the graph below the daily cooling station consumption for the considered week is shown:

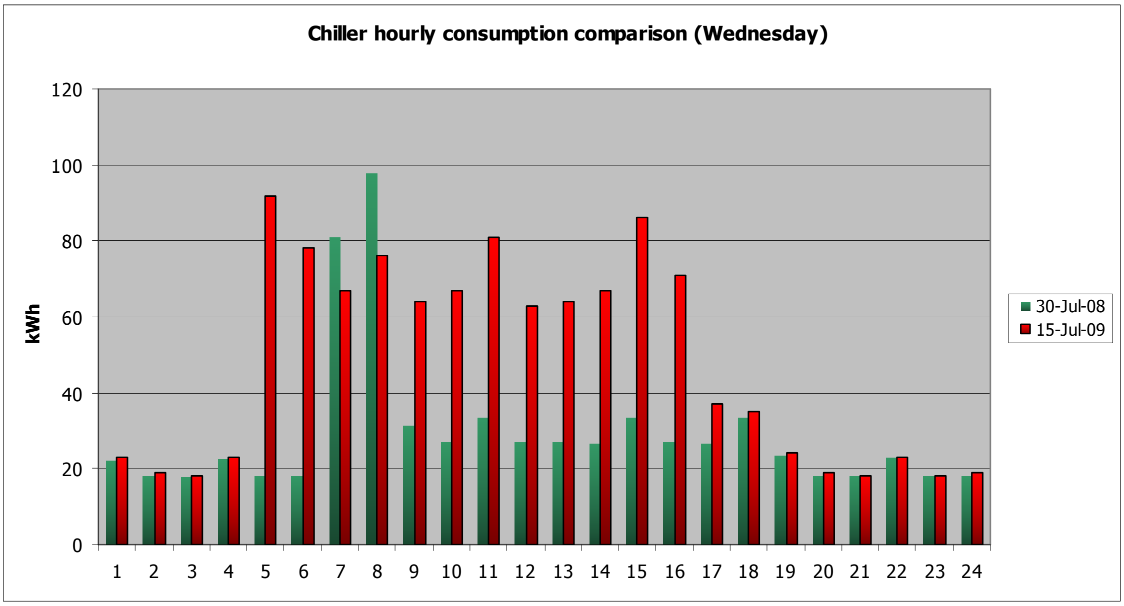
- 28 July - 03 August for 2008 season
- 13 July - 19 July for 2009 season



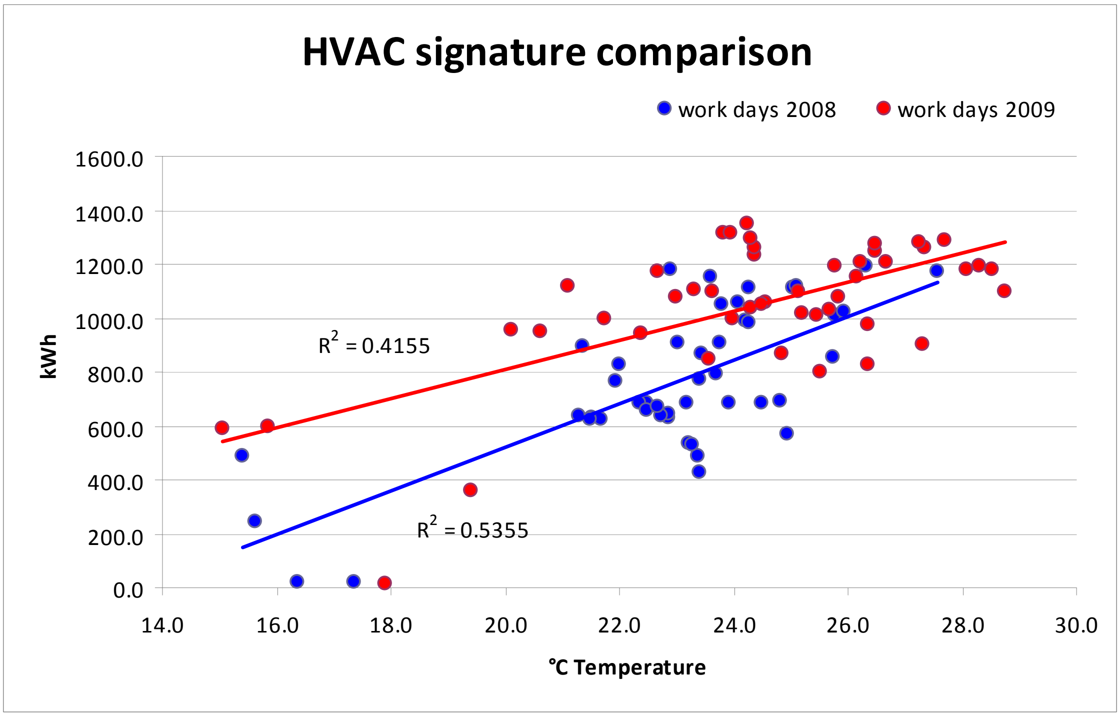
Analyzing the hourly consumption on Monday, the different schedules should be appreciated. As seen in the graph below, there is a common base load consumption due to the pumps, ranging between 18 and 22 kW. In 2008, between 6:00 and 7:00, the input increase to 35 kW: it implies that around this hour the electric chiller starts to operate at minimum load. Between 9:00 to 10:00 a peak consumption appears, due to almost full load of the electric chiller. In 2009 the chiller starts at 4:00 at full load.



Similar considerations should be made for Wednesday consumption, as seen in the graph below. Notice that on 30 July 2008 and 15 July 2009 the external daily average temperature was the same. Considering those two days, in occupation hour, the consumption of 2009 almost doubled that of 2008



To compare the system performance as a function of external temperature during 2008 and 2009, the linear regression technique was used. In the graph below the energy signature for work days is given. It clearly appears that in 2009 the system was consuming more electric energy than in 2008, even at the same average external temperature.



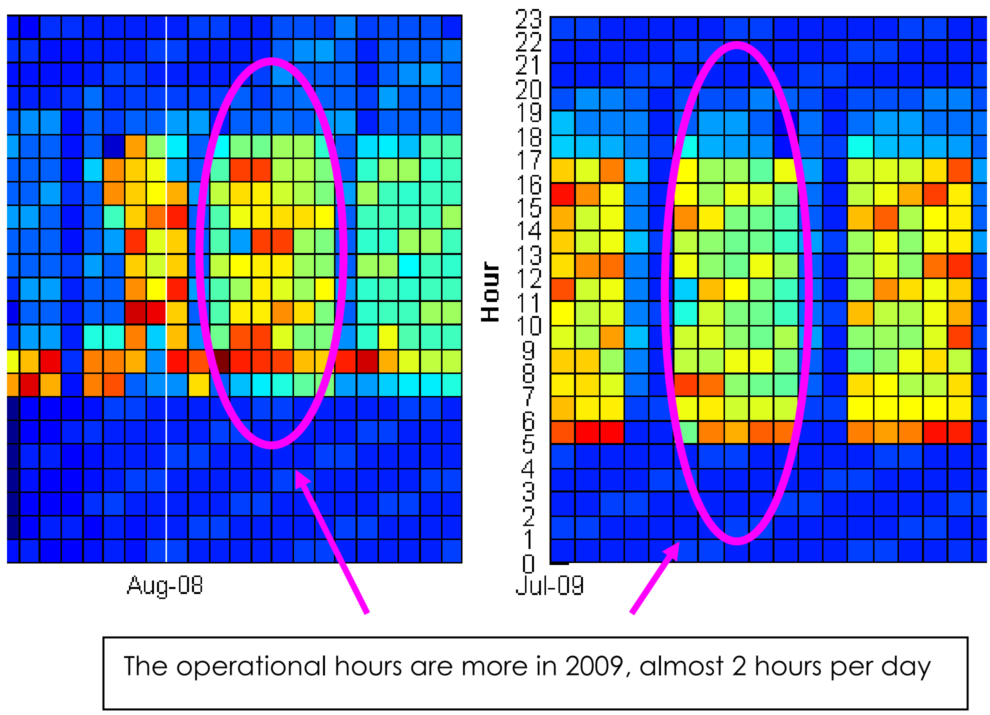
Talking with the building owner and with the Energy Manager, further information was obtained:

1. In October 2008 the HVAC system manager was changed
2. During spring/summer 2009 the glazed façade on north side of the building was replaced: the original double glazed windows were replaced by 4 glass low emissivity windows.

Considering such information and the overall consumption of 2009 summer season, it should be concluded that something in the process was not functioning as expected.

On one side, the sealing of north façade with almost zero permeability windows, decrease the heating energy request in winter, while increase the cooling request in summer. This is due to the drastic reduction of thermal and air exchanges during summer night, when the air temperature inside the building is higher than external temperature.

On the other side, the new HVAC system manager has less knowledge about the system, so he decided the temperature and schedule set point with a big safety margin. This is clearly visible in the carpet plot. In 2009 the system was always started 2-3 hours earlier with respect of 2008. This implies the working of electric chiller alone (the absorber chiller is always turned on with the CHP system, after 8:00 AM), and so a higher consumption of the whole system.



Timing table for first inspection

Inspection Item	Short Description	Time (mins)	Savings	Notes
PI1	Location and number of AC zones	20		
PI2	Documentation per zone	40		
PI3	Images of zones/building	15		
PI4	General zone data/zone	14		
PI5	Construction details/zone	17		
PI6	Building mass/air tightness per zone	15		
PI7	Occupancy schedules per zone	8		
PI8	Monthly schedule exceptions per zone	2		
PI9	HVAC system description and operating setpoints per zone	35		
PI10	Original design conditions per zone	30		
PI11	Current design loads per zone	28		
PI12	Power/energy information per zone	10		
PI13	Source of heating supplying each zone	4		
PI14	Heating storage and control for each zone	15		
PI15	Refrigeration equipment for each zone	15		
PI16	AHU for each zone	5		
PI17	Cooling distribution fluid details per zone	10		
PI18	Cooling terminal units details in each zone	10		
PI19	Energy supply to the system	1		
PI20	Energy supply to the building	1		
PI21	Annual energy consumption of the system	35		The Building is provided with a complete monitoring system, that allows to obtain data about electrical consumption
PI22	Annual energy consumption of the building	25		The Building is provided with a complete monitoring system, that allows to obtain data about electrical consumption
	TOTAL TIME TAKEN (minutes)	**355**		
	TOTAL (seconds/m^2)	**3.31**	Area (m^2)	6440

Centralised system inspection data

Inspection Item	Short Description	Time (mins)	Savings	Notes
PC1	Details of installed refrigeration plant	25		
PC2	Description of system control zones, with schematic drawings.	15		
PC3	Description of method of control of temperature.	15		
PC4	Description of method of control of periods of operation.	2		
PC5	Floor plans, and schematics of air conditioning systems.	16		
PC6	Reports from earlier AC inspections and EPC's	0		not available
PC7	Records of maintenance operations on refrigeration systems	4		
PC8	Records of maintenance operations on air delivery systems.	4		
PC9	Records of maintenance operations on control systems and sensors	0		not available
PC10	Records of sub-metered AC plant use or energy consumption.	15		Advanced BMS
PC11	Commissioning results where relevant	0		not available
PC12	An estimate of the design cooling load for each system	45		
PC13	Records of issues or complaints concerning indoor comfort conditions	0		not available
PC14	Use of BMS	14		
PC15	Monitoring to continually observe performance of AC systems			
C1	Locate relevant plant and compare details	35		
C2	Locate supply the A/C system and install VA logger(s)	160		
C3	Review current inspection and maintenance regime	5		
C4	Compare system size with imposed cooling loads	5		
C5	Estimate Specific Fan Power of relevant air movement systems	4		on label data
C6	Compare AC usage with expected hours or energy use	25		compare mesures of BMS with expected occupancy
C7	Locate refrigeration plant and check operation	10		
C8	Visual appearance of refrigeration plant and immediate area	3		
C9	Check refrigeration plant is capable of providing cooling	5		
C10	Check type, rating and operation of distribution fans and pumps	10		already done in C1
C11	Visually check condition/operation of outdoor heat rejection units	15		

C12	Check for obstructions through heat rejection heat exchangers	10		
C13	Check for signs of refrigerant leakage	9		3 units
C14	Check for the correct rotation of fans	0		not possible
C15	Visually check the condition and operation of indoor units	90		10 min per floor
C16	Check air inlets and outlets for obstruction	20		in addition to C15
C17	Check for obstructions to airflow through the heat exchangers	20		in addition to C15
C18	Check condition of intake air filters.	10		in addition to C15
C19	Check for signs of refrigerant leakage.	10		in addition to C15
C20	Check for the correct rotation of fans	30		in addition to C15
C21	Review air delivery and extract routes from spaces	15		in addition to C15
C22	Review any occupant complaints	0		not available
C23	Assess air supply openings in relation to extract openings.	15		The building has only 2 little UTA for cantine and conference room
C24	Assess the controllability of a sample number of terminal units	20		
C25	Check filter changing or cleaning frequency.	8		
C26	Assess the current state of cleanliness or blockage of filters.	4		
C27	Note the condition of filter differential pressure gauge.	2		
C28	Assess the fit and sealing of filters and housings.	3		
C29	Examine heat exchangers for damage or significant blockage	2		
C30	Examine refrigeration heat exchangers for signs of leakage	2		
C31	Note fan type and method of air speed control	2		
C32	Check for obstructions to inlet grilles, screens and pre-filters.	4		
C33	Check location of inlets for proximity to sources of heat	2		
C34	Assess zoning in relation to internal gain and solar radiation.	15		
C35	Note current time on controllers against the actual time	10		
C36	Note the set on and off periods	6		
C37	Identify zone heating and cooling temperature control sensors	5		per floor
C38	Note zone set temperatures relative to the activities and occupancy	13		per zone
C39	Check control basis to avoid simultaneous heating and cooling	6		
C40	Assess the refrigeration compressor(s) and capacity control	210		with climacheck

C41	Assess control of air flow rate through air supply and exhaust ducts	15		with measurement of air flow at the first and the last of each air channel. The building has only 2 little UTA for cantine and conference room
C42	Assess control of ancillary system components e.g. pumps and fans	10		
C43	Assess how reheat is achieved, particularly in the morning	0		not available
C44	Check actual control basis of system	8		
	TOTAL TIME TAKEN (minutes)	**1'008**		
	TOTAL (seconds/m^2)	**9.39**	Area (m^2)	6440

Main Eco's identified

ECO CODE	DESCRIPTION	ACTION	Saving
E2.4	Correct excessive envelope air leakage	partially windows substitution	-0.6-4% of HVAC consumption in summer -1.5-7.3% of heat consumption in winter
E2.6	Apply night time over ventilation	users or automatic devices	1.5-5% of summer HVAC consumption
E3.1	Upgrade insulation of flat roofs externally	roof insulation	-0.6 on summer HVAC consumption
E3.7	Locate and minimize the effect of thermal bridges	already applied, insulation of overhangs	11.5% on heating energy in winter
E3.9	Use double or triple glaze replacement	partially applied, spot measurements	24.17% on heating energy in winter
P2.12	Consider the possibility of using waste heat for absorption system	applied with CHP, measured by BMS	Value dramatically different between simulation and measurement

ECO E 2.6, Apply night time over ventilation

The analysis of the electric chiller consumption during work days shows that the system operation starts at 8:00 AM. In the first hours of operation the consumption is higher: the system has to reach the set point temperature, after being off for the whole night. If night time over ventilation was provided, the refrigeration power in the first hours of the morning would be lowered.

In the further tables the ECO assessment is resumed:

Chiller Consumption

2008	07 June-16 sept	73'204	kWh
2009	19 May-17 sept	111'021	kWh

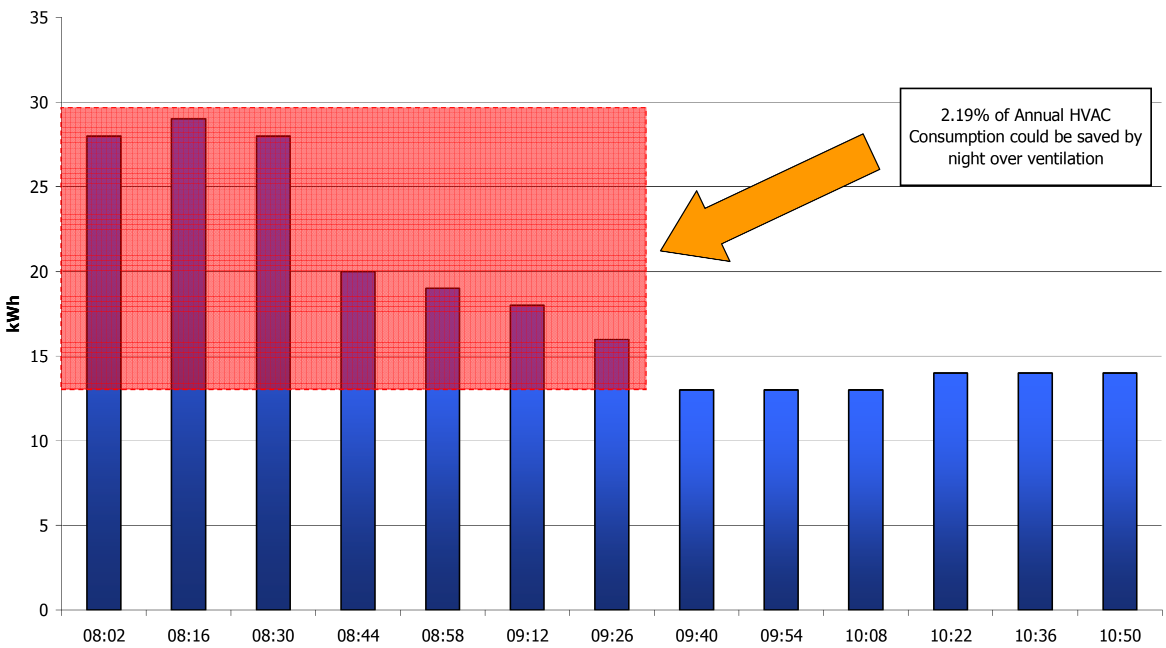
Chiller consumption in summer, aggregated by hour

	2008	2009	
8:00-9:00	5'496	6'937	kWh
9:00:10:00	4'227	6'508	kWh
10:00-11:00	4'058	5'917	kWh

We assume that, in presence of night time over ventilation, the hourly consumption between 8:00 and 10:00 in the morning should be equal to consumption between 10:00 and 11:00. According to this calculation the potential savings are estimated in 1.45-2.19% of chiller annual consumption.

	2008	2009	
Potential saving	**1'606**	**1'611**	**kWh**
	2.19%	**1.45%**	

POLITO CS-ATC HVAC System Consumption, 8:00-11:00 , Work day

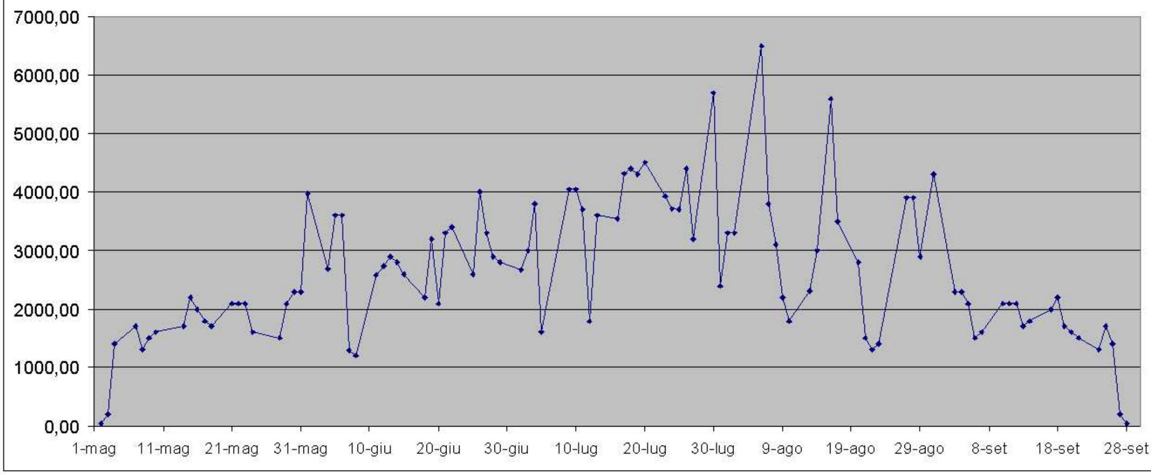


The calculation method most likely underestimates the potential saving, because in the first hours of the day the sun radiation and internal load are less intense than at 11:00. For this reason potential saving could be at least equal to 5% of chiller consumption.

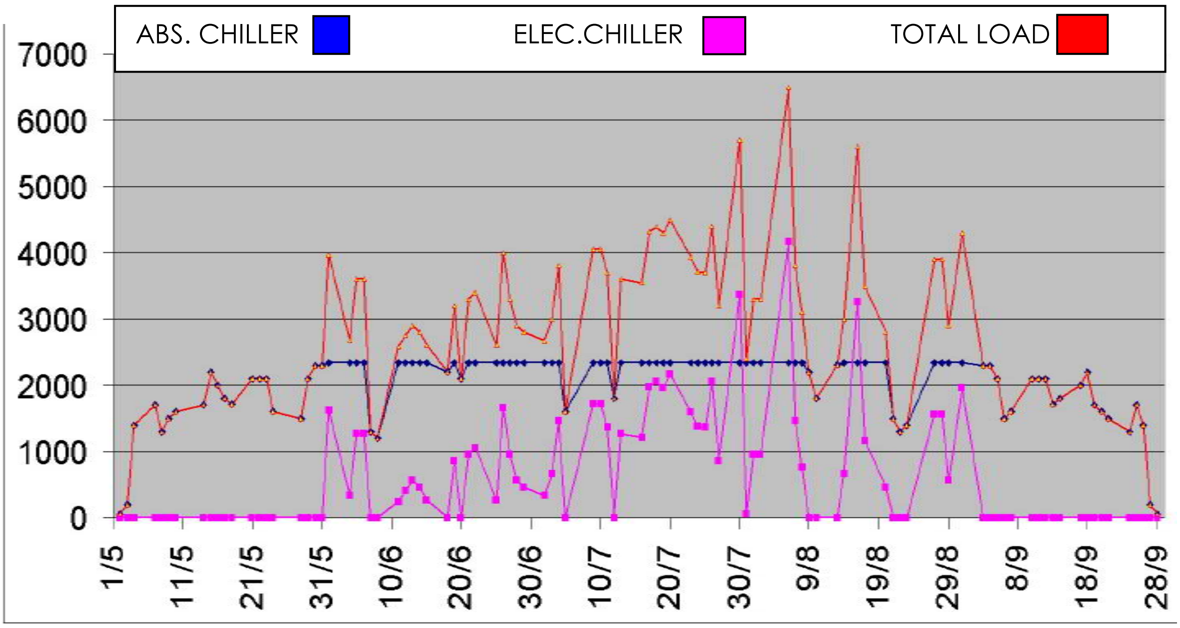
ECO P 2.12, Consider the possibility of using waste heat for absorption system

The system analyzed already had an absorption chiller. This unit was 10 years old and was replaced in summer 2008 by a new unit. Economic and energy analysis was provided. The cooling load was monitored by Policity sensors, as seen in the graph below.

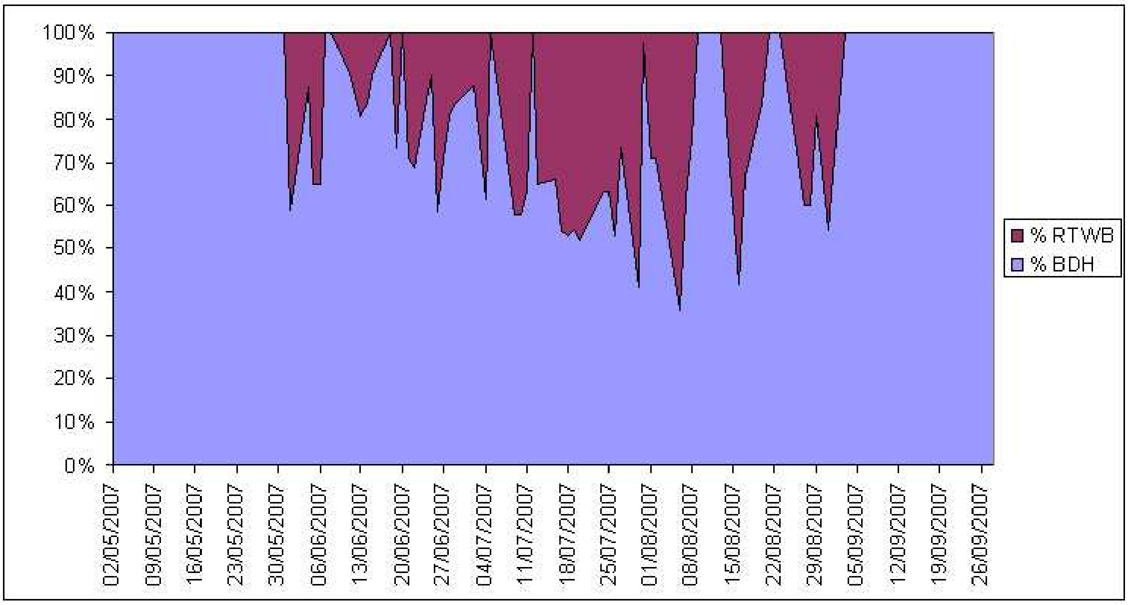
Cooling load of ATC (kWh)



The analysis assumes that the waste heat from CHP system should be directed to an absorption chiller. The base cooling load is then provided by the absorption unit, while the peak load is provided by the existent electric chiller; the graph below shows the load subdivision between the two chillers.



With this hypothesis, the electric chiller is turned on just on the hottest day of the summer season. The graph below shows the ideal operation load for the two units during the hot season. RTWB represents the electric chiller, while BDH represents the absorption unit.



As seen in the graph, the electric chiller ideally works for a limited amount of time, and it can be turned on just from June until the end of August.

Under this hypothesis the payback time for the considered unit was estimated in 9 years, and the saving on electric consumption of the chiller was estimated in 75.5%.

The unit was installed and started for the first time in July 2008 and became fully operative in August 2008. Measurements during summer season permit real quantifying of this ECO.

month	Electric Consumption MWh	Cooling energy delivered MWh	COP
Aug-07	17.8	60.41	3.4
Sep-07	12.1	33.31	2.8
Aug-08	26.0	104.8	4.0
Sep-08	9.7	39.4	4.0

The above table indicates that the COP of the system sensibly increased after the absorption chiller was operated. In the next table the consumption of Aug-Sep 2008 are compared with a hypothetical consumption of the same months without the absorption chiller installed. For this comparison we use the COP of 2007 season.

El. Consumption (MWh)	abs. Chiller	No abs. Chiller	%
Aug-08	26.0	30.8	15.7%
Sep-08	9.7	14.3	31.9%
Total	**35.7**	**45.1**	**20.8%**

The overall result is a 20.8% saving on total chiller electric consumption. This is a good operational result, but dramatically lower than the 75.5% assumed in the simulation.

The major explanation for the different values is that in current operation the absorption unit is not working as stated in the simulation. The nominal performance of the unit is calculated with inlet hot water at 90°C. In the ATC building the hot water to the absorption unit is provided by a combined heat and power system, an IC engine rated at 1 MW electric power.

The installation of CHP was previous to the installation of the chiller; its circuit was designed for a maximum temperature of 90°C. In operation, when the water temperature reaches 85°C, the system stops due to safety valves. For this reason the inlet water to the absorption unit is delivered at 83-84°C, and the COP of the unit is decreased.

Other reasons that affect the performance are that CHP unit is turned on, for cost reasons, just from 8:00 AM to 7:00 PM. Between this hour the electric energy produced by the CHP is sell at the maximum cost (peak hour). This implies that the absorption unit cannot be turned on before 8:00 AM. Moreover, the unit needs some time (almost one hour) to provide full performance.

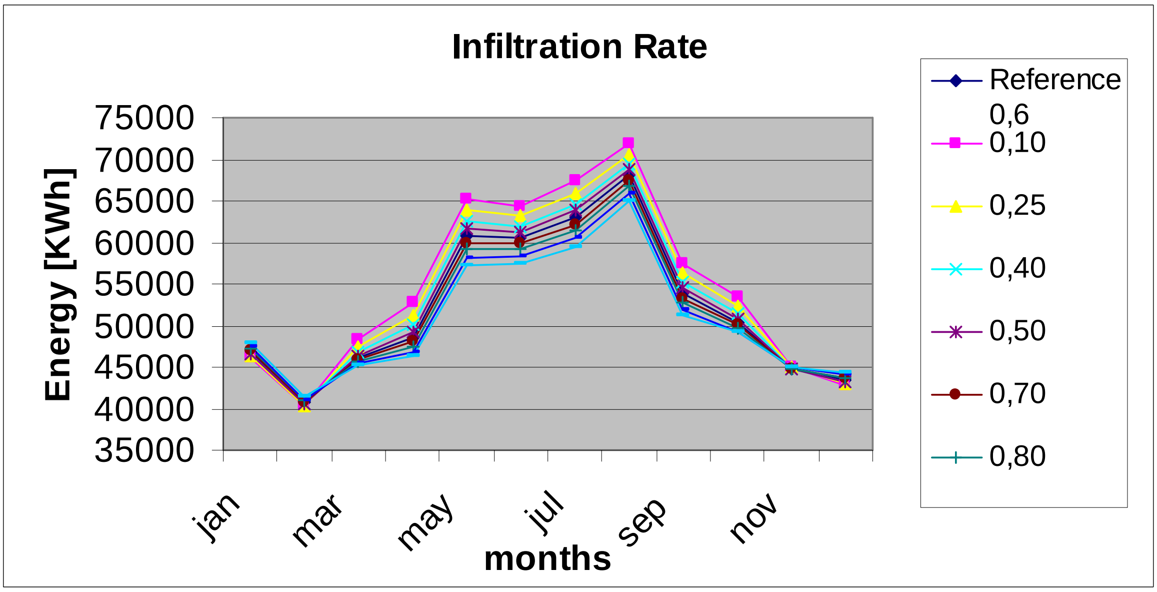
ECOs assessment with tools sensitivity analysis

To estimate the potential ECOs savings, a sensitivity analysis was run. The values of different parameters (listed below) was fixed at design value, then decreased (and increased): the results of different simulations was recorded. The following parameters were modified and taken into account into the simulation:

- Infiltration Rate
- Windows U-value
- Upgrade insulation of flat roofs externally
- Opaque Frontages U-value
- Replace lighting equipment with low consumption types
- Replace electrical equipment with Energy Star or low consumption types

A design point is set for each of them, and reasonable variations from this value are evaluated using the same basis for each of them, so that a consistent comparison could be done.

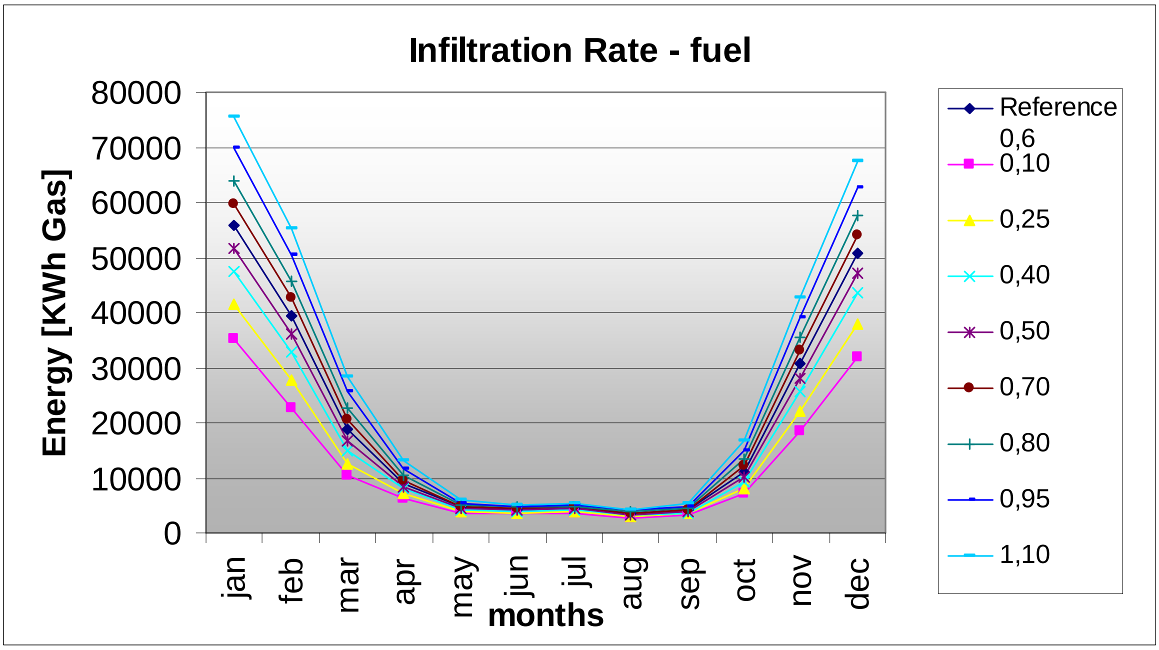
Infiltration Rate



<u>Difference %</u>

	0,10	0,25	0,40	0,50	**Reference 0,6**	0,70	0,80	0,95	1,10
jan	1,59	1,28	0,76	0,42		-0,45	-0,86	-1,40	-2,05
feb	0,79	0,69	0,36	0,16		-0,23	-0,56	-1,06	-1,72
mar	-5,10	-2,97	-1,49	-0,56		0,48	0,86	1,36	1,69
apr	-8,40	-5,53	-2,94	-1,37		1,20	2,38	3,71	4,74
may	-7,35	-5,04	-2,82	-1,37		1,31	2,50	4,25	5,84
jun	-6,44	-4,36	-2,38	-1,16		1,06	2,10	3,57	5,03
jul	-7,00	-4,73	-2,59	-1,28		1,28	2,44	4,05	5,61
aug	-5,67	-3,79	-2,11	-1,03		0,99	1,93	3,26	4,51
sep	-6,73	-4,52	-2,54	-1,21		1,11	2,13	3,56	4,98
oct	-6,02	-3,66	-1,95	-0,93		0,76	1,46	2,16	2,56
nov	-0,77	-0,34	0,03	-0,02		-0,13	-0,20	-0,50	-0,82
dec	1,62	1,11	0,66	0,37		-0,33	-0,63	-1,26	-2,04
	-4,13	-2,65	-1,42	-0,66	**mean**	0,59	1,13	1,81	2,36

Energy consumption considerations
The electrical consumption has a significant variation; a further insight on the fuel consumption would be useful, in order to make an overall energy balance and draw meaningful conclusions on the results that could be expected by changing the infiltration rate on a real building.



Balance

	0,10	0,25	0,40	0,50	Reference 0,6	0,70	0,80	0,95	1,10
jan	-21321,00	-15019,00	-8548,00	-4283,00		4279,00	8475,00	14644,00	20735,00
feb	-16928,00	-11834,00	-6635,00	-3268,00		3283,00	6598,00	11479,00	16445,00
mar	-5860,00	-4790,00	-2957,00	-1605,00		1712,00	3519,00	6249,00	9029,00
apr	1387,00	793,00	336,00	107,00		23,00	118,00	834,00	1856,00
may	3436,00	2337,00	1286,00	612,00		-577,00	-1075,00	-1763,00	-2306,00
jun	3060,00	2062,00	1109,00	530,00		-476,00	-930,00	-1560,00	-2190,00
jul	3472,00	2373,00	1298,00	639,00		-634,00	-1196,00	-1958,00	-2684,00
aug	3034,00	2005,00	1109,00	540,00		-514,00	-1001,00	-1676,00	-2296,00
sep	2714,00	1835,00	1029,00	481,00		-430,00	-761,00	-1111,00	-1358,00
oct	-918,00	-1127,00	-856,00	-492,00		683,00	1493,00	2908,00	4463,00
nov	-11720,00	-8369,00	-4909,00	-2436,00		2493,00	4954,00	8687,00	12399,00
dec	-19433,00	-13290,00	-7474,00	-3724,00		3622,00	7126,00	12404,00	17769,00
	-59077,0	**-43024,0**	**-25212,0**	**-12899,0**	**sum**	**13464,0**	**27320,0**	**49137,0**	**71862,0**
	-7,35	**-5,25**	**-3,01**	**-1,52**	**sum %**	**1,54**	**3,07**	**5,39**	**7,68**

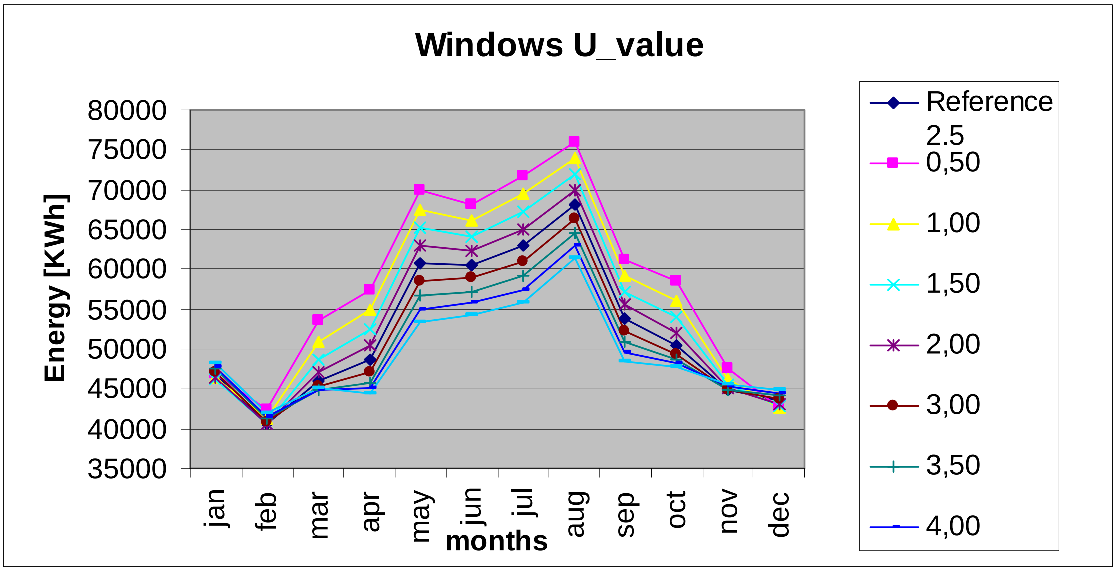
The green results (negative) mean a net energy saving, while the red ones a net energy consumption.

Conclusions

High values of the infiltration rate, evaluated in volumes per hour, lead to electricity savings in summer, due to night infiltration that provides cold fresh air, while increase the energy demand in winter, because conditioned warm air is replaced by cold external air. Low values of the infiltration rate go in the opposite direction.
Stronger effects are shown for lower values. Looking at the fuel demand (natural gas needed on winter to heat the building) it can be seen that there is

a huge effect by air infiltration.
Percentage evaluation may be deceptive, because in summer low consumption (mainly heat losses of the boiler and the low hot water demand) make even a 50% saving negligible, because of its small magnitude.
In conclusion, it will be interesting and cost-effective to install a free cooling solution which permits intake of fresh air only in summer nights.

Windows U-value



Difference

	0,50	1,00	1,50	2,00	Reference 2.5	3,00	3,50	4,00	4,50
jan	-0,17	0,84	1,18	0,77		-0,75	-1,36	-2,02	-2,76
feb	-4,23	-1,26	0,08	0,27		-0,61	-1,41	-2,22	-3,17
mar	-16,58	-10,67	-5,66	-2,39		1,64	2,40	2,44	2,10
apr	-18,04	-12,93	-8,17	-3,92		3,22	5,63	7,45	8,83
mag	-15,20	-11,19	-7,33	-3,65		3,51	6,70	9,67	12,17
jun	-12,75	-9,38	-6,08	-2,96		2,73	5,41	7,92	10,25
jul	-13,79	-10,10	-6,60	-3,20		3,13	6,00	8,84	11,47
aug	-11,71	-8,52	-5,54	-2,65		2,55	5,04	7,48	9,69
sep	-13,53	-9,87	-6,38	-3,21		2,80	5,56	7,83	10,15
oct	-16,22	-11,28	-6,97	-2,98		2,04	3,29	4,41	5,27
nov	-6,15	-3,31	-1,61	-0,49		-0,04	-0,42	-1,01	-1,63
dec	1,85	2,08	1,52	0,78		-0,67	-1,46	-2,29	-3,12
	-10,54	-7,13	-4,30	-1,97	**mean**	1,63	2,95	4,04	4,94

Balance

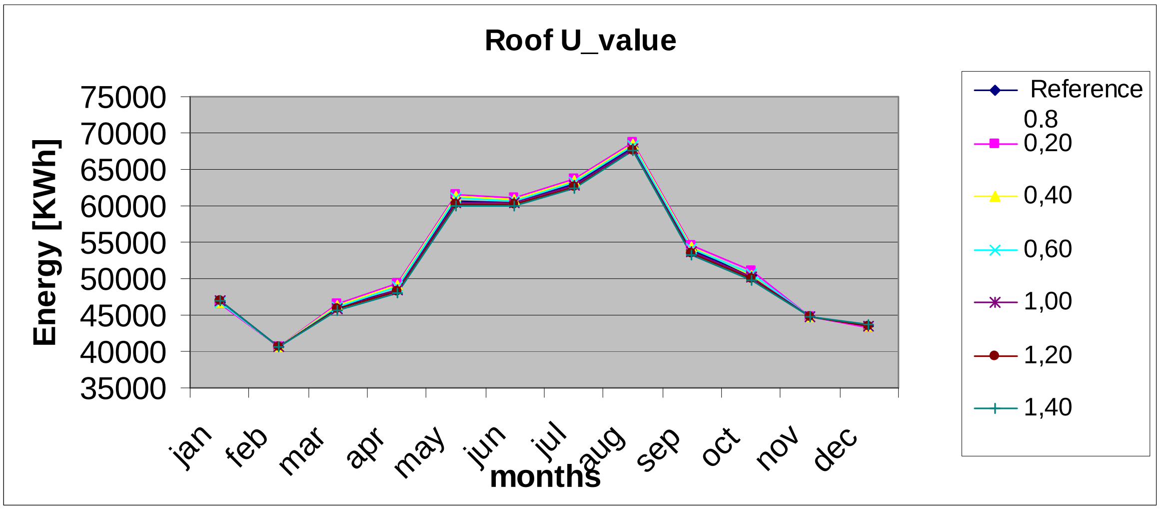
	0,50	1,00	1,50	2,00	**Reference 2.5**	3,00	3,50	4,00	4,50
jan	-30630	-24535	-17201	-8901		9461	19117	28897	38877
feb	-20668	-17549	-12887	-6810		7264	14887	22755	30931
mar	-5571	-6334	-5611	-3205		4037	8598	13539	18867
apr	5717	3279	1320	407		207	1480	3518	6030
may	7981	5679	3558	1699		-1351	-2202	-2686	-2945
jun	8476	6224	4066	2019		-1930	-3652	-5223	-6467
jul	7002	5138	3316	1604		-1452	-2871	-4183	-5365
aug	7977	5822	3795	1836		-1791	-3419	-5020	-6491
sep	7164	5181	3339	1585		-1496	-2764	-3866	-4796
oct	3027	1635	611	22		870	2116	3776	5832
nov	-8758	-8376	-6697	-4024		5131	10924	17140	23537
dec	-27231	-22866	-16191	-8471		8880	18074	27539	37184
	-45514,0	**-46702,0**	**-38582,0**	**-22239,0**	**sum**	**27830,0**	**60288,0**	**96186,0**	**135194,0**
	-5,57	**-6,04**	**-4,94**	**-2,79**	**sum %**	**3,28**	**6,85**	**10,50**	**14,16**

Conclusions

Electricity: stronger effects are on March, April, September and October, months in which during the day there is less difference between ambient temperature and indoor conditions.
Lower values are affecting more the electrical consumption.
Something similar to the infiltration rate effect happens: the lower the transmittance, the higher the consumption.
This is because it's electricity spent in higher cooling demand caused by internal gains (lighting and appliances, people activities etc) and fans and pumps that need to circulate more air.

Fuel: the higher the fuel demand, the stronger the effect; furthermore, there's a sort of asymmetry. Indeed, losses are higher with high values of the transmittance than savings with low values.
The overall energy balance goes in favor of low values of the transmittance, up to 6%.
Curiously, the maximum savings are not obtained with the minimum value.

Upgrade insulation of flat roofs externally



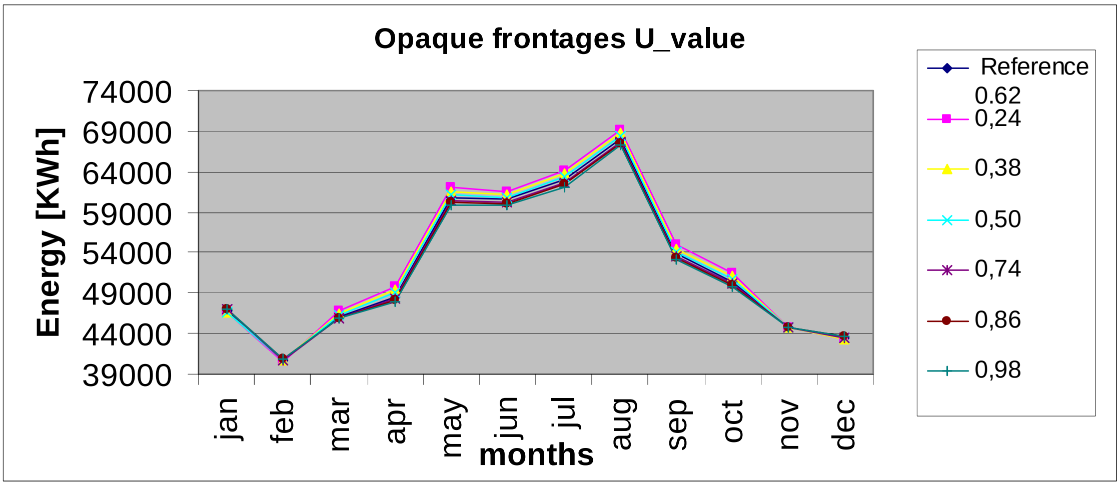
Difference %

	0,20	0,40	0,60	**Reference 0.8**	1,00	1,20	1,40
jan	0,46	0,30	0,17		-0,16	-0,31	-0,44
feb	0,14	0,09	0,02		0,02	-0,08	-0,19
mar	-0,90	-0,55	-0,24		0,23	0,50	0,74
apr	-1,44	-0,95	-0,50		0,42	0,84	1,29
may	-1,26	-0,87	-0,44		0,40	0,77	1,19
jun	-0,83	-0,56	-0,29		0,26	0,51	0,75
jul	-0,91	-0,62	-0,31		0,30	0,62	0,91
aug	-0,82	-0,55	-0,26		0,26	0,54	0,80
sep	-1,24	-0,80	-0,41		0,41	0,77	1,14
oct	-1,31	0,05	-0,39		0,39	0,75	1,08
nov	-0,15	-0,13	-0,06		-0,06	-0,03	-0,02
dec	0,35	0,21	0,13		-0,12	-0,19	-0,32
	-0,66	-0,36	-0,21	**mean**	0,20	0,39	0,58

Conclusions

There are few variations, mostly contained into 1% with a maximum value of -0.66% average after a 75% variation of the parameter.
Opposite influences between summer and winter, with stronger variations on spring and autumn.

Opaque-Frontages U-value



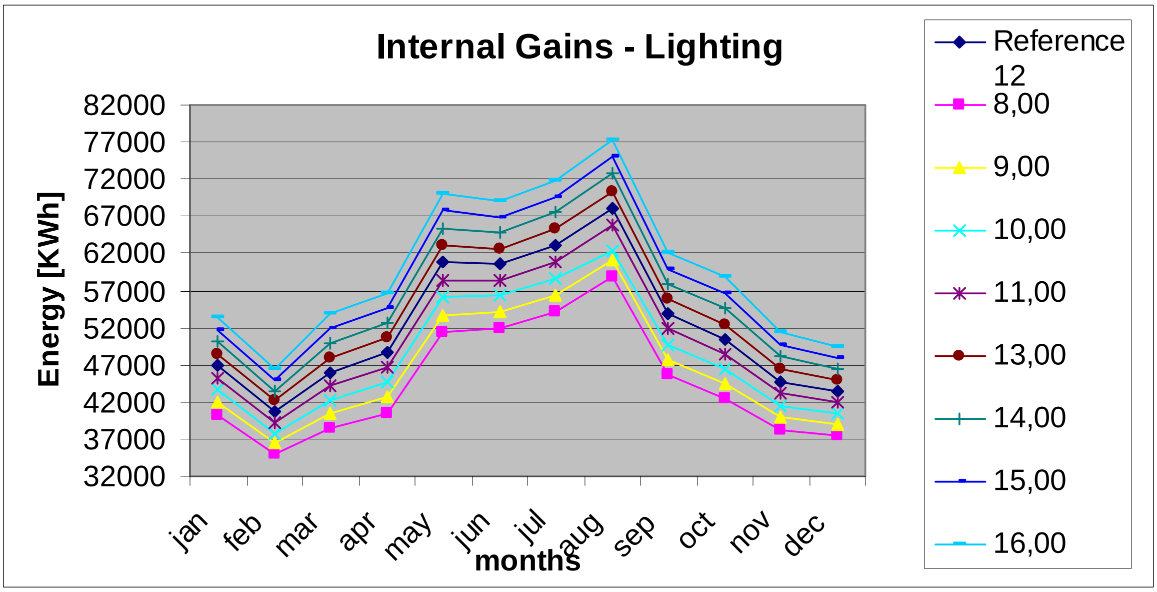
Difference %

	0,24	0,38	0,50	**Reference 0.62**	0,74	0,86	0,98
jan	0,62	0,43	0,24		-0,20	-0,34	-0,49
feb	0,23	0,13	0,03		-0,03	-0,30	-0,37
mar	-1,74	-0,84	-0,48		0,43	0,16	0,37
apr	-2,68	-1,56	-0,81		0,71	0,99	1,49
may	-2,12	-1,25	-0,75		0,66	0,87	1,44
jun	-1,69	-1,04	-0,55		0,50	0,74	1,16
jul	-1,78	-1,12	-0,56		0,55	0,92	1,40
aug	-1,50	-0,96	-0,48		0,47	0,73	1,11
sep	-2,05	-1,30	-0,62		0,60	0,86	1,31
oct	-2,22	-1,34	-0,65		0,56	0,75	1,11
nov	-0,25	-0,03	-0,10		-0,03	-0,20	-0,23
dec	0,57	0,32	0,18		-0,14	-0,25	-0,39
	-1,22	-0,71	-0,38	**mean**	0,34	0,41	0,66

Conclusions

There is higher influence on lower values, maybe because there is more irreversibility due to higher gradients: indeed, the higher the gradient, the higher the irreversibility and the losses during the process, and consequently the higher the energy spent.
It can be seen that there's an opposite influence on winter with respect to the rest of the year, but the overall result is contained into a 1% variation, making this parameter not so relevant.

Replace lighting equipment with low consumption types



The various are translated exactly up or down with respect to the reference point.

Difference %

	8,00	9,00	10,00	11,00	Reference 12	13,00	14,00	15,00	16,00
jan	13,89	10,35	6,90	3,41		-3,42	-6,86	-10,28	-13,73
feb	14,02	10,59	7,14	3,60		-3,63	-7,11	-10,69	-14,32
mar	16,23	12,24	8,14	4,11		-4,13	-8,30	-12,60	-16,94
apr	16,49	12,31	8,21	4,10		-4,18	-8,37	-12,53	-16,80
may	15,35	11,50	7,63	3,82		-3,88	-7,67	-11,52	-15,34
jun	14,08	10,54	7,03	3,53		-3,56	-7,08	-10,63	-14,16
jul	14,09	10,58	7,07	3,54		-3,53	-7,06	-10,58	-14,10
aug	13,69	10,25	8,31	3,42		-3,41	-6,84	-10,26	-13,69
sep	15,11	11,34	7,56	3,79		-3,78	-7,61	-11,41	-15,20
oct	15,74	11,93	8,05	4,07		-4,16	-8,30	-12,46	-16,59
nov	14,45	10,89	7,27	3,59		-3,75	-7,44	-11,16	-14,98
dec	13,80	10,34	6,90	3,46		-3,44	-6,89	-10,32	-13,72
	14,74	11,07	7,52	3,70	**mean**	-3,74	-7,46	-11,20	-14,97

Conclusions

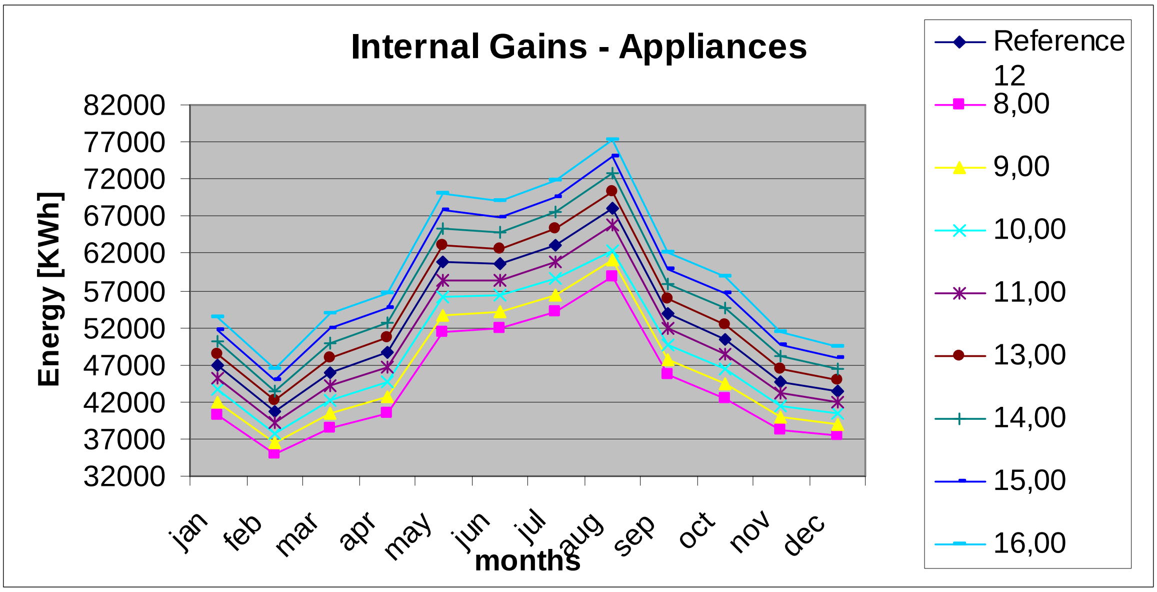
As hinted by the previous curves, there's a sort of translation up or down, with maximum variations around 15% with respect to the mean value of the variation itself.

The distribution is almost symmetric, suggesting that the electricity consumptions here considered come mostly from the lighting devices, increasing or decreasing evenly the contribution of the HVAC system to maintain the indoor climatic conditions.

It is also interesting to observe that reducing the lighting consumption by 33% produce and overall 15% energy saving.

As seen before, lighting devices account for almost half of the overall electrical consumption.

Replace electrical equipment with Energy Star or low consumption types



Difference %

	8,00	9,00	10,00	11,00	**Reference 12**	13,00	14,00	15,00	16,00
jan	13,89	10,35	6,90	3,41		-3,42	-6,86	-10,28	-13,73
feb	14,02	10,59	7,14	3,60		-3,63	-7,11	-10,69	-14,32
mar	16,23	12,24	8,14	4,11		-4,13	-8,30	-12,60	-16,94
apr	16,49	12,31	8,21	4,10		-4,18	-8,37	-12,53	-16,80
may	15,35	11,50	7,63	3,82		-3,88	-7,67	-11,52	-15,34
jun	14,08	10,54	7,03	3,53		-3,56	-7,08	-10,63	-14,16
jul	14,09	10,58	7,07	3,54		-3,53	-7,06	-10,58	-14,10
aug	13,69	10,25	8,31	3,42		-3,41	-6,84	-10,26	-13,69
sep	15,11	11,34	7,56	3,79		-3,78	-7,61	-11,41	-15,20
oct	15,74	11,93	8,05	4,07		-4,16	-8,30	-12,46	-16,59
nov	14,45	10,89	7,27	3,59		-3,75	-7,44	-11,16	-14,98
dec	13,80	10,34	6,90	3,46		-3,44	-6,89	-10,32	-13,72
	14,74	11,07	7,52	3,70	**mean**	-3,74	-7,46	-11,20	-14,97

HarmonAC

Balance

	0,50	1,00	1,50	2,00	**Reference 2.5**	3,00	3,50	4,00	4,50
jan	-893,00	-657,00	-461,00	-229,00		285,00	630,00	996,00	1412,00
feb	-1688,00	-1317,00	-936,00	-496,00		536,00	1057,00	1651,00	2300,00
mar	-5521,00	-4197,00	-2820,00	-1444,00		1477,00	3020,00	4652,00	6317,00
apr	-7757,00	-5797,00	-3871,00	-1938,00		1979,00	3977,00	5968,00	8015,00
may	-9322,00	-6981,00	-4635,00	-2322,00		2353,00	4658,00	6992,00	9316,00
jun	-8516,00	-6376,00	-4255,00	-2134,00		2155,00	4279,00	6427,00	8566,00
jul	-8871,00	-6662,00	-4453,00	-2231,00		2225,00	4451,00	6667,00	8884,00
aug	-9320,00	-6979,00	-5657,00	-2325,00		2324,00	4659,00	6984,00	9322,00
sep	-8127,00	-6096,00	-4063,00	-2037,00		2030,00	4093,00	6138,00	8175,00
oct	-6613,00	-5055,00	-3467,00	-1785,00		1857,00	3731,00	5625,00	7524,00
nov	-2232,00	-1733,00	-1206,00	-599,00		750,00	1530,00	2384,00	3330,00
dec	-301,00	-247,00	-203,00	-117,00		135,00	298,00	485,00	696,00
	-69161,0	**-52097,0**	**-36027,0**	**-17657,0**	**sum**	**18106,0**	**36383,0**	**54969,0**	**73857,0**
	-8,71	**-6,42**	**-4,36**	**-2,09**	**sum %**	**2,05**	**4,04**	**5,99**	**7,88**

Conclusions on Internal Gains

As it was hinted before, the internal gains help the heating plant to heat the building, and so we have absolutely no influence in summer (talking in terms of fuel, electrical energy for cooling is, instead, deeply influenced), which translates in net savings when lighting or/and appliances consumptions are reduced.
This effect is lowered in winter, because the heating plant need to substitute to those heat sources.
Taking into account primary energy balance, the efficiency of heating provided by thermal plant is higher than those provided by internal appliances.

Overall conclusions

This case study present a 1970's office building with a glazed facade and totally refurbished HVAC system.

1. **Night time free cooling could provide medium energy savings (5-10%), but it is difficult to implement**

2. **High performance and cost mixed HVAC system, with absorption unit, could consume as a standard one if the operation strategy is not adequate**

3. **Substitution of windows with low permeability and U-value ones should be adequately considered in respect of cooling loads raising**

4. **Absorption chiller installation with CHP system has to be evaluated really carefully, paying attention to load profiles of the building, and to costs/benefits of producing and selling electrical energy**

5. **"Over cooling" of some zone should be reduced, in order to increase the comfort and decrease the consumption**

6. **Occupants' education should save energy around 5 %, almost costless.**

HARMONAC

IT Case Study 2:
Office and Laboratories – Air and Water system

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DENER, Politecnico di Torino
IT

August 2010

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CASE STUDY: Environment park, Office/Lab building with centralized Air and Water system

This case studies is composed of a variety of sub-buildings hosting laboratories, offices and a conference centre. The ma hot and chilled water distribution network serves all the buildings, while the secondary systems are different: typically all-air for the laboratories and conference rooms, and air-and-water with fan coils, radiant ceilings, or chilled beams for the offices. As a whole, 19 AHU's are present.
The central plant includes three hot water boilers, each rated at 800 kW, two of which running on biomass (wood chips) and one on natural gas.
The cold generators are one Carrier 30HXC 250 (screw) and two absorption Carrier 16JB-018 units.

Building Description

Country & City	Italy, Turin
Building Sector /Main Activity	Office/Laboratories
Net Area[m²]	6840

Installed Plant

Parameter	Installed electrical load / kW	Floor area served / m^2 GIA	Installed capacity W/m^2 GIA	Annual consumption kWh	Average annual power W/m^2	Annual use kWh/m^2	Average annual power (% FLE)
Total Chillers nominal cooling capacity (cooling output)	630.0	4'840.0	130.2				
Total Chillers	100.0	4'840.0	20.7	66'400.0	1.6	13.7	7.6
Total CW pumps[a]	82.0	4'840.0	16.9		-	-	-
Total fans			-		-	-	-
Total humidifiers			-		-	-	-
Total boilers	4.9	6'440.0	0.8	-	-	-	-
Total HW pumps	57.9	6'440.0	9.0	113'200.0	2.0	17.6	22.3
Total HVAC electrical	246.8	6'440.0	38.3		-	-	-
Total Building Elec kWh		6'440.0		1'260'700.0	22.3	195.8	
Total Boilers/Heat kWh		6'440.0	-		-	-	-
Total Building Gas/Heat kWh		6'440.0			-	-	

Energy savings

ECO CODE	DESCRIPTION	ACTION	Saving
O1.2	Hire or appoint an energy manager		-12% on total electric consumption
P2.12	Consider the possibility of using waste heat for absorption system		see paragraph below
E2.6	Apply night time over ventilation		-2.5% on cooling station electric consumption (Summer season)

Overview of building and system

The Environment Park (also called EnviPark) was established in 1996 on a dismissed industrial site in Torino. At present the building is occupied by various private companies and public agencies which are related with environmental research and consulting at different levels. EnviPark is composed of a variety of sub-buildings hosting laboratories, offices and a conference centre.

HVAC system

Different centralized HVAC systems are present, typically all-air for the laboratories and conference rooms, and air-and-water with fan coils, radiant ceilings, or chilled beams for the offices. As a whole, 19 AHU's are present.

The central plant includes three hot water boilers, each rated at 800 kW, two of which running on biomass (wood chips) and one on natural gas.

The cold generators for the system are one Carrier 30HXC 250 (screw) rated at 850 kW cooling capacity, with a maximum electrical consumption of 193 kW, and two absorption Carrier 16JB-018 units, rated at 612 kW cooling each, with a maximum electrical power of 4.1 kW each.
Water is distributed by a primary (22 pumps, 178 kW total) / secondary (31 pumps, 30 kW total) circuit. River water is circulated with 3 pumps (37 kW each) for condenser heat rejection and free cooling.

Since mid 2009 an electrical generator coupled to a Pelton turbine is operative.

Metering

The building has a power metering system (Electrex 3X-box) connected to the river pumps, but it is not working properly due to factory configuration. In June 2008, a METREL MI 2019 power analyzer was installed in the cooling station main electric panel in the framework of Harmonac project. The metering currently available is:

- Main electrical incomer
- River water pump
- Cooling station load (aggregate of chillers and pumps)

The HVAC system has a Johnson Controls BMS. This enables data to be stored on the outstations for items such as external temperature, internal temperature, water temperature, etc. These data have been collected since October 2008.

Summary of building and systems

The following table summarises the main aspects of the building (based on EPA-NR and Harmonac inspection procedures):

Building Description

Building Sector /Main Activity	Office / Laboratories
Net Area[m²]	16000
Max number Occupants	450
N° Zones	4

Zone Description

Zone ID	Activity Type	Net Area	N° Occupants
1	Laboratories / Offices (A1)	5'851	90
2	Laboratories / Offices (A2)	7'132	135
3	Laboratories / Offices (B1)	5'115	90
4	Laboratories / Offices (B2)	6'071	135

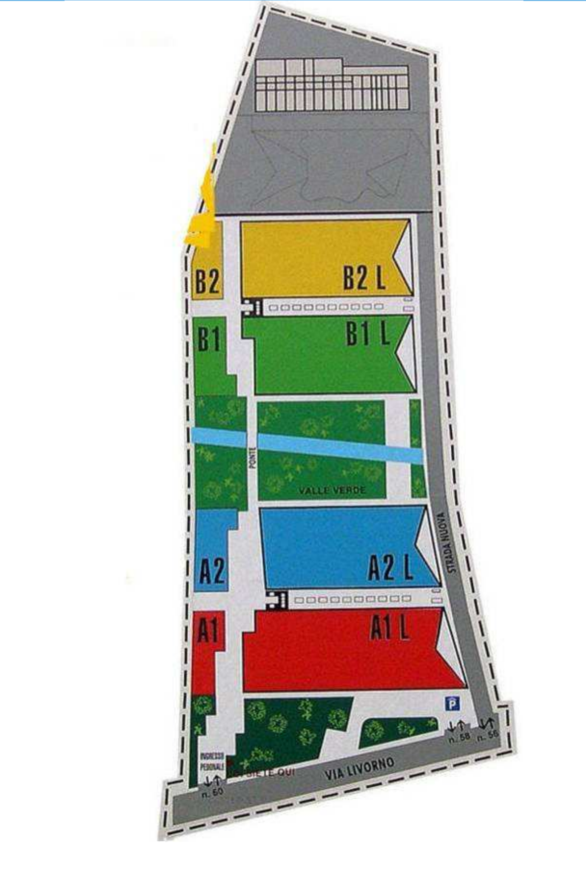
Heating/Cooling Production		**Normalised/m² GIA**	**Notes**
Conditioned net Area	**24'000** [m²]		
Chillers nominal cooling capacity	**2'050** [kW]	**85.4** [W/m²]	850 el.; 1200 ads
Chillers nominal electrical demand	**193** [kW]	**8.0** [W/m²]	
Chillers chilled water circulation pumps nominal electric demand	**27** [kW]	**1.1** [W/m²]	3x4kW adsorb. unit pumps + 2x7.5 kW el. chiller pumps
Electric chiller condensing water pumps	**55.5** [kW]	**2.3** [W/m²]	3x18.5kW
Primary chilled water circulation pumps nominal electric demand	**45** [kW]	**1.9** [W/m²]	3x15kW
River water pumps	**111** [kW]	**4.6** [W/m²]	3x37kW
Chilled beams water circulation pumps nominal electric demand A1	**5.3** [kW]	**0.9** [W/m²] A1	2X2.2 (hot/cool water) 2x0.45 cool water
Chilled beams water circulation pumps nominal electric demand A2	**5.1** [kW]	**0.8** [W/m²] A2	2X2.2 (hot/cool water)

			2x0.35 cool water
Chilled beams water circulation pumps nominal electric demand B1	**4.4** [kW]	**0.8** [W/m²] B1	2X1.1 (hot/cool water) 2x1.1 cool water
Chilled beams water circulation pumps nominal electric demand B2	**1.6** [kW]	**0.2** [W/m²] B2	2X0.45(hot/cool water) 2x0.35 cool water. This area is partially heated and cooled by all air system
COP of electric chiller	**4.59**		nominal
COP of adsorption chillers	**0.7**		nominal
Operation Hours	**1'602**		Jul-Oct 2009
Conditioned net Area	**24'000** [m²]		**1-4**
Boilers nominal heating capacity	**2'400** [kW]	**100.0** w/ m²²	800 kW natural gas boiler; 2x800 kW wood chips boilers
Boilers hot water circulation pumps nominal electrical demand	**48.8** [kW]	**2.0** w/ m²	7.5 primary circuit; 41.3 secondary circuit
Nominal Efficiency	**75**[%]		wood chips boiler
Nominal Efficiency	**92**[%]		gas boiler
Operation Hours	**8'000**		one wood chips boiler is on for almost the whole year. The second wood chips boiler is turned on just for winter season, while the gas boiler is fired rarely, to deliver thermal energy on peak demand

Measured annual performance

		Normalised/ m^2 GIA	Notes
Total Building Electrical Consumption	**4'129.9** [MWh]	**171.7** kWh/m^2	
HVAC Equipment	**273.8** [MWh]	**11.4** kWh/m^2	El. chiller + ads. chillers + primary pumps
Wood chips consumption	**1'952** [tons]	**81.3** kg/m^2	Wood chips has an average humidity of 42%
Wood chips consumption	**3'904** [MWh]	**162.7** kWh/m^2	
Total Building Gas Consumption	**1'469** [MWh]	**61.2** kWh/m^2	
Total Building Water Consumption	**26'727** [m^3]	**1'113** l/m^2	
HVACs' system components			
Heating Boilers	**2'400** [kW]	**100.0** W/ m^{22}	? % of Full Load Equivalent (FLE) and zone served
Main boilers Hot Water and chiller water circulation pumps	**105.2** [MWh]	**4.4** kWh/m^2	
Electric Chiller	**171.5** [MWh]	**7.1** kWh/m^2	

Case study details - Building Description



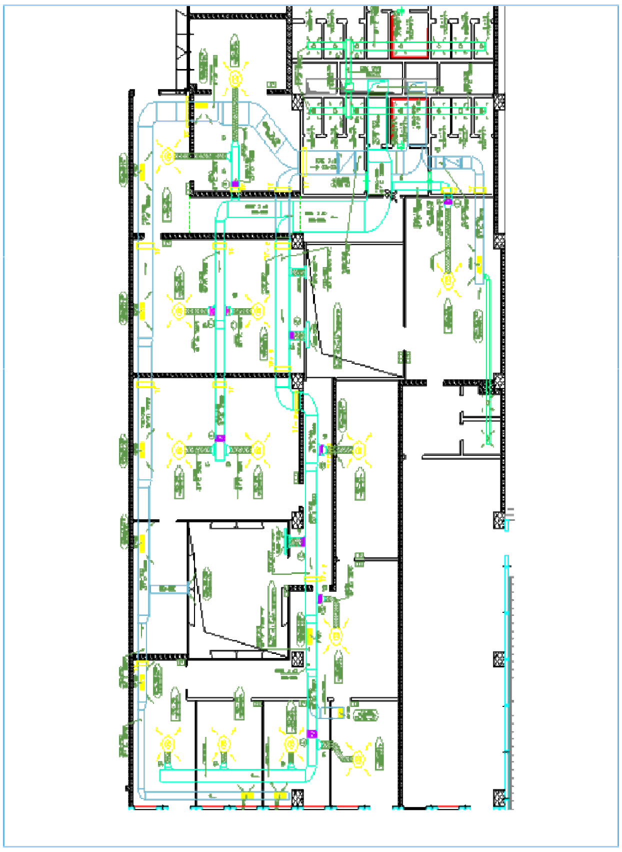
General building data	
Country/City	Italy – Turin
Latitude/Longitude[°]	45°4'41''16 N-07°40'33''96 E
Elevation [m]	240
Cooling Degree Days	2617
Building Sector/Main Activity	Tertiary/Offices-Laboratories
Total net floor area [m²]	24000
Ceiling height [m²]	3
Number of floors	2

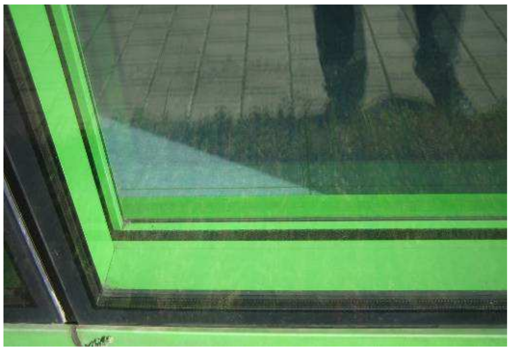
Case study details - Constructions details

Small descriptions of the building construction type - envelope include the foundation, roof, walls, and windows.

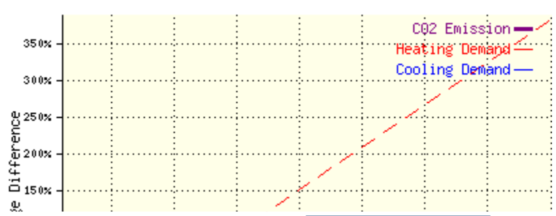
Envelope – Heat Transfer Coefficient [W/m².K]	
External wall (predominant)	0.75
Floor (predominant)	0.5
Intermediated floor (predominant)	1.4
Roof (predominant)	0.6

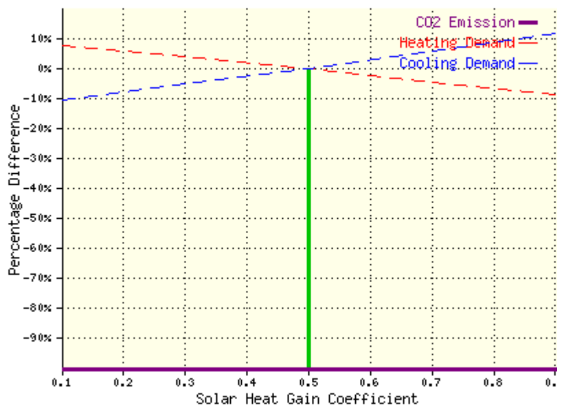
Windows	
U- value (predominant) [W/m².K]	2.4
Window type	double
Window gas	air
Solar Factor	0.5
Solar Protection Devices	
Window Overhangs	**no**
Shading Device	**venetians**





Details of ventilated facade






Details of venetian blinds

Internal gains and operation schedules per zone

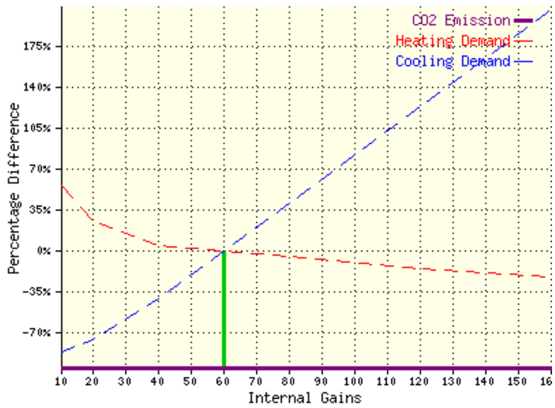
Zone ID:	**All**
Activity type	**Office/Labs**

Equipment electric loads/Schedules	**Design**	**Measure/observe - Winter/Summer (average)**
Office equipment [W/m²]	20	22
Working schedule	9:00-17:00	9:00-18:00
Permanent/variable occupancy	450	n.a.
Cleaning staff schedule	-	-
Lighting [W/m²]	20	21
Type of lighting	fluorescent tubes	fluorescent tubes
Lighting control	manual	manual
Lighting schedule	seasonal	seasonal

Some parts of the buildings are lighted by solar tubes, as shown in the figures.

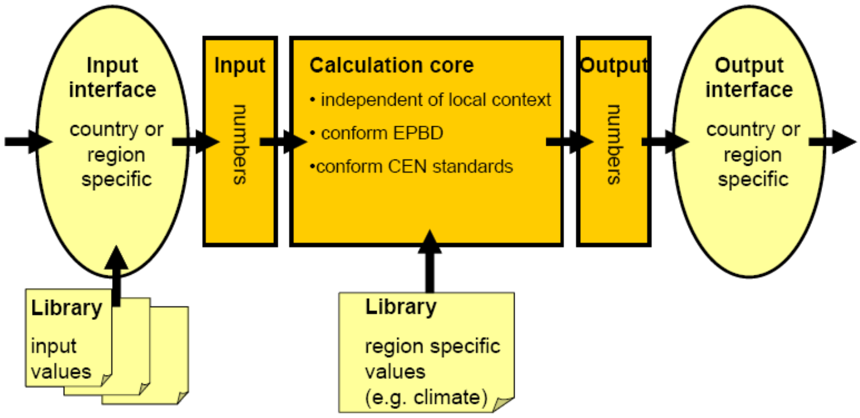

Details of solar tubes, external devices


Details of skilights and solar tubes

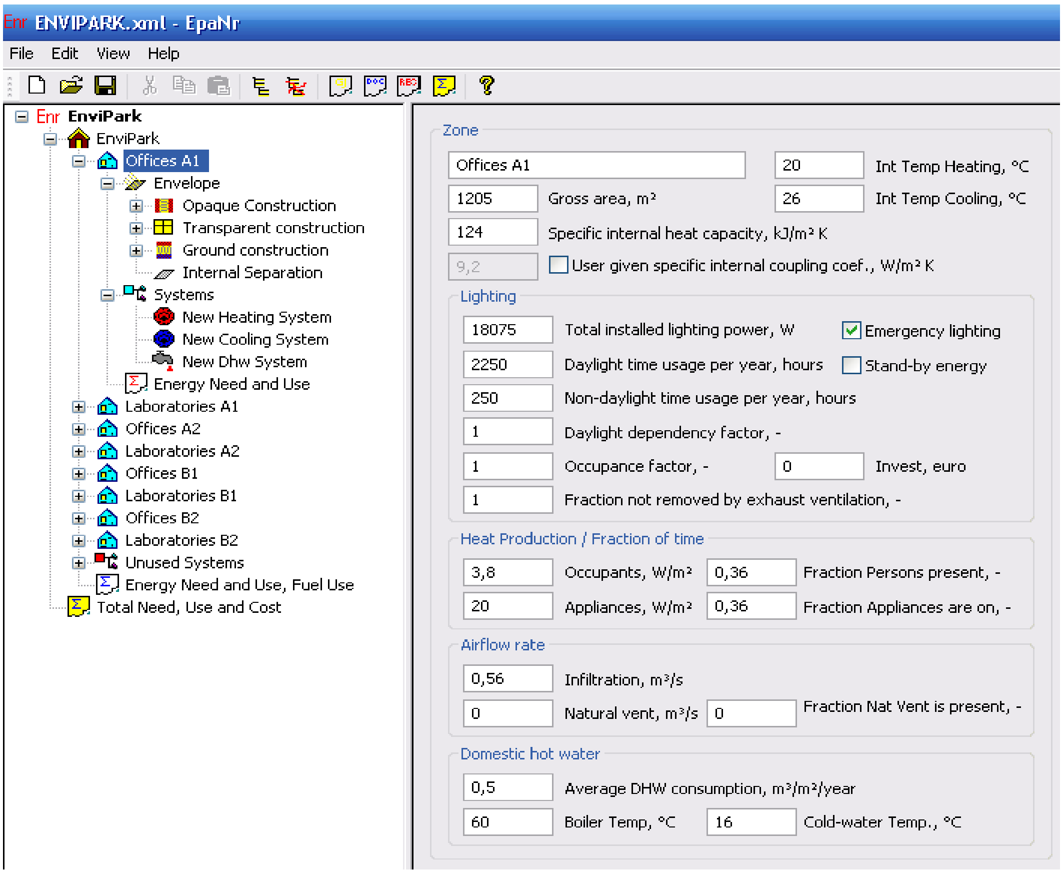


Simulation of energy consumption for the building

The present case study, due to the presence of multiple buildings, did not permit the utilization of Simaudit/Benchmark. For this reason the EPA-NR software was used. This software was developed by the EPA-NR ("Energy Performace Assesment of Existing Non-Residential Buildings") project, which was developed in 2004-2007 (EC contract: EIE/04/125/S07.38651) and produced a complete tool to asses energy consumption. This tool permits the presence of multiple buildings and zones. The limitation of the tools is that its "engine" is static; this implies that cooling energy consumption estimation may not be accurate enough, and that the output is on a monthly basis.

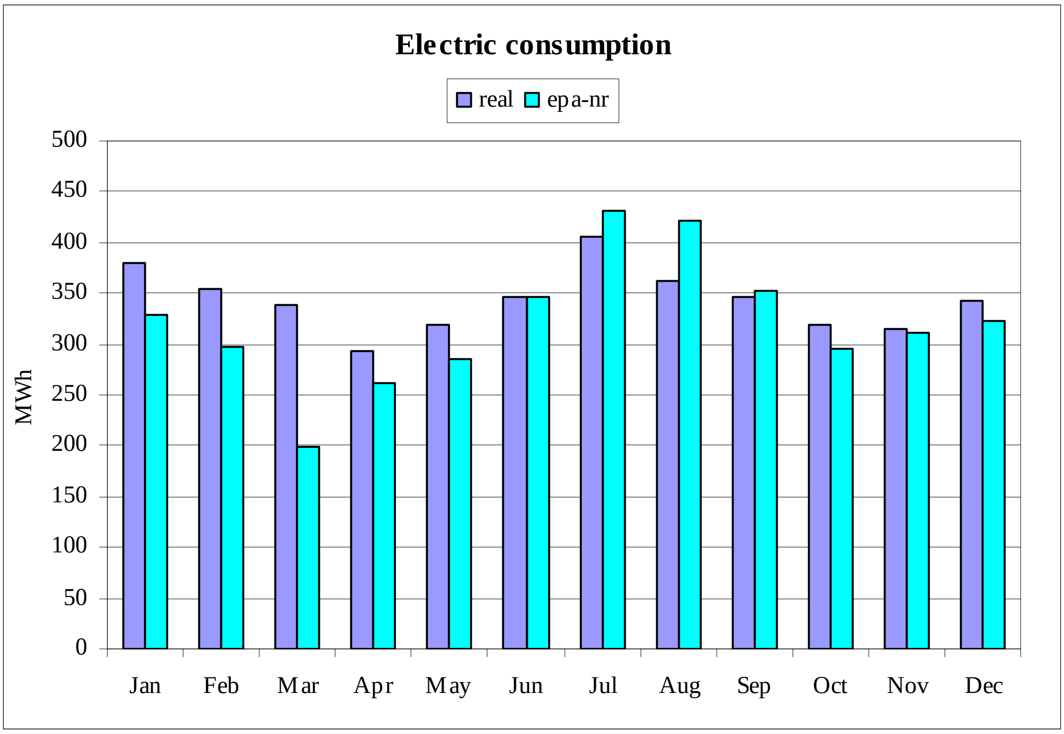


View of the data flow of EPA-NR software

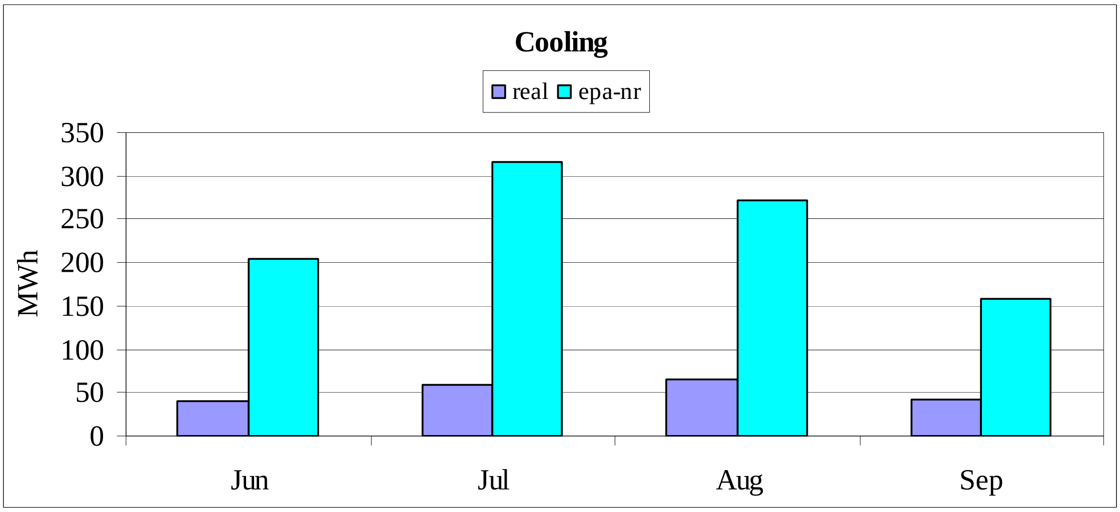


View of the case study model on EPA-NR software, on the left side are shown the different zones

The simulation was run for the 4 different buildings considered in this case study. As seen in the graph below, the results quality was different, depending on the parameter analyzed. In the EPA-NR software it is not possible to simulate the absorption chillers: for this reason an equivalent electric chiller was inserted in the simulation. The simulated consumption for cooling production is not comparable with real consumption, because the system is different. It is useful to simulate the electric consumption of a theoretical chiller to measure the consumption avoided by absorption chillers.



Graph of electric consumption of the whole building. The simulation overestimates the summer consumption. This is due to the hypothesis of electric chiller.



Graph of electric consumption for cooling production. In this case the simulated values represent the consumption, assuming that cooling was provided by electric chillers only.

Environment parameters

Description of the environment design conditions, Heating/cooling loads, design temperatures (from UNI EN 10349).

Outdoor Environment Parameters	**Design**	**Measure/observe - Winter/Summer (average)**
Outdoor air temperature [°C] Winter/Summer	**mean 0.4/23.3**	**min -3 / max 36.4 avg: 6.1/ 25.3**
Outdoor Relative Humidity [%] Winter/Summer	**85% / 46%**	**77%/ 61.6%**
Max. Solar Radiation [W/m²]		**max 1119 (10.06.2008) avg : 63.6 / 203.1 (on 24h)**

Zone ID:	**1-4**
Activity type	**Office/Laboratories**

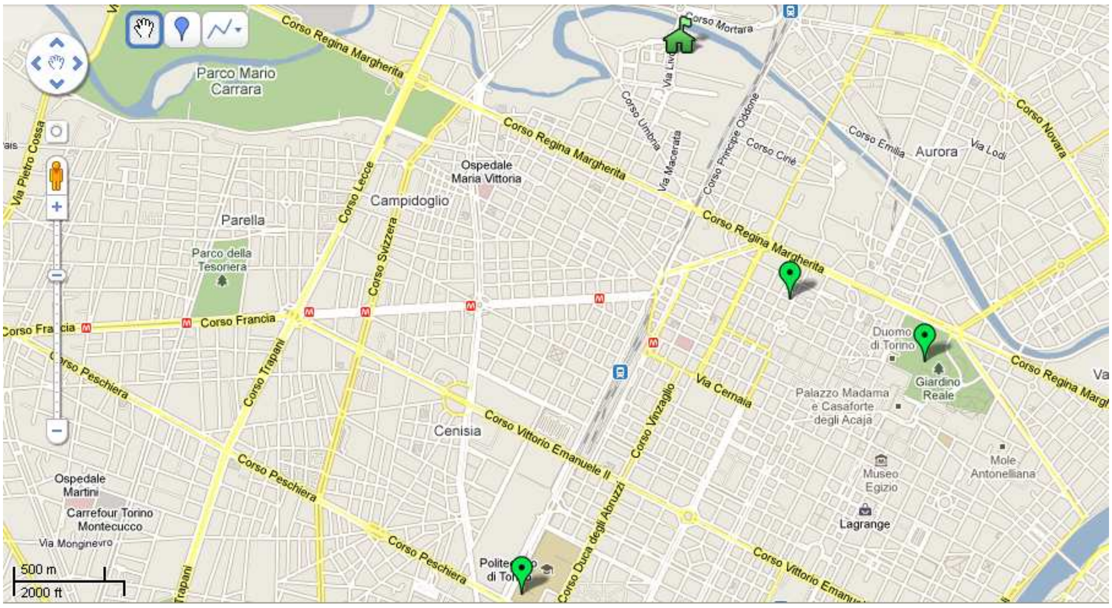
Indoor Environment Parameters per zone	**Design**	**Measure/observe - Winter/Summer (average)**
Ventilation Rate [ach]	**0.5**	
CO_2 threshold / CO_2 measured [ppm]		
Indoor Relative Humidity [%]	**50%**	
Indoor air Temperature [°C] – Winter/Summer (state whether air temperature or operative temperature)	**air temperature 20/25**	**21.5/24.5**

Monitoring observations for environmental parameters

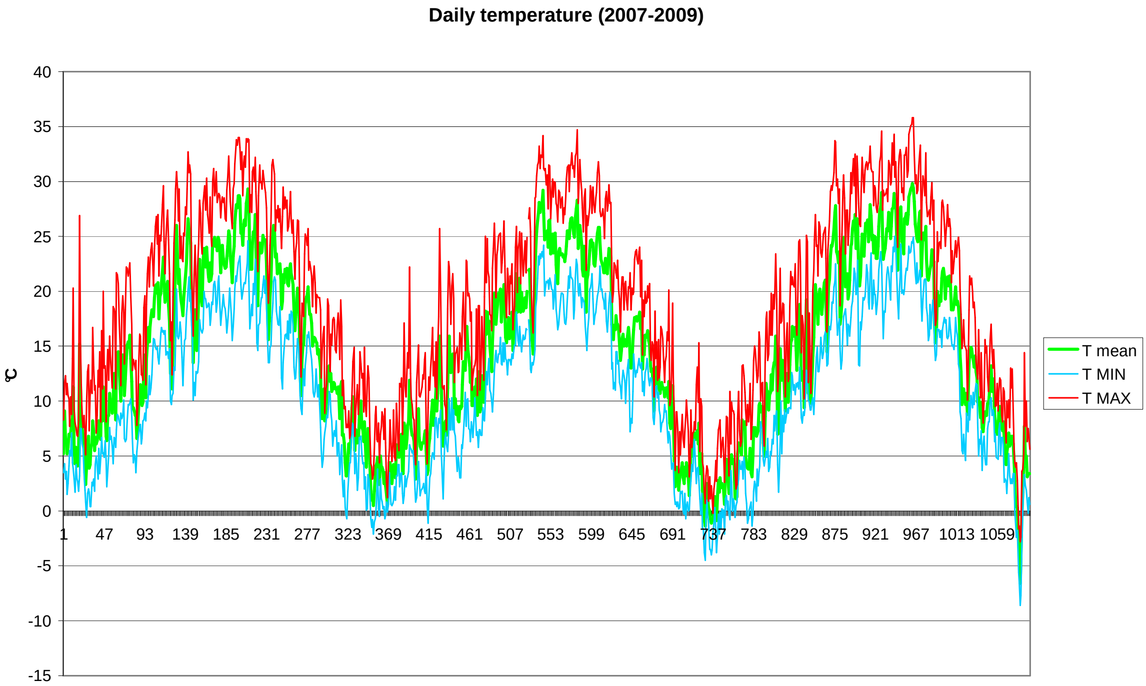
The meteo data for Torino was provided by two different sources:

1. meteo data provided by NEMEST project (station installed on Politecnico di Torino)
2. meteo data provided by ARPA Piemonte, the regional environmental protection agency

For the consumption and statistical analysis ARPA data were used. These data, in fact, showed statistical robustness, provided by 2 meteo station in a 4 km radius from the case study location.



The green house represents Environment park, while the three green pointers represent the 3 meteo station (the two station closer to the building are ARPA stations, while the other one is the Nemest).



Carpet plots of external temperature are provided for different years (2008, 2009). Air enthalpy was calculated with the formula below (Ashrae 2009, Fundamentals) from external temperature, relative humidity and air pressure:

$$h = 1.006t + W(2501 + 1.86t)$$

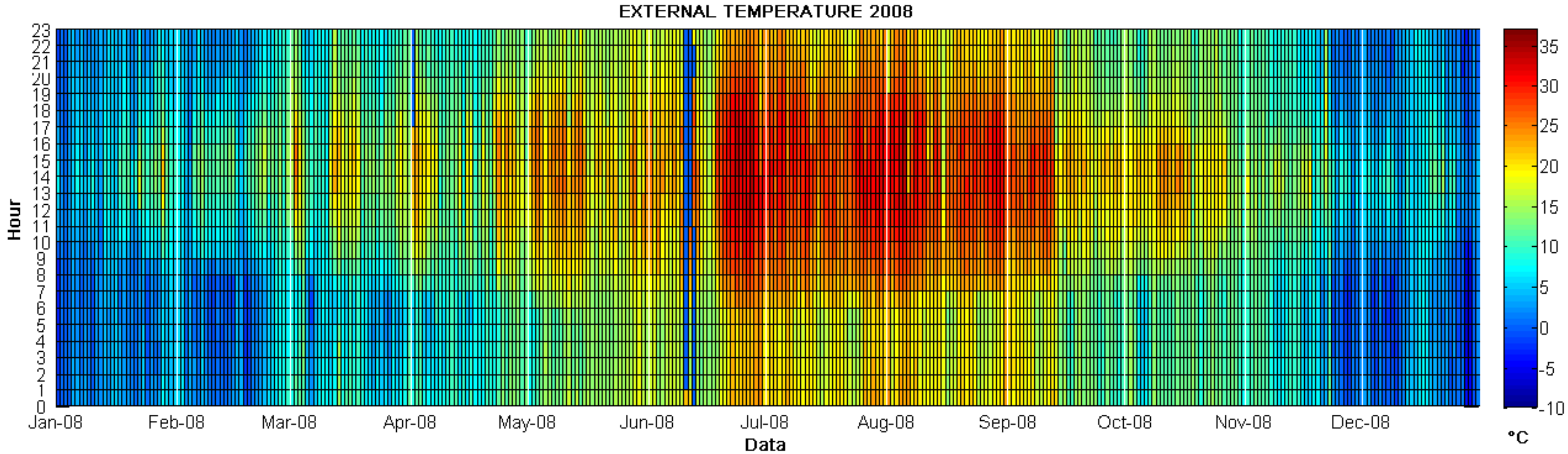
$$W = 0.621945 \frac{p_w}{p - p_w}$$

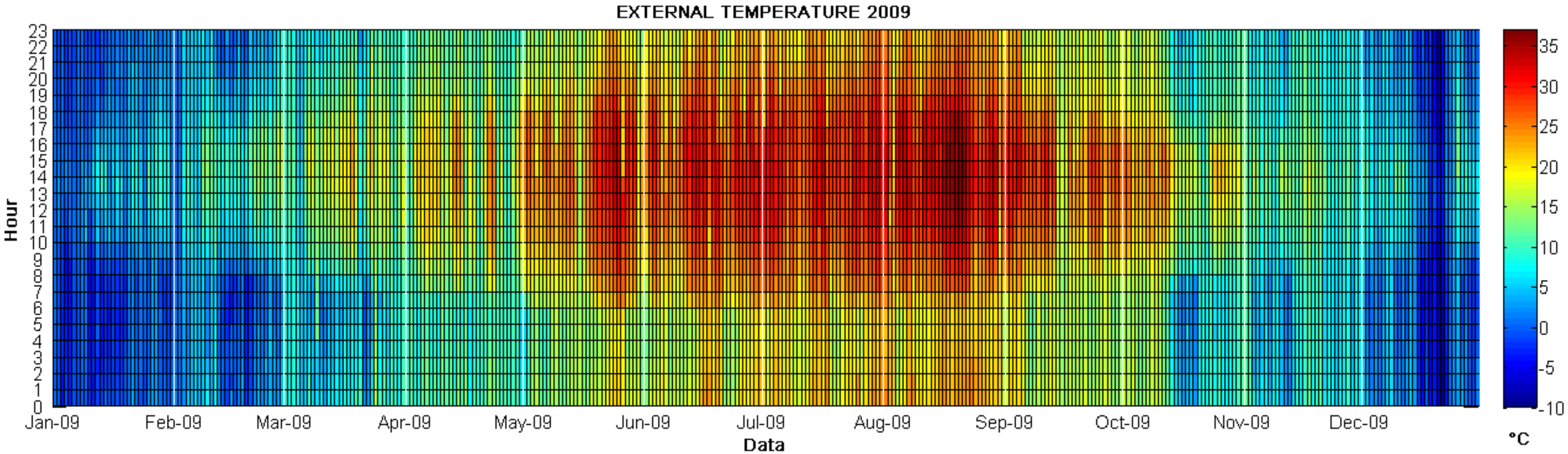
$$p_w = RH \cdot p_{ws}$$

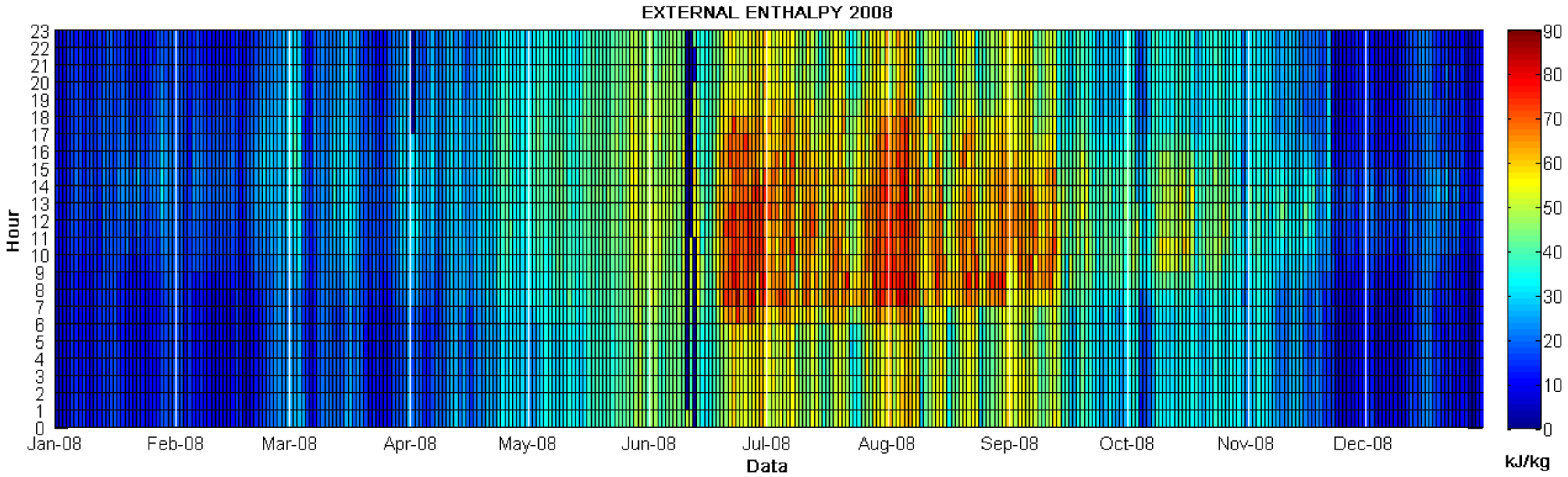
$$\ln(p_{ws}) = \frac{C8}{T} + C9 + C10T + C11T^2 + C12T^3 + C13 \ln T$$

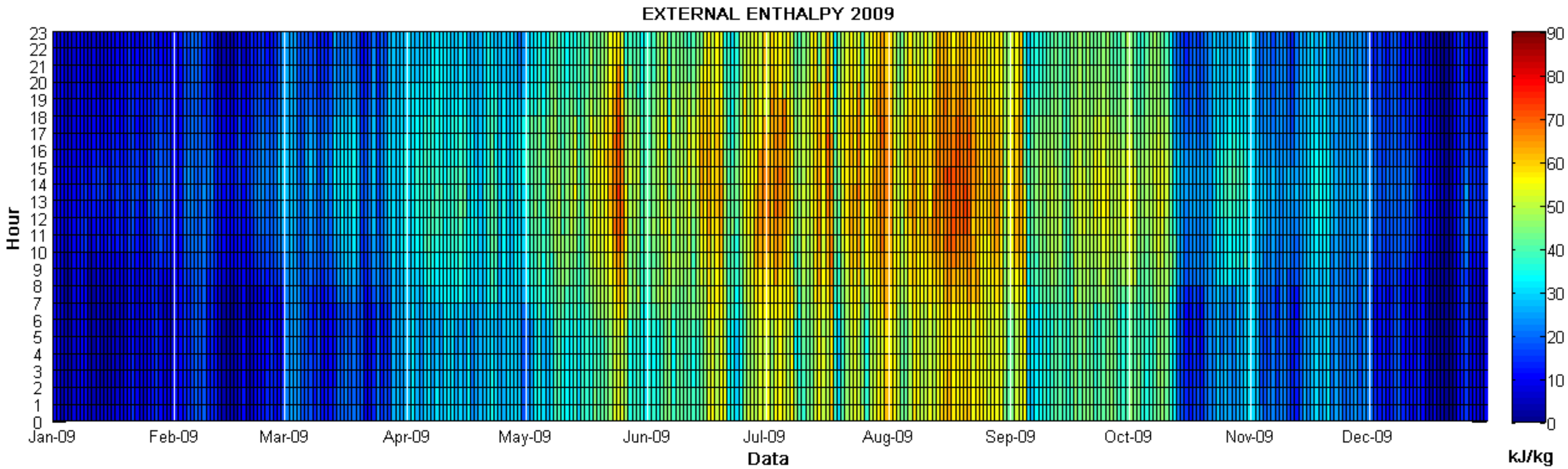
With:

h	=	air enthalpy
t	=	ait temperature (°C)
Pw	=	vapour pressure
Pws	=	saturated vapour pressure
RH	=	relative humidity
C9-C13	=	constants

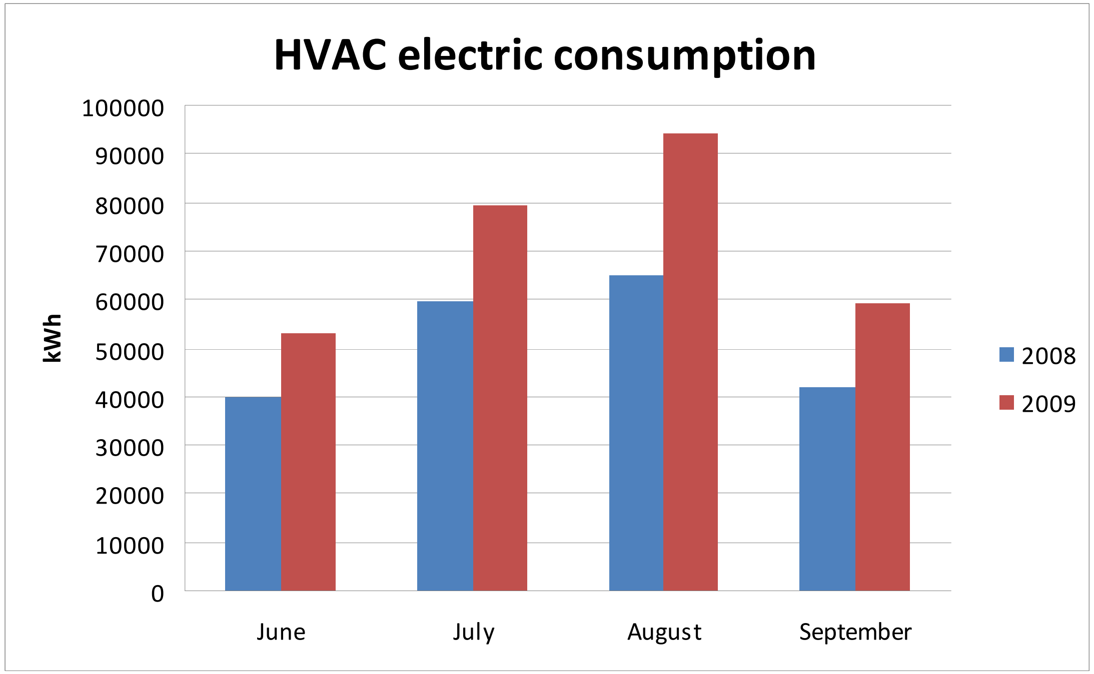

EXTERNAL TEMPERATURE 2008
Hour
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Data
35
30
25
20
15
10
5
0
-5
-10
°C


EXTERNAL TEMPERATURE 2009
Hour
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
Data
35
30
25
20
15
10
5
0
-5
-10
°C


EXTERNAL ENTHALPY 2008
Hour
Data
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
kJ/kg


EXTERNAL ENTHALPY 2009
Hour
Data
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
kJ/kg

As seen in the graphs, 2009 season was characterized by external air temperature higher that 2008 season. This implies, on a first analysis, an higher load for the cooling system. Nevertheless is interesting that air enthalpy on 2009 season is lower than in 2008 season.
The system analyzed provides mechanical ventilation, 2009 season needed more cooling load than 2008. This difference was due to external conditions, but also to some changes on system efficiency(explained in the **Energy consumption data** section).



HVAC system components

Different centralized HVAC systems are present, typically all-air for the laboratories and conference rooms, and air-and-water with fan coils, radiant ceilings, or chilled beams for the offices. As a whole, 19 AHU's are present.

The central plant includes three hot water boilers, each rated at 800 kW, two of which running on biomass (wood chips) and one on natural gas.

The cold generators for the system are one Carrier 30HXC 250 (screw) rated at 850 kW cooling capacity, with a maximum electrical consumption of 193 kW, and two absorption Carrier 16JB-018 units, rated at 612 kW cooling each, with a maximum electrical power of 4.1 kW each.
Water is distributed by a primary (22 pumps, 178 kW total) / secondary (31 pumps, 30 kW total) circuit. River water is circulated with 3 pumps (37 kW each) for condenser heat rejection and free cooling.

The Case Study considers each of the components of the system individually in the following order and which of the zones are served with each system:

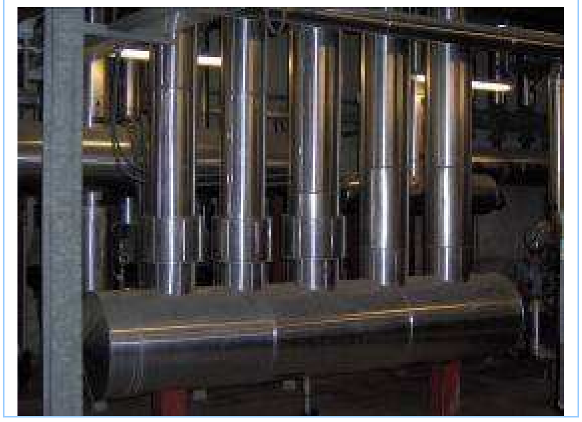
- Electric chiller
- Absorption chiller
- Pumps and fan

Audit-case study

Cold Generator

Chiller Identification	
Manufacture/Model	Carrier 30HXC 250
Year	1998
System Type	Vapour compression
Compressor Type	Screw
Fuel Type	El.
Performance Data	
Nominal Cooling Capacity [kW]	850
Installed Cooling Capacity /m² GIA	
Nominal Electric Power [kW]	193
COP	4.4
SEER	
Refrigerant Gas	R1134a
Electrical data	
Power supply [V/Ph/Hz]	400/3/50
Start-up amps [A]	300 (Y)

Auxiliary Equipment	
Fan Electrical Demand [kW]	N.A.
Pumps Electric Demand [kW]	7.5



Monitoring observations

Inspection	
Maintenance status	Satisfactory
Previous inspection/maintenance Reports	Yes Data of last:2009
Operation time estimated [h]	
Operating mode	automatic
Thermal Insulation (Visual)	Satisfactory
Vibration eliminators	Satisfactory
Worn couplings	Satisfactory
Equipment cleanliness	Satisfactory
Compressor oil level	Satisfactory
Compressor oil pressure	Satisfactory
Refrigerant temperature	Satisfactory
Refrigerant pressure	Satisfactory
Chilled water systems leaks	No
Sensors calibration records	No
Refrigerant leaks	No
Location of the equipment	Indoor

Field measurements	
Electricity consumption [kWh]	50991 from 01 to 31 July 2008 56123 from 01 to 31 August 2008 33154 from 01 to 30 September 2008
Electric voltage [V]	380 V, anomalies on single phases <2% in the 95% of data

Cold Generator

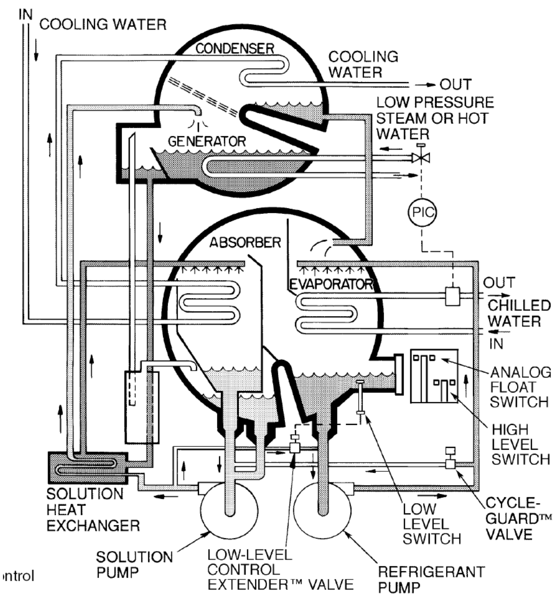
Chiller Identification	
Manufacture/Model	Carrier 16JB-018
Year	1998
System Type	adsorbtion chiller
Refrigerant	Water
Solution	LiBr
Performance Data	
Nominal Cooling Capacity [kW]	612
Installed Cooling Capacity /m² GIA	
Nominal Electric Power [kW]	4.1
COP/EER (Eurovent)	
SEER	
Refrigerant Gas	
Electrical data	
Power supply [V/Ph/Hz]	
Start-up amps [A]	

Auxiliary Equipment	
Fan Electrical Demand [kW]	
Pumps Electric Demand [kW]	
Other	

Monitoring observations

Inspection	
Maintenance status	Satisfactory
Previous inspection/maintenance Reports	Yes Data of last:2009
Operation time estimated [h]	
Operating mode	
Thermal Insulation (Visual)	Satisfactory
Vibration eliminators	Satisfactory
Worn couplings	Satisfactory
Equipment cleanliness	Satisfactory
Compressor oil level	N.A.
Compressor oil pressure	N.A.
Refrigerant temperature	N.A.
Refrigerant pressure	N.A.
Chilled water systems leaks	No
Sensors calibration records	No
Refrigerant leaks	No
Location of the equipment	Indoor

Field measurements	
Electricity consumption [kWh]	
Electric voltage [V]	
Electric current [A]	



Pumps and Fan list

Elem.	Sett.	Utenza	N_{elem}	$P_{inst\_N=1}$ [kW]	P_{tot} [kW]	N_{cont}	P_{cont} [kW]	$Q_{N=1}$ (mc/h)	$H_{N=1}$ (m)
EP	CT	Wood heat generator primary circuit	3	0,75	2,25	2	1,5	40,5	3,6
EP	CT	Gas heat generator primary circuit	2	0,75	1,5	1	0,75	40,5	3,6
EP	CT	Heat exchangers, absorption hot water primary circuit	2	7,5	15	1	7,5	196	9,0
EP	CT	Domesti hot water	2	15	30	1	15	150	21,4
EP	CT	Absorption cool water primary circuit	3	4	12	2	8	92	7,9
EP	CT	Electric chiller cool water primary circuit	2	7,5	15	1	7,5	146	10,3
EP	CT	Cool water primary circuit (to the buildings part)	3	15	45	2	30	150	21,4
EP	CT	Cooling generators Condenser circuit	3	18,5	55,5	2	37	196	23
EP	CT	Plant load	2	1,1	2,2	1	1,1	5	60
EP	CAF	River pumps for free-cooling/condensing	2	37	74	1	37	176	43
EP	CAF	River pumps for free-cooling/condensing	1	37	37	1	37	176	43
EP	CAF	Alimentazione vasca di irrigazione	2	3	6	1	3	18	20
EP	A1	Cool water secondary circuit (to the chilled beams)	2	0,45	0,9	2	0,9	6,09	9,9
EP	A1	Cool/hot water secondary circuit (to the ch. beams)	2	2,2	4,4	2	4,4	8,95	13,8
EP	A1	Estrazione aria facciata blue building	1	0,18	0,18	1	0,18	3,64	7
VNT	A1	Espulsione aria livello autorimessa	1	3	3	1	3	7.400	
VNT	A1	UTA1_uffici livello 0-1	1	4	4	1	4	7.400	
CMP	A1	UTA1_uffici livello 0-1	1	5,5	5,5	1	5,5		
VNT	A1	UTA2 SCT laboratori	1	18,5	18,5	1	18,5	24.500	
VNT	A1	UTA3 SCT laboratori	1	15	15	1	15	22.100	
VNT	A1	UTA4 SCT laboratori	1	4	4	1	4	7.000	
VNT	A1	UTA5 SCT laboratori	1	5,5	5,5	1	5,5	8.000	
VNT	A1	UTA6 SCT laboratori	1	5,5	5,5	1	5,5	7.000	
VNT	A1	UTA7 SCT laboratori	1	11	11	1	11	16.500	
EP	A1	Ricircolo preriscaldo UTA6_7	1	0,18	0,18	1	0,18	2,8	7
EP	A1	Produzione ACS settore A1 lab.	1	0,06	0,06	1	0,06	2,5	3
EP	A2	Cool water secondary circuit (to the chilled beams)	2	2,2	4,4	2	4,4	5,63	14,4
EP	A2	Cool/hot water secondary circuit (to the ch. beams)	2	0,35	0,7	2	0,7	6,66	8,4
EP	A2	Acqua calda postriscaldo VAV	2	1,1	2,2	2	2,2	5,26	12,9
EP	A2	Presa immissione glicole	1	0,45	0,45	1	0,45	12,32	7
EP	A2	Produzione ACS settori A1-A2	1	0,06	0,06	1	0,06	2,5	3
VNT	A2	Estrazione uffici liv. 0-1-2	1	9,2	9,2	1	9,2	21.000	
VNT	A2	UTA8_uffici livello 0-1-2	1	18,5	18,5	1	18,5	26.400	
CMP	A2	UTA8_uffici livello 0-1-2	1	18,5	18,5	1	18,5		
VNT	A2	UTA13_SCT laboratori	1	3	3	1	3	4.500	
VNT	A2	UTA14_SCT laboratori	1	3	3	1	3	5.000	
EP	A2	Produzione ACS settore A2 lab.	1	0,06	0,06	1	0,06	2,5	3

EP	A2	Ricircolo preriscaldo UTA13_14	1	0,18	0,18	1	0,18	1,89	7
EP	B1	Cool water secondary circuit (to the chilled beams)	2	1,1	2,2	2	2,2	12,2	9,8
EP	B1	Cool/hot water secondary circuit (to the ch. beams)	2	1,1	2,2	2	2,2	15,34	10,7
EP	B1	Produzione ACS settori B1-B2	1	0,35	0,35	1	0,35	5,76	7
VNT	B1	Estrazione aria facciata blue building	1	4	4	1	4	11.350	
VNT	B1	UTA15_uffici liv. 0-1	1	7,5	7,5	1	7,5	11.500	
CMP	B1	UTA15_uffici liv. 0-1	1	18,5	18,5	1	18,5		
EP	B2	Cool water secondary circuit (to the chilled beams)	2	0,35	0,7	2	0,7	7,06	7,7
EP	B2	Cool/hot water secondary circuit (to the ch. beams)	2	0,45	0,9	2	0,9	8,8	8,8
EP	B2	Presa immissione glicole	1	0,18	0,18	1	0,18	3,7	7
VNT	B2	Estrazione aria facciata blue building	1	2,2	2,2	1	2,2	6.400	
VNT	B2	UTA22_uffici liv.0-1	1	4	4	1	4	6.800	
CMP	B2	UTA22_uffici liv.0-1	1	5,5	5,5	1	5,5		
VNT	B2	UTA23_SCT laboratori	1	15	15	1	15	19.000	
VNT	B2	UTA24_SCT laboratori	1	18,5	18,5	1	18,5	22.100	
VNT	B2	UTA25_SCT laboratori	1	5,5	5,5	1	5,5	8.500	
VNT	B2	UTA26_SCT laboratori	1	5,5	5,5	1	5,5	8.500	
VNT	B2	UTA27_SCT laboratori	1	4	4	1	4	7.000	
VNT	B2	UTA28_SCT laboratori	1	7,5	7,5	1	7,5	9.500	
EP	B2	Ricircolo preriscaldo UTA27_28	1	0,35	0,35	1	0,35	5,98	7
EP	B2	Produzione ACS settore B2 laboratori	1	0,06	0,06	1	0,06	2,5	3

Control systems

The control system is based on a Johnson Control® BEMS.
The high amount of low temperature surface water (from a river) permits a free-cooling strategy. This strategy is used with intermediate external temperature (generally below 22°C) in medium and summer seasons. When the external temperature increases over 24°C and the free-cooling is not sufficient to neutralize the cooling loads, the absorption chiller is turned on. The absorption chiller is fed with hot water by the wood chips boilers. For this reason a wood chips boiler is always on, also in the summer season.
The control strategy for chiller is based on return chilled water temperature, if this temperature increases more than the set point, then the other absorber is turned on. If the two absorption chillers are not sufficient then the electric chiller is turned on.

Energy consumption data

Metering information

This section shows how the metering was arranged in the Case Study. An electric power meter, with 15 minutes logging, was installed on the main electric panel of cooling station. It logged the consumption of the further equipments:

- primary fluid pumps (hot and cool water)
- absorption chillers
- electric chiller

The monitoring lasted more than one year, from June 2008 to October 2009.

The HVAC system manager changed the BEMS acquisition to provide useful data. The logging time was set to 15 minutes, the data acquired are listed below.

Internal rooms temperature

AHUs:

- status (ON/OFF)
- inlet air temperature
- outlet air temperature
- outlet relative humidity

Electric chiller:

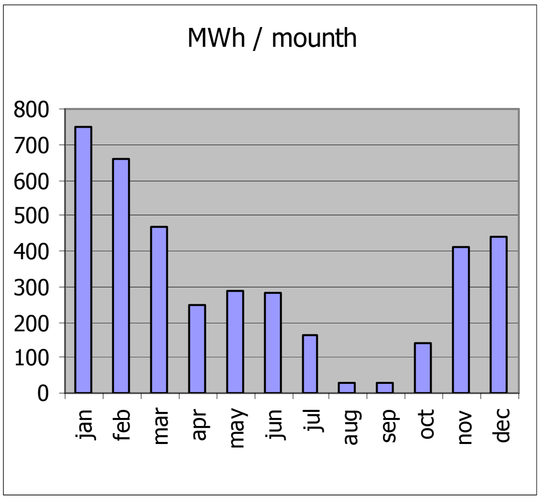
- compressor 1 status(ON/OFF)
- compressor 2 status(ON/OFF)
- compressor 3 status(ON/OFF)
- condenser inlet water temperature
- condenser outlet water temperature
- evaporator inlet water temperature
- evaporator outlet water temperature

Absorptipon chillers:

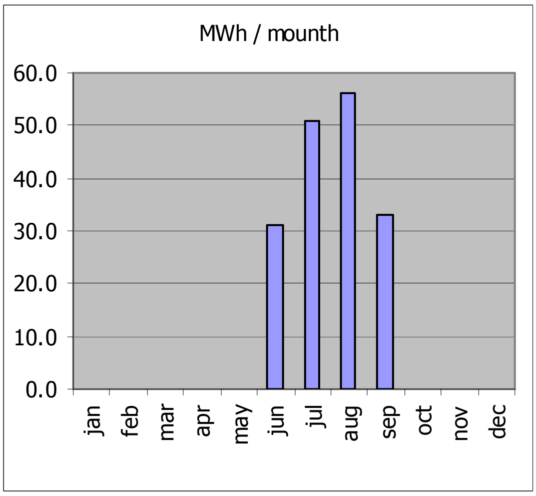
- chiller 1 status(ON/OFF)
- chiller 2 status(ON/OFF)
- condenser inlet water temperature
- condenser outlet water temperature
- evaporator inlet water temperature
- evaporator outlet water temperature

Monitoring observations

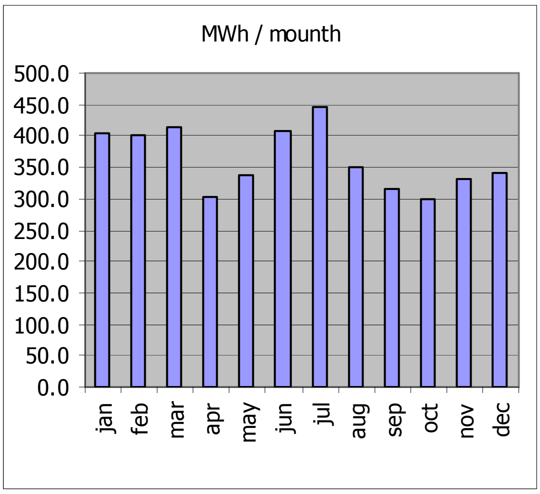
Heating [MWh]



Cooling el. consumtption [MWh]



Electricity [kWh/year]



Water [m³/year]

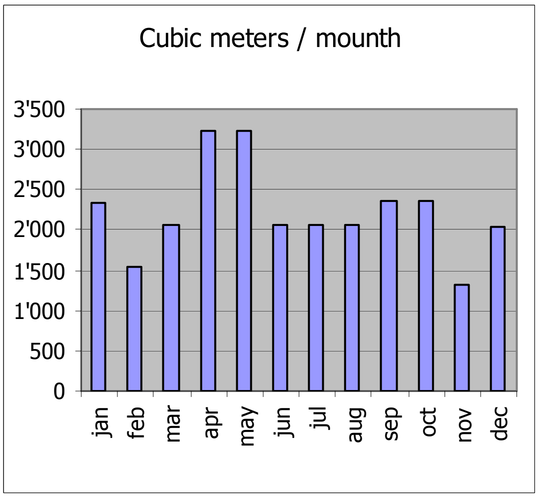
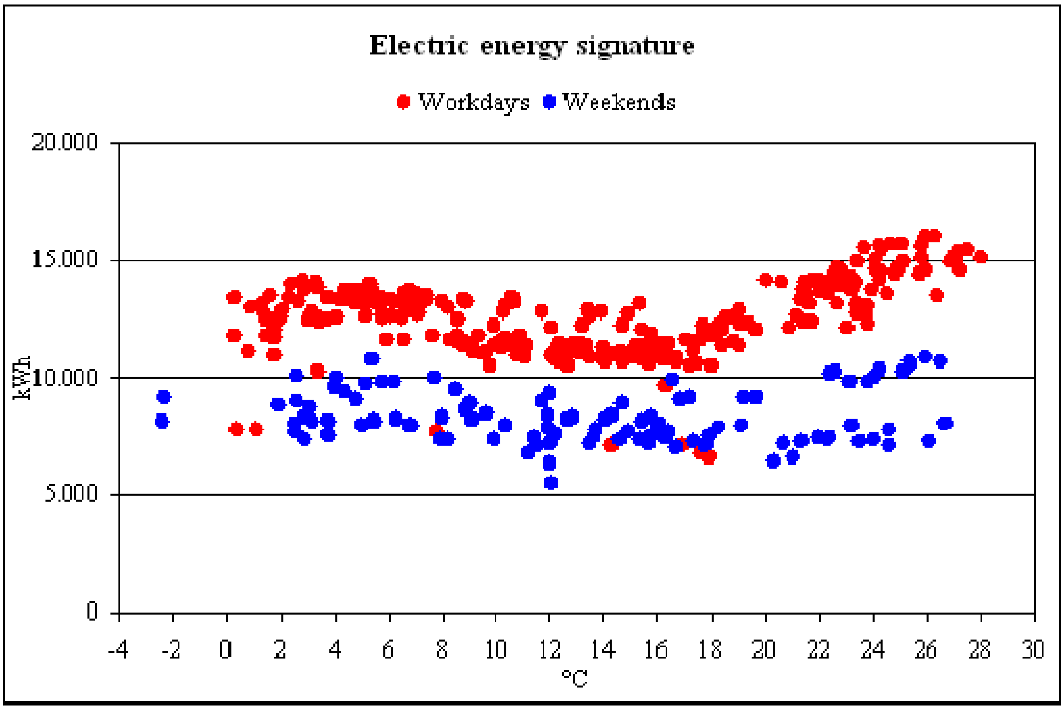
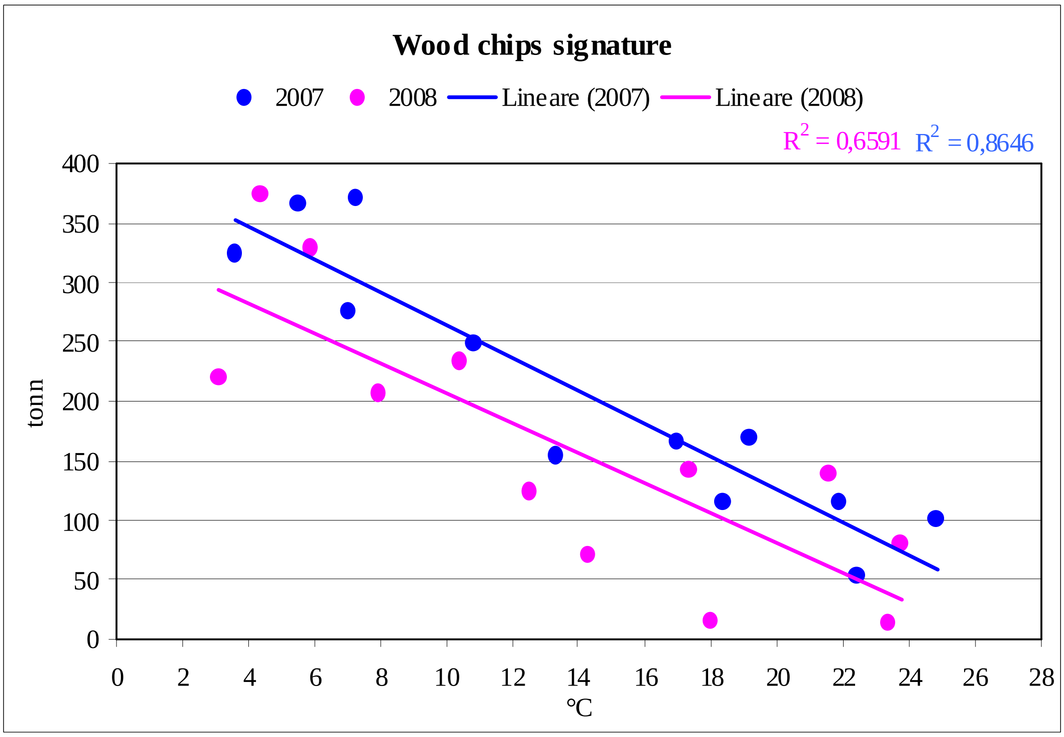


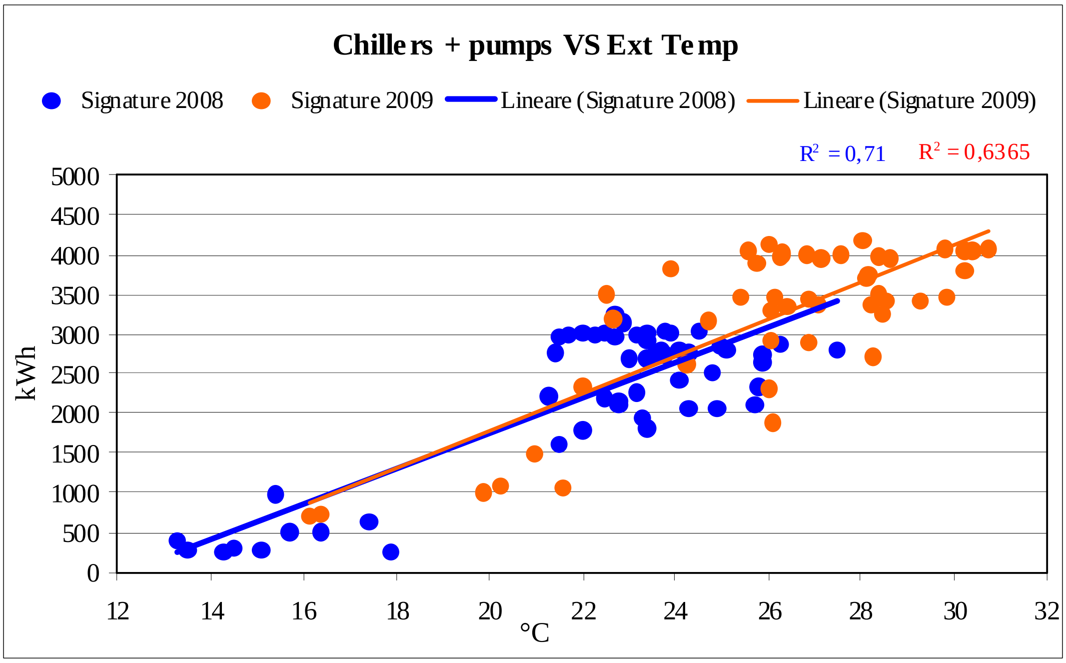
Fig: Summary of heating, cooling, electricity, gas and water consumption per month over the measurement period.

Energy Signature on overall electricity consumption shows a general lowering of consumption during weekend. Some exceptions are represented by Saturdays, which is a partial occupation day.
The workday mean consumption shows increasing values for high external temperature, and also for temperature below 8 °C. This should be explained with the relative rise of electrical lighting consumption in cold months.
The carpet plots below show in detail this behaviour.

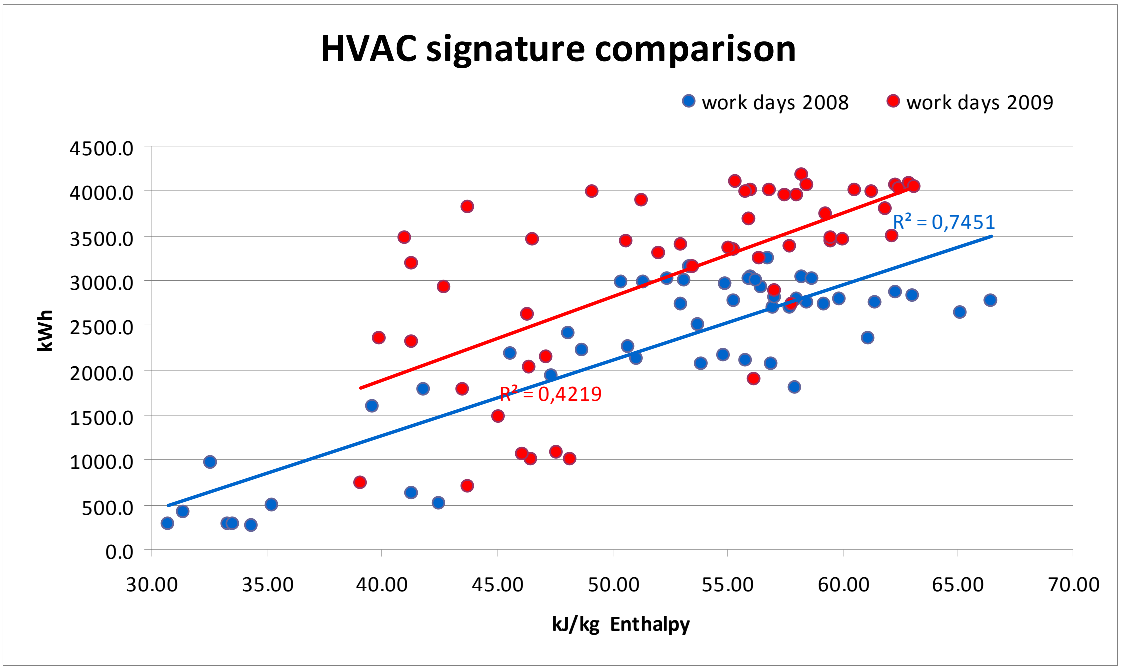


The thermal energy signature refers to wood chips consumption. Wood chips loads are delivered almost each day and registered. The data below refers to the deliveries. A large buffer of about 150 m^3 is used. To minimize the influence of the buffer on data analysis, monthly data were analyzed. As seen below it appears that the system consumption in 2008 lowered in respect to 2007 values.

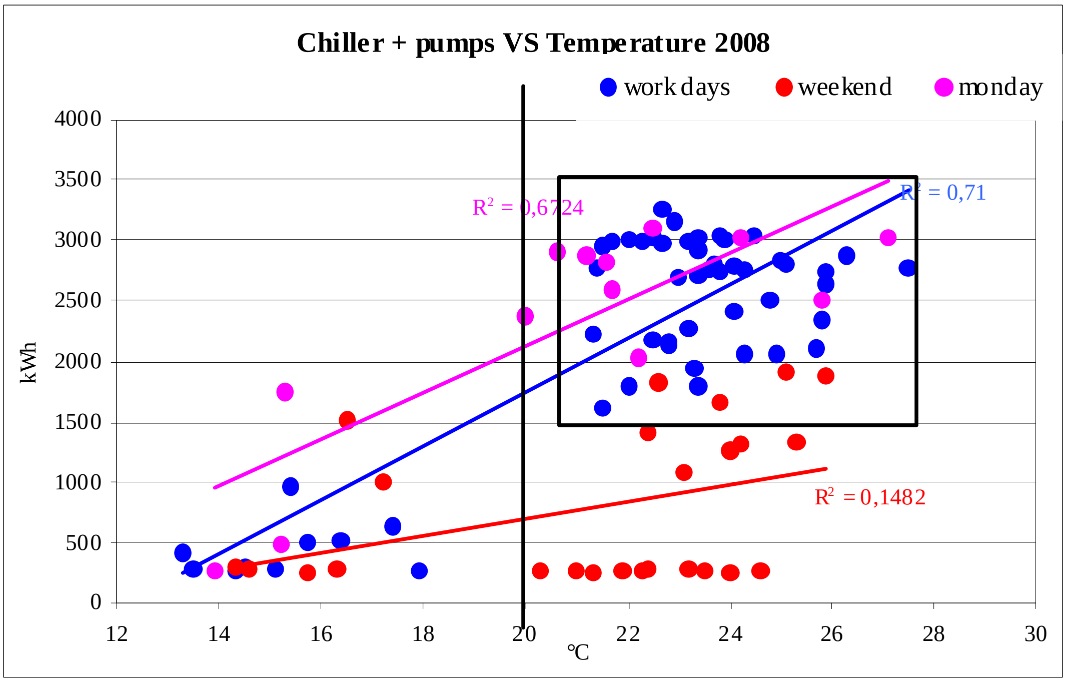




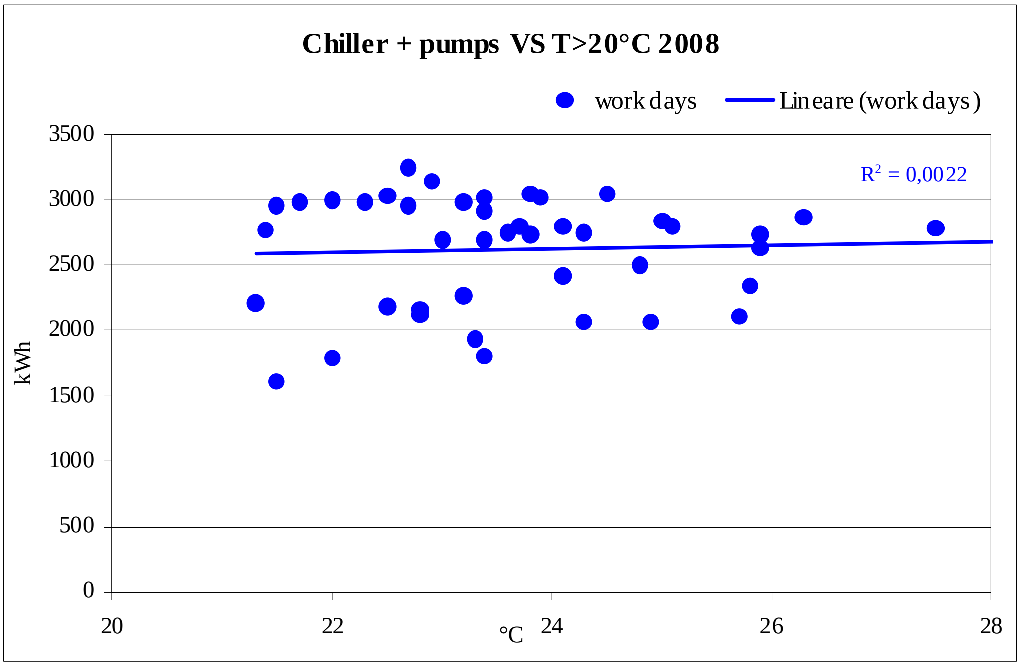
Daily chiller consumption shows poor dependence on external temperature, with an almost constant efficiency from 2008 to 2009: the signature did not change, even if the 2009 year was generally hotter than 2008. Further analysis, indeed, shows that something was changed on the cooling consumption.
Analyzing the Consumption over Air Enthalpy should be seen a medium increase of 2009 consumption over 2008, even at the same average external temperature. This should be explained with a partial lowering of the system efficiency and/or an increase of internal electric loads.



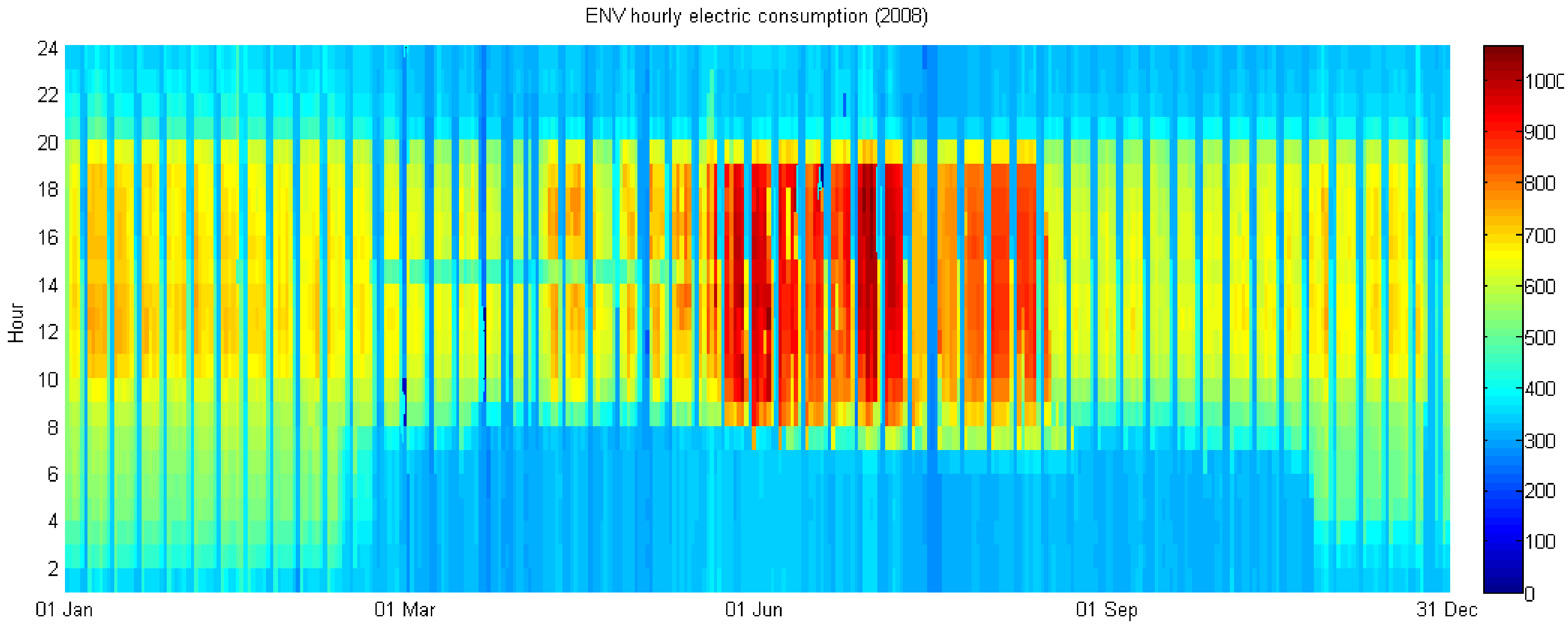
Analyzing the graphs it appears that the external temperature/daily consumption points are divided in two clearly separate groups: below 20°C and over 20°C.

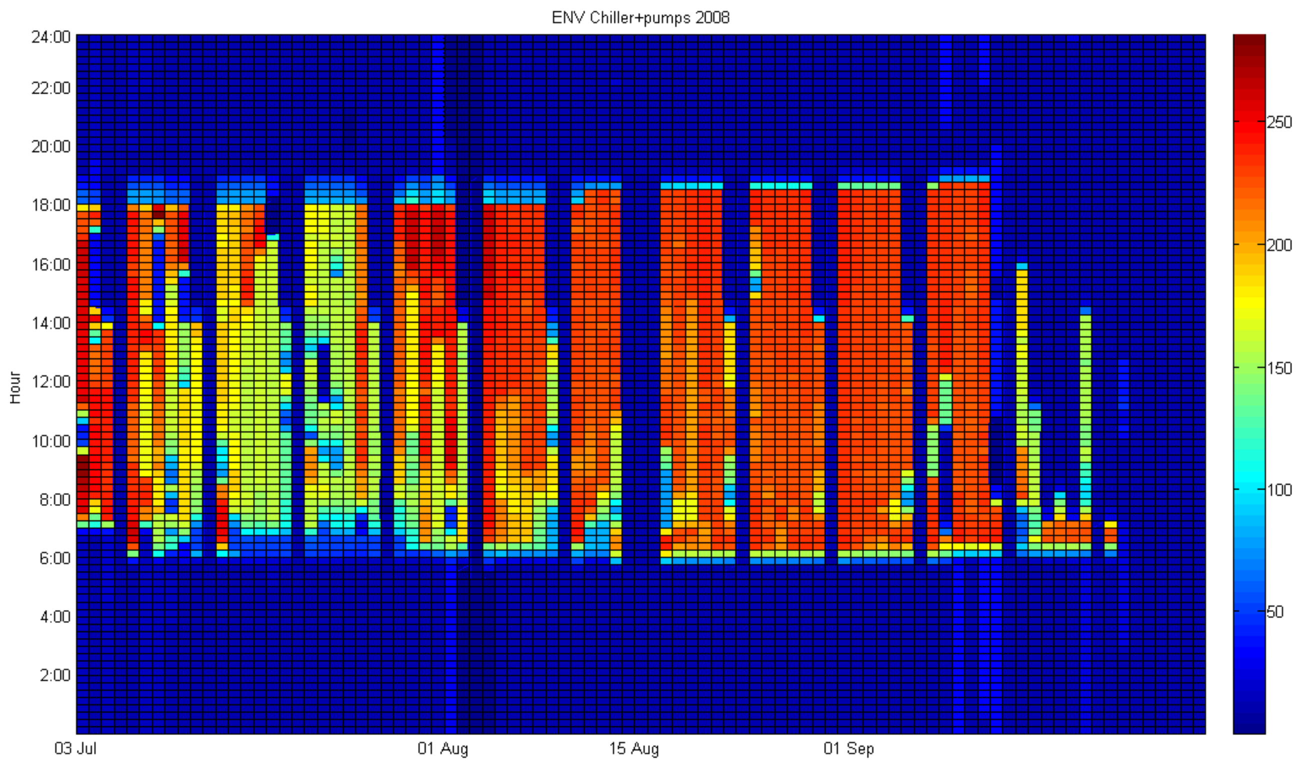


Focusing on 2008 summer season, different days of the week were analyzed. It appears that the energy signature of Monday is always higher than the same value on other workdays; this behaviour should be explained by schedule: in summer the system is turned on some hours before occupation, especially on Monday. The data was then divided in two groups: above 20°C and below 20°C external temperature. Below this value the consumption is really low: in fact the absorption chiller and the free cooling strategy are sufficient to cool the building. Over 20°C the system consumption is not correlated with temperature at all, as seen in the graph below.

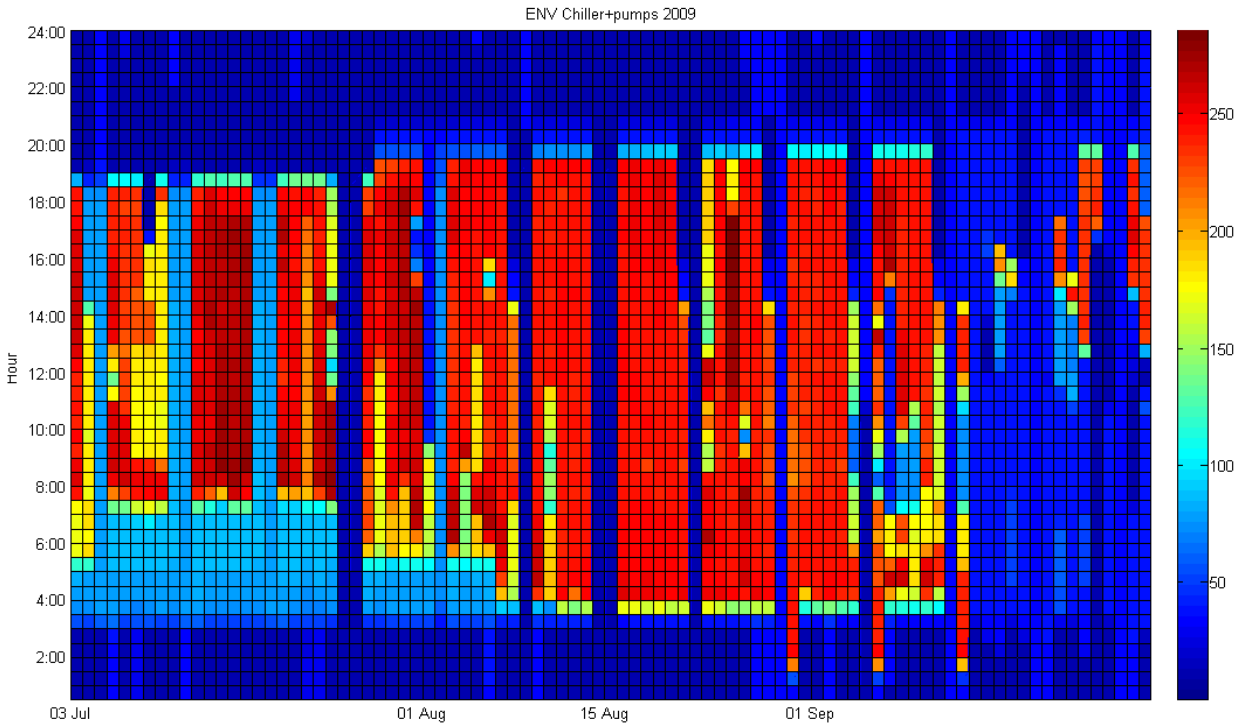


Total electric energy consumption carpet plot show clearly the increase of consumption during summer season due to electric chiller and chilled water pumping system. The building heating system is composed by two wood chips boiler and a support gas fired boiler. Nevertheless an increase of consumption appears also during winter season, with high consumption also during night. In the day-time the rise is explained by a general increase of electric lighting. On night-time the consumption is due to early turning on of AHUs and pumps to provide the required heating. A generalized lowering of consumption during lunch time can be appreciated during the whole year: this is due to a specific strategy of the energy manager who decided to turn off all the HVAC system for one hour, during lunch-time.



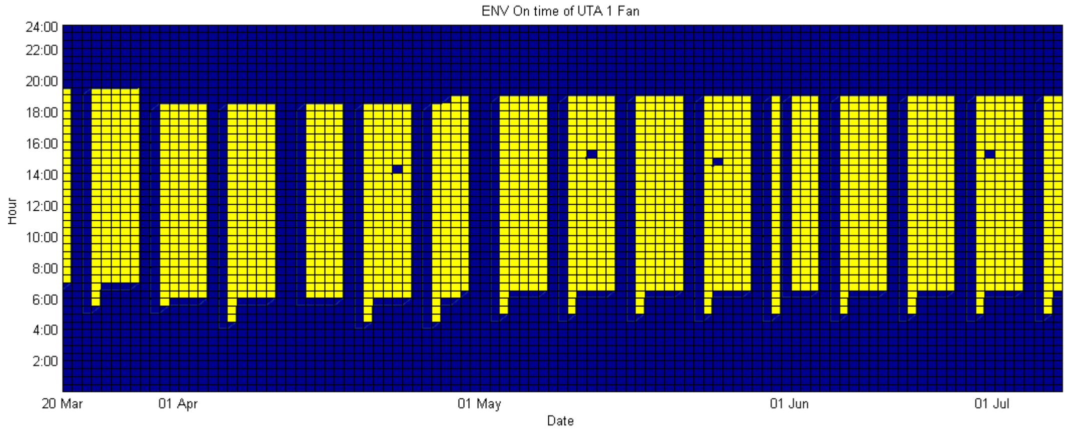


The 2008 cooling station consumption shows a good control and schedule strategy, as seen during weekend and national holidays (15 August) almost all equipment is shut off. While in July the electric power utilized is below 200 kW, in August almost all the power available is utilized. This implies that all the cooling capacity of the system is needed by the building. The variation of power during a single day is an indicator of the proper operation of the control system.



During 2009 the weather was characterized by average temperatures higher than in 2008 summer. For this reason the HVAC system manager decided to change the cooling station schedule. As seen in the graph, in July the cooling station begins operation at 4:00 AM by turning on absorption chillers and primary pumps. The electric chiller was turned on at 8:00 AM. In August this strategy was insufficient to provide adequate comfort conditions, and the electric chiller operation schedule began earlier. In the last part of summer, from the first of September, the electric chiller started operation with the cooling station at 2 AM. This period was characterized by the highest cooling load because the weather was hot and the offices and spaces were completely utilized.

Analyzing the status of AHUs, in the graph below, demonstrate, as stated, that the system schedule is correct, including weekend shutoff and national holidays (in the graph is seen the 2nd of June).



Timing table for first inspection

Inspection Item	Short Description	Time (mins)	Savings	Notes
PI1	Location and number of AC zones	15		
PI2	Documentation per zone	10		
PI3	Images of zones/building	15		
PI4	General zone data/zone	15		
PI5	Construction details/zone	8		
PI6	Building mass/air tightness per zone	4		
PI7	Occupancy schedules per zone	10		
PI8	Monthly schedule exceptions per zone	1		
PI9	HVAC system description and operating setpoints per zone	12		
PI10	Original design conditions per zone	11		
PI11	Current design loads per zone	55		
PI12	Power/energy information per zone	3		
PI13	Source of heating supplying each zone	2		
PI14	Heating storage and control for each zone	7		
PI15	Refrigeration equipment for each zone	4		
PI16	AHU for each zone	13		per zone, the AHU are 30
PI17	Cooling distribution fluid details per zone	6		
PI18	Cooling terminal units details in each zone	2		
PI19	Energy supply to the system	2		
PI20	Energy supply to the building	1		
PI21	Annual energy consumption of the system	0		not available
PI22	Annual energy consumption of the building	5		
	TOTAL TIME TAKEN (minutes)	**201**		
	TOTAL (seconds/m²)	**0.50**	Area (m²)	24000

Centralised system inspection data

Inspection Item	Short Description	Time (mins)	Savings	Notes
PC1	Details of installed refrigeration plant	5		3 unit
PC2	Description of system control zones, with schematic drawings.	12		
PC3	Description of method of control of temperature.	6		
PC4	Description of method of control of periods of operation.	2		
PC5	Floor plans, and schematics of air conditioning systems.	2		time taken to obtain files
PC6	Reports from earlier AC inspections and EPC's	0		not available
PC7	Records of maintenance operations on refrigeration systems	5		
PC8	Records of maintenance operations on air delivery systems.	2		per AHU
PC9	Records of maintenance operations on control systems and sensors	0		not available
PC10	Records of sub-metered AC plant use or energy consumption.	9		partial data available from energy manager study
PC11	Commissioning results where relevant	0		
PC12	An estimate of the design cooling load for each system	5		from chiller label data
PC13	Records of issues or complaints concerning indoor comfort conditions	0		not available
PC14	Use of BMS	11		
PC15	Monitoring to continually observe performance of AC systems	0		see C2
C1	Locate relevant plant and compare details	30		
C2	Locate supply the A/C system and install VA logger(s)	140		
C3	Review current inspection and maintenance regime	6		
C4	Compare system size with imposed cooling loads	35		
C5	Estimate Specific Fan Power of relevant air movement systems	32		19 AHU
C6	Compare AC usage with expected hours or energy use	25		

C7	Locate refrigeration plant and check operation	5		already done in C1, the small amount of time is due only ti check Temp and Pressure gauge
C8	Visual appearance of refrigeration plant and immediate area	3		
C9	Check refrigeration plant is capable of providing cooling	3		ONLY observation on primary flow pumps status AND Temperature gauges IN/OUT from the evaporator
C10	Check type, rating and operation of distribution fans and pumps	2		partially done, see C1
C11	Visually check condition/operation of outdoor heat rejection units	25		heat rejection is achieved by river pumps, located in a differetn part of the building
C12	Check for obstructions through heat rejection heat exchangers	0		not available
C13	Check for signs of refrigerant leakage	0		not possible
C14	Check for the correct rotation of fans	0		no fans, water/water heat rejection
C15	Visually check the condition and operation of indoor units	120		20 min per zone, 6 zones
C16	Check air inlets and outlets for obstruction	120		20 min per zone, 6 zones
C17	Check for obstructions to airflow through the heat exchangers	120		20 min per zone, 6 zones
C18	Check condition of intake air filters.	120		20 min per zone, 6 zones
C19	Check for signs of refrigerant leakage.	120		20 min per zone, 6 zones
C20	Check for the correct rotation of fans	120		20 min per zone, 6 zones
C21	Review air delivery and extract routes from spaces	120		20 min per zone, 6 zones
C22	Review any occupant complaints	0		not available
C23	Assess air supply openings in relation to extract openings.	180		30 min per zone, 6 zones

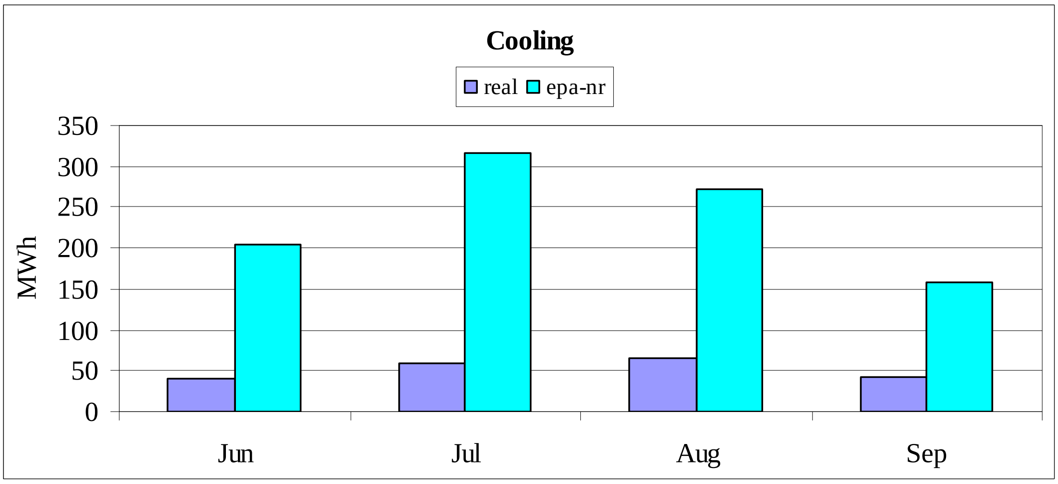
C24	Assess the controllability of a sample number of terminal units	90		15 min for each zone
C25	Check filter changing or cleaning frequency.	57		3 min per AHU, 19 AHU
C26	Assess the current state of cleanliness or blockage of filters.	57		3 min per AHU, 19 AHU
C27	Note the condition of filter differential pressure gauge.	19		1 min per AHU, 19 AHU
C28	Assess the fit and sealing of filters and housings.	57		3 min per AHU, 19 AHU
C29	Examine heat exchangers for damage or significant blockage	57		3 min per AHU, 19 AHU
C30	Examine refrigeration heat exchangers for signs of leakage	57		3 min per AHU, 19 AHU
C31	Note fan type and method of air speed control	57		3 min per AHU, 19 AHU
C32	Check for obstructions to inlet grilles, screens and pre-filters.	19		1 min per AHU, 19 AHU
C33	Check location of inlets for proximity to sources of heat	19		1 min per AHU, 19 AHU
C34	Assess zoning in relation to internal gain and solar radiation.	25		
C35	Note current time on controllers against the actual time	12		
C36	Note the set on and off periods	4		
C37	Identify zone heating and cooling temperature control sensors	30		5 min per zone.
C38	Note zone set temperatures relative to the activities and occupancy	35		by BMS acquisitions
C39	Check control basis to avoid simultaneous heating and cooling	15		
C40	Assess the refrigeration compressor(s) and capacity control	10		
C41	Assess control of air flow rate through air supply and exhaust ducts	25		
C42	Assess control of ancillary system components e.g. pumps and fans	25		
C43	Assess how reheat is achieved, particularly in the morning	8		
C44	Check actual control basis of system	5		
	TOTAL TIME TAKEN (minutes)	**2'068**		
	TOTAL (seconds/m²)	**5.17**	Area (m²)	24000

Main Eco's identified

ECO CODE	DESCRIPTION	ACTION	Saving
O1.2	Hire or appoint an energy manager		-12% on total electric consumption
P2.12	Consider the possibility of using waste heat for absorption system		see paragraph below
E2.6	Apply night time over ventilation		-2.5% on cooling station electric consumption (Summer season)

ECO P 2.12, Consider the possibility of using waste heat for absorption system

The HVAC system already includes two absorption units; an estimation of the electric energy saved by this solution is provided. The actual chillers consumption (2 absorption + 1 electric) was compared with the simulated consumption of a theoretical HVAC system, based only on electric chillers. The simulation was made with the EPA-NR software.



The difference on cooling station consumption is listed below. The percentage savings are really high, similar to the estimates in the Italian CS n°1. An important issue is that this result is possible with the combination of multiple factors, among the others:

- free cooling applied with surface water
- correct HVAC system schedule and strategy

Monthly consumption of cooling station (MWh)			
2008	REAL	EPA-NR	Difference
Jun	40.5	204.2	80.2%
Jul	59.8	317.1	81.1%
Aug	64.9	271.8	76.1%
Sep	41.8	158.7	73.6%

It is really difficult to subdivide the savings among the different good practices in use on this case study.

ECO E 2.6, Apply night time over ventilation

The analysis of the cooling station consumption (2008 data) during work days shows that the system operation starts at 6:00 AM. In the first hours of operation the system has to reach the set point temperature, after being off for the whole night. If night time over ventilation was provided, the refrigeration power in the first hours of the morning would be lowered. Two estimations are provided.

In the further tables the ECO assessment is summarized:

Cooling station Consumption

01 Jun-31 sept	205'660 kWh

Cooling station consumption in summer, aggregated by hour

2008	Jun	Jul	Aug	Sep	Tot	% on the whole season
5:00-6:00	421	427	606	553	2'007	1.0%
6:00-7:00	2'534	2'011	4'177	3'499	12'222	5.9%
7:00-8:00	3'342	4'297	4'437	3'327	15'402	7.5%
8:00-9:00	2'654	4'969	4'782	2'857	15'262	7.4%
9:00:10:00	2'623	4'817	5'095	2'868	15'403	7.5%
10:00-11:00	2'675	4'826	5'198	2'959	15'658	7.6%

As seen, the 36% of consumption happens during the first 5 hour of operation of the cooling station.

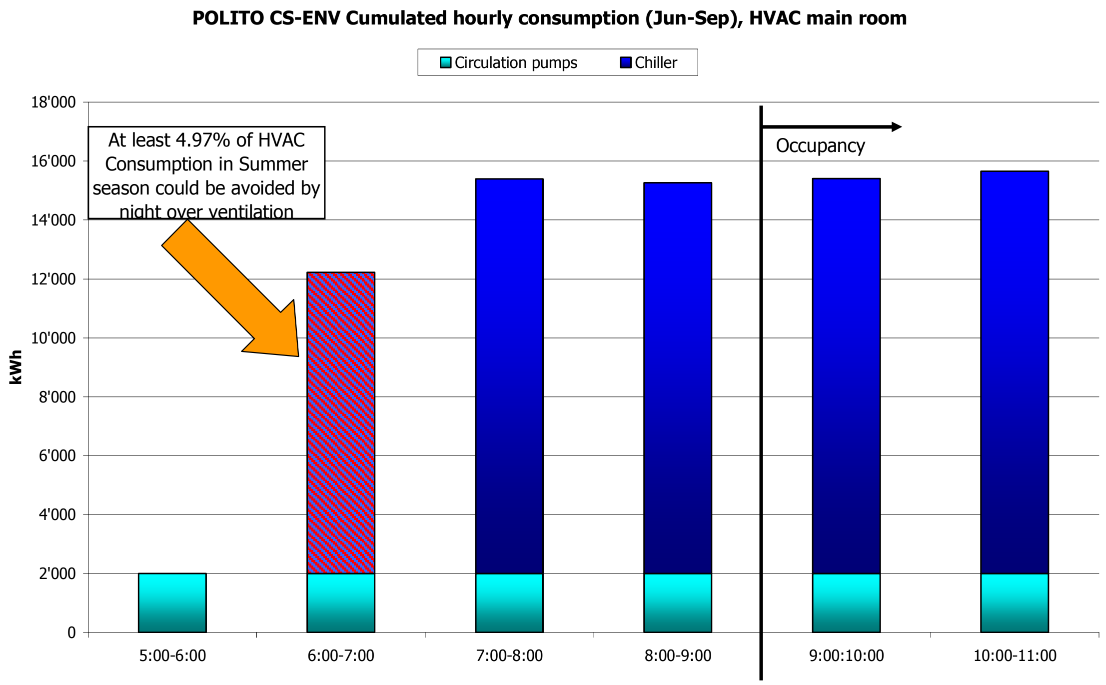
We assume that, in presence of night time over ventilation, the hour of beginning operation of the cooling station should be late by one hour.

According to this calculation the potential savings are estimated at 5% of cooling station Summer consumption.

Conservative estimation (ON at 7:00)

Potential saving	**10'215**	**kWh**
	4.97%	**(on Summer HVAC consumption)**

This solution, indeed, has to be evaluated with the increasing ventilation consumption required. We assume that this increase represents 50% of the total savings. This implies that <u>the overall savings is estimated at 2.5 % on cooling station Summer consumption</u>.



Overall conclusions

This case study present a relatively new building for environmental research laboratories and offices. The building and its HVAC system was designed to minimize energy consumption. In addiction, an energy manager was hired in 2007. The measurements and inspection made shows a state of the art HVAC system and operation strategy.
This case study demonstrate that a correct design of building and system, coupled with a strict control of operation parameters permits high energy savings. Among the Italian Case studies the medium specific consumption for cooling production is about 50 kWh/m^2 per year. This building consumes about 14 kWh/m^2.

Due to extremely low consumption, the possibility to improve this system is limited. Considering the building design, which minimize solar load, a possible improve of HVAC system should be a system which minimize latent load.
The installation of a desiccant cooling system should be an option.

In summary, this case study show that:

1. **Absorption chiller is an option that should decrease dramatically electric consumption of HVAC system, if it is operated in the correct form and if there are a reliable flow of waste heat.**

2. **In large system/buildings the presence of an Energy manager with an expertise HVAC system technician is absolutely needed to guarantee correct operation and efficiency of the system.**

3. **Presence of surface water is a good way to provide free-cooling and condenser refrigeration.**

HARMONAC

IT Case Study 3:
Retirement home – All air system

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CASE STUDY:
ITIS: Retirement Home with all air system

The main building, dating from the early XIX Century, has been completely refurbished. The A/C system monitored in this building is an all air system.
The central thermal plant includes three gas-fired boilers (with oil-fired boiler used as a backup) for space heating and one gas-fired boiler for SHW production; the total power rating is 5'232 kW, excluding the back up.
The cooling plant includes three electrical chillers with cooling tower heat rejection, rated at 1'468 kW cooling capacity.

Building Description

Country & City	Italy, Trieste
Building Sector /Main Activity	Retirement home
Net Area[m²]	25065

Installed Plant

Parameter	Installed electrical load / kW	Floor area served / m^2 GIA	Installed capacity W/m^2 GIA	Annual consumption kWh	Average annual power W/m^2	Annual use kWh/m^2	Average annual power (% FLE)
Total Chillers nominal cooling capacity (cooling output)	1'468.0	8'000.0	183.5				
Total Chillers	410.0	8'000.0	51.3	244'200.0	3.5	30.5	6.8
Total CW pumps	56.0	8'000.0	7.0	31'500.0	0.4	3.9	6.4
Total fans	15.0	8'000.0	1.9		-	-	-
Total humidifiers			-		-	-	-
Total boilers		25'065.0	-		-	-	-
Total HW pumps	35.4	25'065.0	1.4	63'720.0	0.3	2.5	20.5
Total HVAC electrical		25'065.0	-		-	-	-
Total Building Elec kWh		25'065.0		1'614'786.0	7.4	64.4	
Total Boilers/Heat kWh	5'232.0	25'065.0	208.7	2'902'100.0	13.2	115.8	6.3
Total Building Gas/Heat kWh		25'065.0		2'902'100.0	13.2	115.8	

Energy savings

ECO CODE	DESCRIPTION	ACTION	Saving
P2.12	Consider the possibility of using waste heat for absorption system	applied with CHP, simulated	52% on year cooling energy needs

Overview of building and system

ITIS is a public structure hosting non self-sufficient elderly people. The structure is also used for cultural activities jointly with the Municipality of Trieste and for teaching and practicing by the School of Medicine of the Trieste university.

The main building, dating from the early XIX Century, has been completely refurbished. The annex service building (kitchen, boiler room, etc) was built around 1970. The conditioned area is about 8'000 m^2.

The A/C system monitored in this building is an all air system.

HVAC system

The central thermal plant includes three gas-fired boilers (with oil-fired boiler used as a backup) for space heating and one gas-fired boiler for SHW production; the total power rating is 5'232 kW, excluding the back up.

The cooling plant includes three electrical chillers with cooling tower heat rejection, rated at 1'468 kW cooling capacity.

The water/air HVAC system includes 10 AHUs (primary air only); water terminals are two-pipe radiators for heating; in summer season the system works as an all-air system.

The yearly electricity consumption is on about 1.6 GWh.

Metering

The building is equipped with a BMS. The BMS controls the system, but logging data are not available. By the end of July 2008, a "Ducati Sistemi" power analyzer and a "Coster" temperature analyzer were installed in order to monitor the following quantities:

- Electrical load and consumption of the chiller
- Inlet and Outlet Air Temperature of two AHU, serving zone 1
- Outside Temperature

Summary of building and systems

The following table summarises the main aspects of the building (based on EPA-NR and Harmonac inspection procedures):

Building Description

Building Sector /Main Activity	Health and care/Retirement Home
Net Area [m²]	25'065
Max number Occupants	300
N° Zones	2

Zone Description

Zone ID	Activity Type	Gross net Area	N° Occupants
1	Guest rooms, only heating	25065	300
1 (cooled)	Guest rooms, heat and cool	8000	78

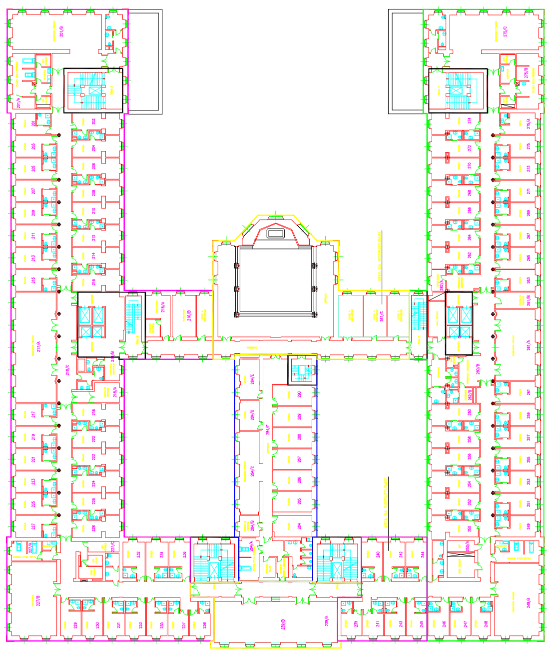
Heating/Cooling Production		**Normalised/m² GIA**	**Notes**
Conditioned net Area	8000 [m²]		1
Chillers nominal cooling capacity	1'468[kW]	183.5 W/m²	532 + 500 + 436
Chillers nominal electrical demand	410[kW]	51.3 W/m²	161 + 137 + 112
Chillers chilled water circulation pumps nominal electric demand	56 [kW]	7.0 W/m²	2x4 kW, 2x5.5 kW, 2x7.5 kw ; heat rejection system: 2x3 kW, 2x4 kW, 2x4 kW
COP	3.5		*Measured at full load*
Operation Hours	1500		mean (14h X 107 days)
Operation Hours of pumps (cooling)	1500		mean (14 h X 107 days)
Heated net Area	25'065 [m²]		1, 2
Boilers nominal heating capacity for heating	5232 [kW]	208.7 W/m²	3x 1744 heating 1x930 (DHW)
Boilers hot water circulation pumps nominal electrical demand	35.4 [kW]	1.4 W/m²	2x 3 kW, 2x 1.5 kW, 2x 11 kW, 2x 1.1 kW, 2x 1.1 kW
Nominal Efficiency	90%		
Operation Hours	1800		mean (10 h X 180

		days)
Operation Hours of pumps (heat)	3600	mean (20 h X 180 days)

Measured annual performance

		Normalised/ m² GIA	Notes
Total Building Electrical Consumption	**1614.5** [MWh]	**64,4** kWh/m²	2008 data
• HVAC Equipment (cooling)	**275.7** [MWh]	**34.5** kWh/m²	2008 data, chillers + cold water pumps + ev. tower
Total Building Gas Consumption	**2902** [MWh]	**115.8** kWh/m²	2008 data
Domestic Hot Water Consumption	**8050** [m³]	**259** l/m²	DHW only
DHW Gas consumption	**740** [MWh]	**23.8** kWh/m²	2008 data
HVACs' system components			
Heating Boilers	**2902** [MWh]	**115.8** kWh/m²	? % of Full Load Equivalent (FLE) and zone served
Main boilers Hot Water circulation pumps	**63.7** [MWh]	**2.5** kWh/m²	extimate
Main Chillers	**244.2** [MWh]	**30.5** kWh/m²	? % of Full Load Equivalent (FLE) and zone served
Main Chillers Chilled Water circulation pumps	**31.5** [MWh]	**3.9** kWh/m²	extimate
Cooling towers water pumps	**6** [MWh]	**0.8** kWh/m²	extimate

Case study details - Building Description



General building data

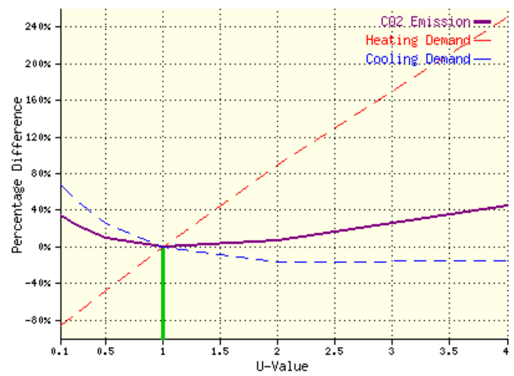
Country/City	Italy/ Trieste
Latitude/Longitude[°]	45°38'10''32 N 13°48'15''12 E
Elevation [m]	0
Cooling Degree Days	2102
Building Sector/Main Activity	Health and Care/Retirement Home
Total net floor area [m²]	31065
Ceiling height [m²]	4.5 (mean)
Number of floors	4

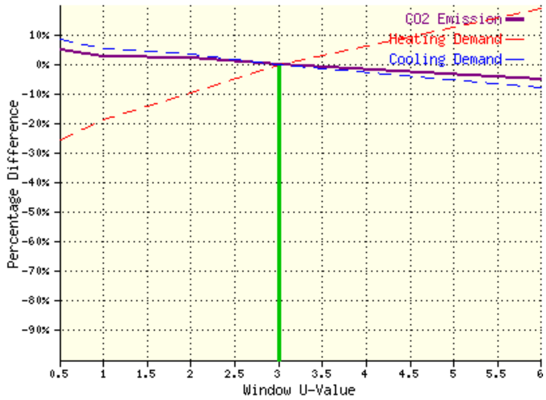
Case study details - Constructions details

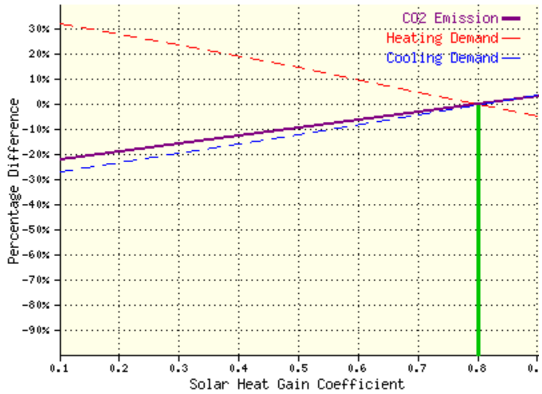
The building considered was built in early XIX century. The structure is mainly composed by brick wall, with a minimum thickness of about 50 cm. This implies a good thermal resistance and an extremely high thermal capacity. For this reason the building envelope avoids thermal load peaks.

Envelope – Heat Transfer Coefficient [W/m².K]	
External wall (predominant)	1
Floor (predominant)	1.2
Intermediated floor (predominant)	1.2
Roof (predominant)	1.3

Windows	
U- value (predominant) [W/m².K]	3
Window type	wood/aluminium
Window gas	air
Solar Factor	0.8
Solar Protection Devices	
Window Overhangs	**no**
Shading Device	**curtains**




CO2 Emission
Heating Demand
Cooling Demand
Percentage Difference
10%
0%
-10%
-20%
-30%
-40%
-50%
-60%
-70%
-80%
-90%
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Window U-Value


CO2 Emission
Heating Demand
Cooling Demand
Percentage Difference
30%
20%
10%
0%
-10%
-20%
-30%
-40%
-50%
-60%
-70%
-80%
-90%
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Solar Heat Gain Coefficient

Internal gains and operation schedules per zone

Zone ID:	**1**
Activity type	**Guests rooms**

Equipment electric loads/Schedules	**Design**	**Measure/observe - Winter/Summer (average)**
Office equipment [W/m²]		2
Working schedule	24 h 7/7	
Permanent/variable occupancy	80	78/82
Cleaning staff schedule		10:00 14:00
Lighting [W/m²]		12
Type of lighting		Fluorescent tubes
Lighting control		manual on/off
Lighting schedule		

Figure – Luminaires position/distribution

Environment parameters

The ARPA Friuli Venezia Giulia (ARPA FVG), the regional environmental protection agency provides climatic data for Trieste.

Outdoor Environment Parameters	**Design**	**Measure/observe - Winter/Summer (average)**
Outdoor air temperature [°C] Winter/Summer	-5/30	**-2** / **29** avg. min **-5** / max **36**
Outdoor Relative Humidity [%] Winter/Summer	none / 50	**65%** / **60%**
Max. Solar Radiation [W/m²]		

Zone ID:	**1,2**
Activity type	**guests rooms**

Indoor Environment Parameters per zone	**Design**	**Measure/observe - Winter/Summer (average)**
Ventilation Rate [ach]	0.5	
CO_2 threshold / CO_2 measured [ppm]	none	
Indoor Relative Humidity [%]	50	
Indoor air Temperature [°C] – Winter/Summer	21 / 25 air °C	**22**/**26** air °C

Monitoring observations for environmental parameters

Air Flows Rates Environment Parameters per zone	Design	Measure (average during operation)
Total air flow rate supplied to the zone [m³/h] or[h⁻¹]	36.000 m³/h	**31.300** m³/h
Total air flow rate extracted from the zone [m³/h]or[h⁻¹]	32.000 m³/h	**31.300** m³/h

The CAT graph estimates the % effect that the overall ventilation rate (in air changes/hour) has on the overall heating and cooling demands.

HVAC system components

The central thermal plant includes two gas-fired boilers (with oil backup) for space heating and two gas-fired boilers for SHW production; the total thermal power installed is 6823 kW.

The cooling plant includes three electrical chillers with cooling tower heat rejection, the total cooling power installed is 1468 kW. Actually only two chillers are operational, and, due to electric power availability constrain, just one should be turn on at a time.

The water/air HVAC system includes 10 AHUs (primary air only); water terminals are two-pipe radiators for heating; in summer season the system works as an all air system.

The yearly electricity consumption is on the order of 1.6 GWh

The Case Study considers each of the components of the system individually in the following order:

- Heating systems (heat generators) and pumps
- Cooling systems (cold generators) and pumps
- Heat rejection and pumps

Heat Generator and Pumps

Boiler Identification	
Manufacture/Model	ICI TNA 150
Year	
Equipment Type	gas boiler
Fuel Type	Natural gas
Performance Data	
Nominal Heating Capacity [kW]	1744
Installed Heating Capacity /m² GIA	168.4
Nominal Efficiency [%]	90
Water outlet temperature [°C]	90
Water inlet temperature[°C]	65
Electrical data	
Power supply [V/Ph/Hz]	380/3/50
Start-up amps [A]	11

Auxiliary Equipment	
Fan Electrical Demand [kW]	/
Pumps Electric Demand [kW]	17.7
Other	/

Monitoring observations

Inspection	
Maintenance status	Satisfactory
Previous inspection/maintenance Reports	Yes Data of last: monthly
Operation time estimated [h]	10000
Operating mode	Automatic
Dirtiness of burner	No
Thermal Insulation (Visual)	Satisfactory
Fuel leaks	No
Water leaks	No
Pressure status	Satisfactory
Sensors calibration records	No
Meter readings data	overall monthly gas consumption

Field measurements	
Electricity consumption [kWh]	N.A.
Fossil fuels consumption [kWh]	2'901'000 of natural gas
Electric voltage [V]	379
Electric current [A]	5

Cold Generator (X3)

Chiller Identification	
Manufacture/Model	Mc Quay WHR 130.2
Year	1998
System Type	2 circuits
Compressor Type	Reciprocating
Fuel Type	electric
Performance Data	
Nominal Cooling Capacity [kW]	450
Installed Cooling Capacity /m² GIA	183.5
Nominal Electric Power [kW]	112
COP/EER (Eurovent)	4
Refrigerant Gas	R 22
Electrical data	
Power supply [V/Ph/Hz]	400/3/50
Start-up amps [A]	1122

Auxiliary Equipment	
Fan Electrical Demand [kW]	25 (heat rejection system)
Pumps Electric Demand [kW]	17

Monitoring observations

Inspection	
Maintenance status	**Unsatisfactory**
Previous inspection/maintenance Reports	**No**
Operation time estimated [h]	**1500 each**
Operating mode	**automatic**
Thermal Insulation (Visual)	**Satisfactory**
Vibration eliminators	**Satisfactory**
Worn couplings	**Satisfactory**
Equipment cleanliness	**Unsatisfactory**
Compressor oil level	**Satisfactory**
Compressor oil pressure	**Satisfactory**
Refrigerant temperature	**Unsatisfactory**
Refrigerant pressure	**Satisfactory**
Chilled water systems leaks	**No**
Sensors calibration records	**No**
Refrigerant leaks	**No**
Location of the equipment	**Indoor**
Oil leaks	**Yes (minor)**

Field measurements	
Electricity consumption [kWh]	50’000 from 1 to 30 September 2008 71’000 from 1 July to 31 August 2009

Heat Rejection System

Heat Rejection Identification	
Manufacture/Model	Sital Clima TRS 140
Year	1998
Cooling method	evaporative
Performance Data	
Nominal Cooling Capacity [kW]	600
Installed Cooling Capacity /m² GIA	N.A.
Nominal Electric Power [kW]	15
Total Heat Rejection [kW]	N.A.
Water flow rate [m³/h]	N.A.
Water Pressure Drop [kPa]	N.A.
Electrical data	
Power supply [V/Ph/Hz]	400/3/50
Start-up amps [A]	

Auxiliary Equipment	
Fan Electrical Demand [kW]	15
Pumps Electric Demand [kW]	4

Monitoring observations

Inspection	
Maintenance status	**Satisfactory**
Previous inspection/maintenance Reports	**No**
Operation time estimated [h]	**1500 (annual)**
Operating mode	**automatic**
Thermal Insulation (Visual)	**Satisfactory**
Equipment cleanliness	**Satisfactory**
Operating water level (sump)	**Satisfactory**
Fan shaft bearings lubrification	**N.A.**
Drive system belt condition and tension	**N.A.**
Heat transfer section cleanliness	**Satisfactory**
Refrigerant leaks	**No**
Water systems leaks	**No**
Sensors calibration records	**No**
Correct rotation of the fan	**Yes**
Bleed rate [l/s]	**N.A.**

Field measurements	
Electricity consumption [kWh]	**N.A.**
Electric voltage [V]	**N.A.**
Electric current [A]	**N.A.**

Control systems

The control system consists of a COSTER BEMS. The secondary circuit, feeding the fan coils, is regulated by 3-way motorized valves (photo below). The AHUs are provided with 3-way valves on board.
The chiller load is regulated by the control on the return temperature. A set point of 13°C is set on the main BEMS server.

Energy consumption data

Metering information

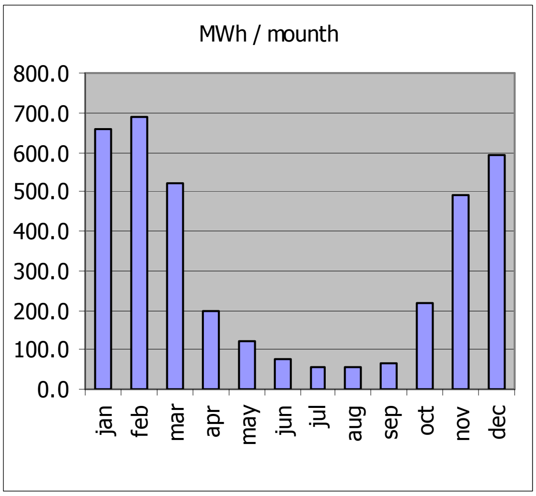
The metering for the ITIS chiller plant was divided into two seasons: during 2008 season the metering system was installed on the central main power panel, while in the 2009 season it was installed on one chiller power panel. Data available were:

- Summer 2008: 15 min consumption of chillers + primary cool water pumps
- Summer 2009: 15 min consumption of one chiller

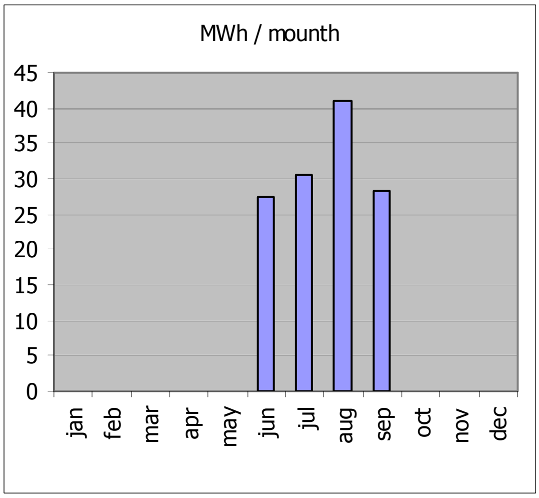
The chillers installed in the cooling plant are three, but actually only two are operational, and, due to electric power availability constrain, just one should be turn on at a time.

Monitoring observations

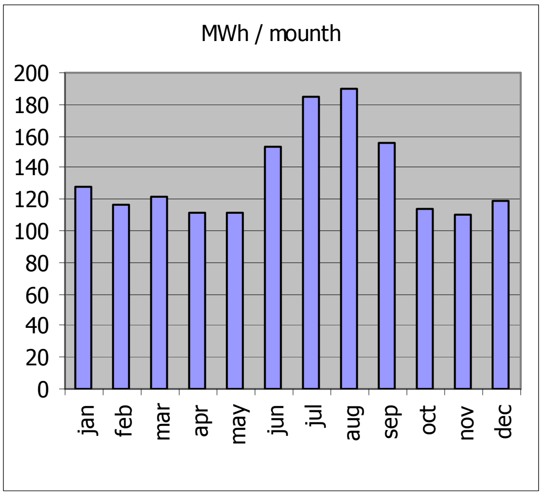
Heating [MWh]



Cooling [MWh]



Electricity [kWh/year]

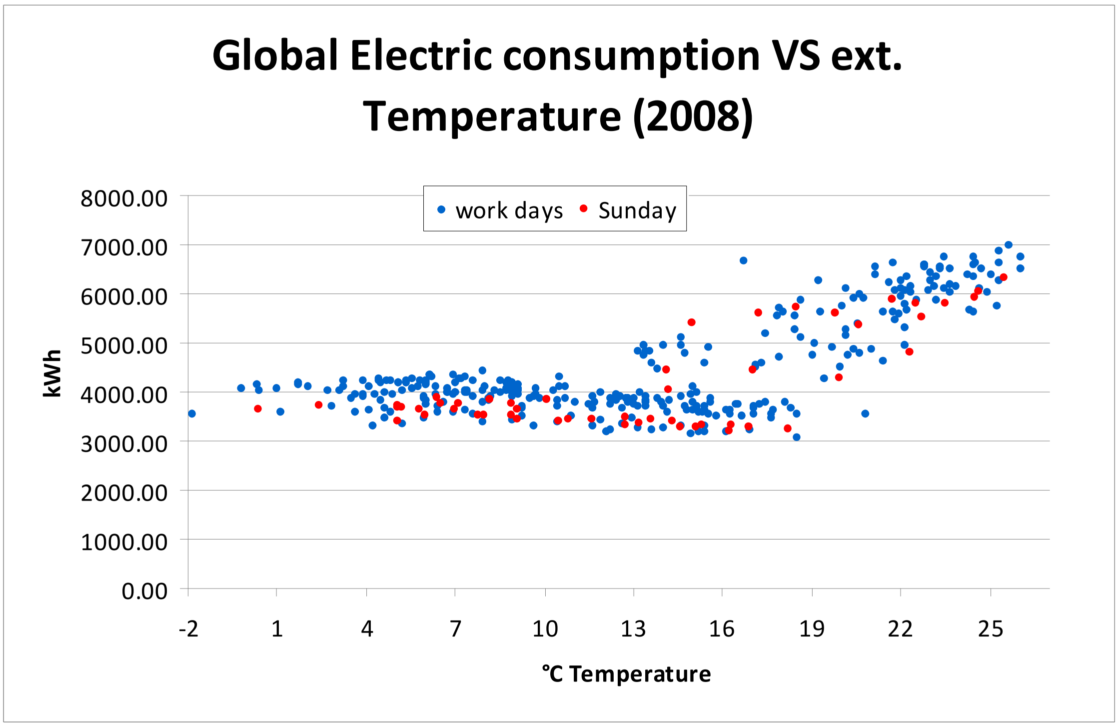


Domestic Hot Water [MWh/year]

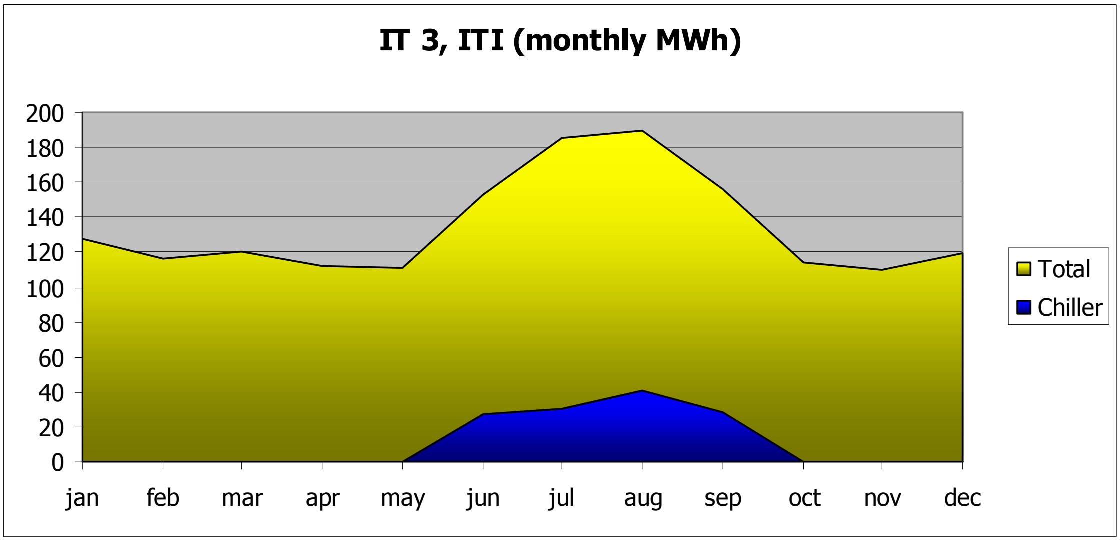
739.5 MWh / year (2008)

The building envelope is characterised by good thermal properties. Relatively high thermal resistance and extremely high thermal capacity are similar to Italian CS n°5. This structure avoids thermal peaks in Summer and Winter.
The use of the structure, 24 h a day, 365 days per year, represents the most intensive schedule among the Italian Case studies.

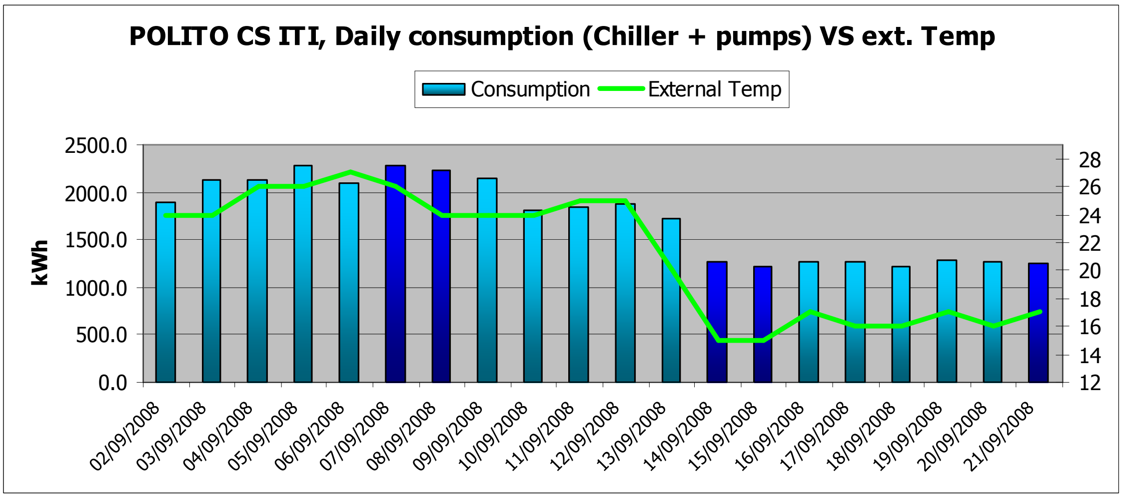
The low installed specific electrical power, which is almost entirely due to lighting, permits to see a clear seasonality of electrical consumption. A small raise of the daily consumption should be seen in the data set, above 10°C; this is probably due to the decrease of lighting consumption corresponding to more natural light hours in the day. Above 13°C of mean external temperature is clearly seen an increase in the electrical consumption due to cooling production. The daily consumption increases about 75%, from 4'000 kWh per day to 7'000 kWh per day in the hottest days of the year.
As seen in the graph below, the difference between Sunday consumption and week day consumption is perceptible but small, around 10-15% based on the same mean external temperature.



The total building consumption increase is due to the centralized cooling production plant, but also to some VRF systems. The VRF system was not specifically metered due to difficulty to install a large number of metering units (in fact, each VRF is connected to a different electric panel).



As expected, the monthly global electrical consumption shows an increase around 75%, similar to the increase analyzed in the daily consumption.
The following graphs shows September consumption of the chiller. As seen the chillers consumption shows a good correlation with external temperature.



Main Eco's identified

ITEM	ACTION	ECOS CODE	TOOLS
Consider the possibility of using waste heat for absorption system	Install CHP system and absorption chiller	P2.12	Simulation

ECO P 2.12, Consider the possibility of using waste heat for absorption system

This building is the most suitable for CHP-absorption chiller installation among Italian Case studies, the reason are mainly:

- Actual limited availability of electric power
- 24 hours operation, 7 days per week
- High DHW consumption

A preliminary analysis on CHP-absorption chiller installation was made considering an internal combustion engine, feeded with natural gas.

Two different systems were assessed:

A. CHP rated at 140 electrical kW and absorption chiller rated at 147 kW of cooling power
B. CHP rated at 200 electrical kW and absorption chiller rated at 205 kW of cooling power

SOLUTION A

This solution permits to use almost all the electrical power in winter days, while during nights its operation has to be carefully selected, depending on electricity and fuel costs. During summer it will be possible to use the heat power to feed the absorption chiller, while the electric power provided make possible to turn on two electric chiller at the same time (actually just one could be turn on).
The parameters used for the energy assessment are:

- Gas flow: 41.6 Nm^3/h
- Thermal power input: 399 kW

- Electrical power output: 140 kWe
- Electric efficiency: 35.08 %
- Thermal power output: 207 kW
- Cooling power output: 147 kW
- C.O.P. absorption chiller: 0.711

The comparison was made between actual electric consumption and expected electric production by CHP system.

Month	Engine running hours		CHP Electric power	CHP Electric energy	Electric energy consumption	Electric energy used
	[h/d]	[d/month]	[kWe]	[kWhe]	[kWhe]	[%]
January	20	31	140	86'800	127'652	68.0%
February	20	28	140	78'400	116'671	67.2%
March	20	31	140	86'800	120'939	71.8%
April	20	20	140	56'000	111'896	50.0%
May	15	31	140	65'100	111'242	58.5%
June	20	30	140	84'000	152'988	54.9%
July	22	31	140	95'480	185'130	51.6%
August	22	31	140	95'480	189'489	50.4%
September	20	30	140	84'000	156'104	53.8%
October	20	20	140	56'000	113'866	49.2%
November	20	30	140	84'000	109'534	76.7%
December	20	31	140	86'800	119'279	72.8%
TOTAL	**6116 [h/year**			**958'860**	**1'614'790**	**59.4%**

Analogous comparison was made for the thermal consumption in Winter season.

Month	Engine running hours		CHP Thermal power	CHP thermal energy	Thermal energy consumption	Thermal energy used
	[h/d]	[d/month]	[kWt]	[kWht]	[kWht]	[%]
January	20	31	209	129'580	659'894	19.6%
February	20	28	209	117'040	552'238	21.2%
March	20	31	209	129'580	487'902	26.6%
April	20	20	209	83'600	199'373	41.9%
October	20	20	209	83'600	153'224	54.6%
November	20	30	209	125'400	351'900	35.6%
December	20	31	209	129'580	682'187	19.0%
TOTAL	**3820 [h]**			**798'380**	**3'086'718**	**25.9%**

SOLUTION B

This solution considers a bigger CHP system and absorption unit. This implies that in Winter days the system should be turn on for less hours than those expected in Solution A.

The parameters used for the energy assessment are:

- Gas flow: 57.7 Nm³/h
- Thermal power input: 553 kW
- Electrical power output: 200 kWe
- Electric efficiency: 36.7 %
- Thermal power output: 291 kW
- Cooling power output: 205 kW
- C.O.P. absorption chiller: 0.704

As for the solution A, the further tables represents the expected electric and thermal energy produced against the energy used.

Month	Engine running hours		CHP Electric power	CHP Electric energy	Electric energy consumption	Electric energy used
	[h/d]	[d/month]	[kWe]	[kWhe]	[kWhe]	[%]
January	20	31	200	124'000	127'652	97.1%
February	20	28	200	112'000	116'671	96.0%
March	20	31	200	124'000	120'939	102.5%
April	20	20	200	80'000	111'896	71.5%
May	15	31	200	93'000	111'242	83.6%
June	20	30	200	120'000	152'988	78.4%
July	22	31	200	136'400	185'130	73.7%
August	22	31	200	136'400	189'489	72.0%
September	20	30	200	120'000	156'104	76.9%
October	20	20	200	80'000	113'866	70.3%
November	20	30	200	120'000	109'534	109.6%
December	20	31	200	124'000	119'279	104.0%
TOTAL	**6116 [h/year**			**1'369'800**	**1'614'790**	**84.8%**

Month	Engine running hours		CHP Thermal power	CHP thermal energy	Thermal energy consumption	Thermal energy used
	[h/d]	[d/month]	[kWt]	[kWht]	[kWht]	[%]
January	20	31	291	180'420	659'894	27.3%
February	20	28	291	162'960	552'238	29.5%
March	20	31	291	180'420	487'902	37.0%
April	20	20	291	116'400	199'373	58.4%
October	20	20	291	116'400	153'224	76.0%
November	20	30	291	174'600	351'900	49.6%
December	20	31	291	180'420	682'187	26.4%
TOTAL	**3820 [h/year]**			**1'111'620**	**3'086'718**	**36.0%**

The economic assessment results in a simple payback time of 4.17 years for solution A and 4.07 years for solution B. For solution A the investment cost is about 280.000 €, while for solution B the cost is about 350.000 €. Considering the investment cost, solution A seems the more economically reliable.

On solution A, energy saving was calculated taking into account Italian conversion factor of electric energy (0.45) and a COP equal to 2.5 of the substituted electric chiller. The calculation taking into account the primary energy consumption, as input in gas flow to the CHP and the primary energy saved, as gross amount of primary energy needed for thermal, electric and cooling energy production. The difference between those two values represents the net primary energy saved by the CHP system and absorption chiller. <u>This amount is about 650 MWh per year</u>, as seen in the table below.

Solution A		
Energy input		
Gas consumption of CHP	**2'825.5**	MWh
COP electric chiller substituted	2.5	
Conversion factor (ITALY)	0.5	kW elec. / kW P.E.
Generated energy		
Electric energy output	980.6	MWh elec.
Thermal energy output	790.7	MWh thermal
Cooling energy output	468.1	MWh thermal
Primary energy needed with conventional generation		
Electric energy	2'179.0	MWh
Thermal energy	878.6	MWh

Cooling energy	416.0	MWh
TOTAL	3'473.7	MWh
Saved primary energy	**648.1**	**MWh**

Timing table for first inspection

Pre-inspection data (mainly building)

Inspection Item	Short Description	Time (mins)	Savings	Notes
PI1	Location and number of AC zones	20		
PI2	Documentation per zone	10		
PI3	Images of zones/building	18		
PI4	General zone data/zone	20		
PI5	Construction details/zone	30		
PI6	Building mass/air tightness per zone	4		
PI7	Occupancy schedules per zone	10		
PI8	Monthly schedule exceptions per zone	1		
PI9	HVAC system description and operating setpoints per zone	55		
PI10	Original design conditions per zone	20		
PI11	Current design loads per zone	120		
PI12	Power/energy information per zone	3		
PI13	Source of heating supplying each zone	5		direct contact with plant operator, if not available 30 min
PI14	Heating storage and control for each zone	4		direct contact with plant operator, if not available 30 min
PI15	Refrigeration equipment for each zone	5		direct contact with plant operator, if not available 30 min
PI16	AHU for each zone	25		
PI17	Cooling distribution fluid details per zone	3		
PI18	Cooling terminal units details in each zone	0		not available
PI19	Energy supply to the system	2		
PI20	Energy supply to the building	2		
PI21	Annual energy consumption of the system	140		net time, they lated 4 mounths to give us preliminary measures
PI22	Annual energy consumption of the building	120		as before
	TOTAL TIME TAKEN (minutes)	**617**		
	TOTAL (seconds/m^2)	**1.19**	Area (m^2)	31065

Centralised system inspection data

Inspection Item	Short Description	Time (mins)	Savings	Notes
PC1	Details of installed refrigeration plant	25		
PC2	Description of system control zones, with schematic drawings.	10		
PC3	Description of method of control of temperature.	10		
PC4	Description of method of control of periods of operation.	10		
PC5	Floor plans, and schematics of air conditioning systems.	0		already available from pre-inspection
PC6	Reports from earlier AC inspections and EPC's	0		not available
PC7	Records of maintenance operations on refrigeration systems	12		4 min for each chiller
PC8	Records of maintenance operations on air delivery systems.	24		3 min for each AHU
PC9	Records of maintenance operations on control systems and sensors	0		not available
PC10	Records of sub-metered AC plant use or energy consumption.	0		not available
PC11	Commissioning results where relevant	0		not available
PC12	An estimate of the design cooling load for each system	80		affected from tha availability and order of the pre-inspection data
PC13	Records of issues or complaints concerning indoor comfort conditions	0		not available
PC14	Use of BMS	15		
PC15	Monitoring to continually observe performance of AC systems	0		not yet executed
C1	Locate relevant plant and compare details	30		
C2	Locate supply the A/C system and install VA logger(s)	120		
C3	Review current inspection and maintenance regime	3		
C4	Compare system size with imposed cooling loads	15		
C5	Estimate Specific Fan Power of relevant air movement systems	10		
C6	Compare AC usage with expected hours or energy use	15		
C7	Locate refrigeration plant and check operation	11		
C8	Visual appearance of refrigeration plant and immediate area	3		

C9	Check refrigeration plant is capable of providing cooling	5		
C10	Check type, rating and operation of distribution fans and pumps	0		already made in C1
C11	Visually check condition/operation of outdoor heat rejection units	22		
C12	Check for obstructions through heat rejection heat exchangers	0		not possible
C13	Check for signs of refrigerant leakage	6		
C14	Check for the correct rotation of fans	0		impossible
C15	Visually check the condition and operation of indoor units	0		all air
C16	Check air inlets and outlets for obstruction	0		
C17	Check for obstructions to airflow through the heat exchangers	0		
C18	Check condition of intake air filters.	16		2 min for each AHU
C19	Check for signs of refrigerant leakage.	8		1 min for each AHU
C20	Check for the correct rotation of fans	32		4 min for each AHU
C21	Review air delivery and extract routes from spaces	40		
C22	Review any occupant complaints	0		
C23	Assess air supply openings in relation to extract openings.	480		extimate for ALL openings in ALL zones
C24	Assess the controllability of a sample number of terminal units	25		
C25	Check filter changing or cleaning frequency.	5		
C26	Assess the current state of cleanliness or blockage of filters.	16		2 min for each AHU
C27	Note the condition of filter differential pressure gauge.	8		1 min for each UTA
C28	Assess the fit and sealing of filters and housings.	16		2 min for each AHU
C29	Examine heat exchangers for damage or significant blockage	16		2 min for each AHU
C30	Examine refrigeration heat exchangers for signs of leakage	16		2 min for each AHU
C31	Note fan type and method of air speed control	8		1 min for each AHU
C32	Check for obstructions to inlet grilles, screens and pre-filters.	8		1 min for each AHU
C33	Check location of inlets for proximity to sources of heat	8		1 min for each AHU
C34	Assess zoning in relation to internal gain and solar radiation.	60		

C35	Note current time on controllers against the actual time	5		on BMS
C36	Note the set on and off periods	2		on BMS
C37	Identify zone heating and cooling temperature control sensors	5		in addiction to travel time, already take in count in other part of the inspection
C38	Note zone set temperatures relative to the activities and occupancy	25		as before
C39	Check control basis to avoid simultaneous heating and cooling	1		
C40	Assess the refrigeration compressor(s) and capacity control	15		5 min for each compressor, by the machine display
C41	Assess control of air flow rate through air supply and exhaust ducts	120		with measurement of air flow at the first and the last of each air channel
C42	Assess control of ancillary system components e.g. pumps and fans	3		
C43	Assess how reheat is achieved, particularly in the morning	0		not available
C44	Check actual control basis of system	10		
	TOTAL TIME TAKEN (minutes)	**1'374**		
	TOTAL (seconds/m^2)	**2.65**	Area (m^2)	31065

Overall conclusions

This case study is unique for some of its features:

- high amount of potential cooling power, but lack of electric power to run all the chillers
- 24 hours operation, every day of the year
- low internal load (for a tertiary sector building)

For those reasons the building owner is considering the installation of a Combined Heat and Power system, running on natural gas (Otto cycle). An energy and economic balance was made, demonstrating that this installation has a payback time of about 4 years, if the system will be correctly managed.
The system should be coupled to an absorption system to provide cooling power in summer.

In summary, this case study shows that:

1. **Absorption chiller coupled with CHP system is an option that should decrease dramatically electric consumption of HVAC system, if it is operated in the correct form.**

2. **Installation of additional cooling capacity has to be accurately assessed, not only taking into account building thermal load, but also electric peak power available.**

3. **Buildings aged more than one century does not permit major envelope modifications. Transparent surfaces should be improved, but with low energy savings (and extremely high payback time).**

IT Case Study 4:
Office and Laboratories –Air and Water system

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CASE STUDY:
SELEX: Office/Labs in a 16 floors tower with air/water system

This case study examines a 16 floor office/laboratories building built in 2004. The A/C system is an air and water, two-pipe chilled beams type. Mechanical ventilation is provided by 3 AHU's. The HVAC system is supported by district heating and screw compressor chillers.
The cold generators for the system are two electric chillers McQuay WHS.266.2 ST 134 (screw compressors).

Building Description

Country & City	Italy, Genova
Building Sector /Main Activity	Office / Laboratories
Net Area[m²]	8591

Installed Plant

Parameter	Installed electrical load / kW	Floor area served / m^2 GIA	Installed capacity W/m^2 GIA	Annual consumption kWh	Average annual power W/m^2	Annual use kWh/m^2	Average annual power (% FLE)
Total Chillers nominal cooling capacity (cooling output)	1'868.0	8'591.0	217.4				
Total Chillers	414.0	8'591.0	48.2	253'000.0	3.4	29.4	7.0
Total CW pumps[a]	125.5	8'591.0	14.6	383'601.0	5.1	44.7	34.9
Total fans	64.0	8'591.0	7.4	195'621.2	2.6	22.8	34.9
Total humidifiers			-		-	-	-
Total boilers		8'591.0	-		-	-	-
Total HW pumps	65.0	8'591.0	7.6	198'677.8	2.6	23.1	34.9
Total HVAC electrical	668.5	8'591.0	77.8	1'030'900.0	13.7	120.0	17.6
Total Building Elec kWh		8'591.0		4'851'400.0	64.5	564.7	
Total Boilers/Heat kWh	1'700.0	8'591.0	197.9	2'569'000.0	34.1	299.0	17.3
Total Building Gas/Heat kWh		8'591.0			-	-	

Energy savings

ECO CODE	DESCRIPTION	TOOLS	Saving
E1.1	Install window film or tinted glass[1]	Simulated with Benchmark	-10% on summer monthly electric consumption of HVAC system
E2.4	Correct excessive envelope air leakage	Simulated with Benchmark	-4-10% of HVAC consumption in summer -10-15% of heat consumption in winter[2]
E2.6	Apply night time over ventilation	Measured on summer consumption	1.5-5% of summer HVAC consumption
E3.9	Use double or triple glaze replacement	Simulated with Benchmark	-15% on summer monthly electric consumption of HVAC system
E4.5	Replace electrical equipment with Energy Star or low consumption types	Simulated with Benchmark	-13.3% on annual electric consumption of the whole building
E4.6	Replace lighting equipment with low consumption types	Simulated with Benchmark	-10.6% on annual electric consumption of the whole building

[1] This solution has some criticism: in hot summer days the glass resistance to high temperature is not guaranteed

[2] The variability of the estimation is due to the uncertain assessment of actual envelope leakage

Overview of building and system

This case study examines a 16 floor office/laboratories building built in 2003-4, which hosts the headquarters of Selex Communications, a company which designs and produces communication systems for military applications. The A/C system is an air and water, two-pipe chilled beams type. Mechanical ventilation is provided by 3 AHU's; fan power is rated at 30 kW for two larger units and 5 kW for the smaller one. The lighting system in the building is standard, without any type of PIR control.

The HVAC system is supported by district heating and screw compressor chiller. There are 3 heat exchangers for the heating circuit (2 rated at 850 kW each and one rated at 150 kW thermal power) and 2 for the cooling circuit (each one rated at 440 kW cooling power). The heating water is circulated on a primary circuit by 2 x 3 kW pumps. The hot water is circulated by 2 pumps, rated at 1.1 and 4 kW each.

The cold generators for the system are two electric chillers McQuay WHS.266.2 ST 134 (screw compressors) rated at 934 kW of cooling capacity each, with a maximum electrical consumption of 207 kW each, manufactured in 2004. The chilled water produced by these chillers is distributed by 3 x 15 kW fixed speed pumps on the primary circuit. Condenser heat rejection is achieved with a water loop including two evaporative towers. The water loop circulating pumps are 3 and rated at 18,5 kW each.

The building has an electrical consumption metering system connected to the BMS.

The values currently available are:

- Main electrical consumption
- Electrical consumption of the HVAC centrals and sub-centrals,
- Electrical consumption of other loads
- Thermal consumption of heat exchangers
- Water consumption of the building
- Water consumption of evaporative towers

Summary of building and systems

The following table summarises the main aspects of the building (based on EPA-NR and and Harmonac inspection procedures):

Building Description	
Building Sector /Main Activity	Office/Laboratories
Net Area[m²]	8591
Max number Occupants	844
N° Zones	3

Zone Description

Zone ID	Activity Type	Net Area	N° Occupants
1	Offices	8591	844

Heating/Cooling Production		Normalised/m² GIA	Notes
Conditioned net Area	[m²]	8591	1-3
Chillers nominal cooling capacity	1868 [kW]	217.4 W/m²	2x 934 kW
Chillers nominal electrical demand	414 [kW]	48.2 W/m²	
Chillers chilled water circulation pumps nominal electric demand	70 [kW]	8.1 W/m²	
Heat rejection unit water pumps nominal electric demand	55.5 [kW]	6.5 W/m²	3x 18.5, normally 2 in function
COP	4.5	-	
Operation Hours	2641	-	total hours. 1500 starts
Heated net Area	[m²]	8591	
Heat Exchanger heating capacity	1850 [kW]	215.3 W/m²	2x850 + 1x150 Heat exchanger (DISTRICT HEATING)
Heat Exchanger hot water circulation pumps nominal electrical demand	65 [kW]	7.6 W/m²	
Nominal Efficiency	95 [%]	-	

Measured annual performance

		Normalised/ m² GIA	Notes
Total Building Electrical Consumption	**4851.4** [MWh]	**564.7** kWh/m²	2008 data
• HVAC Equipment	**1030.9** [MWh]	**120.0** kWh/m²	2008 data
Total Building Heat Consumption	**2569.0** [MWh]	**299.0** kWh/m²	district heating
Total Building Water Consumption	**13516.5** [m³/year]	**1573.3** l/m²	**16.0** [m³/person*year]
HVACs' system components			
Main Chillers	**253.0** [MWh]	**29.5** kWh/m²	**7.0** % of Full Load Equivalent (FLE)

Main Eco's identified

ECO CODE	DESCRIPTION	TOOLS	Saving
E1.1	Install window film or tinted glass[3]	Simulated with Benchmark	-10% on summer monthly electric consumption of HVAC system
E2.4	Correct excessive envelope air leakage	Simulated with Benchmark	-4-10% of HVAC consumption in summer -10-15% of heat consumption in winter[4]
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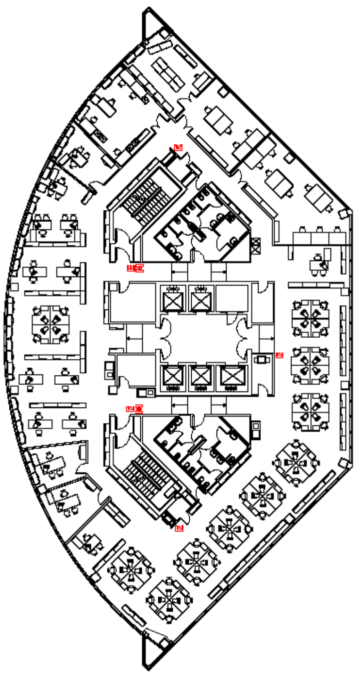
3 This solution has some criticism: in hot summer days the glass resistance to high temperature is not guaranteed

4 The variability of the estimation is due to the uncertain assessment of actual envelope leakage

Case study details - Building Description



General building data

Country/City	Italy/Genova
Latitude/Longitude[°]	44°25'19''92 N 08°54'18''72 E
Elevation [m]	15
Cooling Degree Days	1'435
Building Sector/Main Activity	Office/Office
Total net floor area [m²]	8'591
Ceiling height [m²]	3.1
Number of floors	16

Case study details - Constructions details

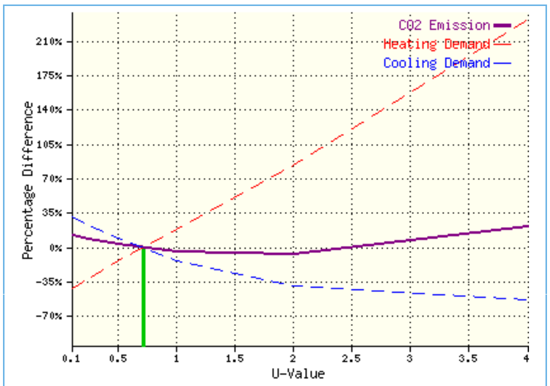
The building has a steel structure and cast concrete slabs.

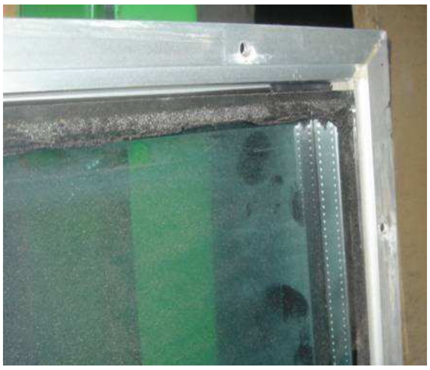
Envelope – Heat Transfer Coefficient [W/m².K]	
External wall (predominant)	**0.71**
Floor (predominant)	**1**
Intermediated floor (predominant)	**1.6**
Roof (predominant)	**0.5**

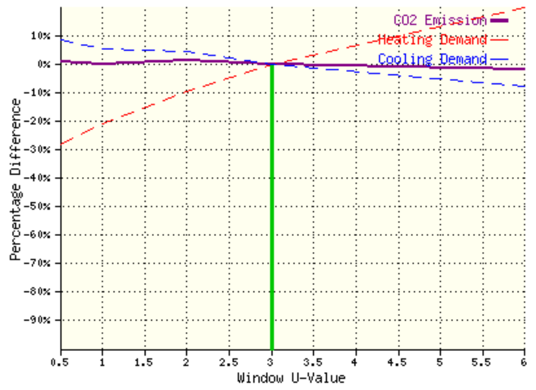
Windows	
U- value (predominant) [W/m².K]	**2.98**
Window type	**8mm OPTIFLOAT BLUE GREEN + 16mm AIR + 6,8mm OPTILAM**
Window gas	**AIR**
Solar Factor	**0.424**
Solar Protection Devices	
Window Overhangs	**NO**
Shading Device	**CURTAINS**

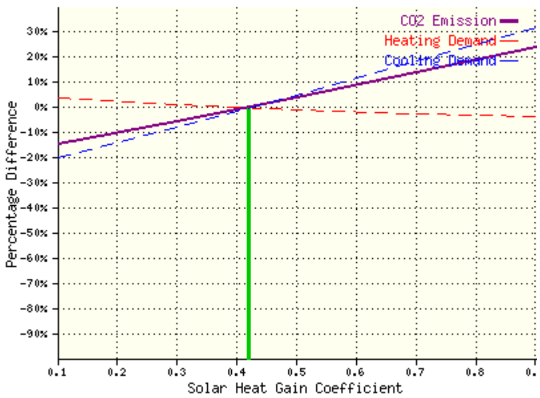
Figure – Construction details

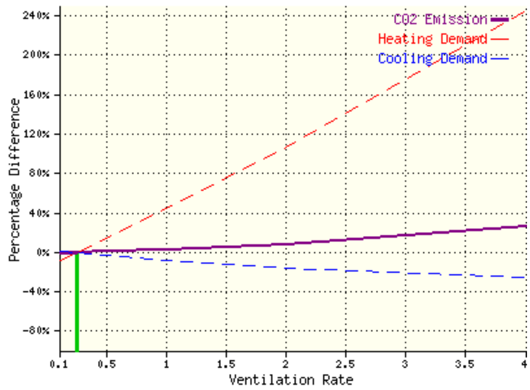
Figure – Curtains











Internal gains and operation schedules per zone

Zone ID:	**1**
Activity type	**Office**

Equipment electric loads/Schedules	**Design**	**Measure/observe - Winter/Summer (average)**
Office equipment [W/m²]	20	**22**
Working schedule		**8:00-18:00 Mon-Fri**
Permanent/variable occupancy		**844/900**
Cleaning staff schedule	-	**N.A.**
Lighting [W/m²]	30	**28**
Type of lighting		**fluorescent tubes**
Lighting control		**manual**
Lighting schedule		as working schedule, but depending on natural light availability

Due to the high percentage of transparent surfaces, should be assessed the feasibility of a PIR automatic control for lightning.

Figure – Luminaries position/distribution

Figure – Luminaries position/distribution

Monitoring observations for internal gains

Harmonac tools were used on this Case Study to determine the thermal loads and to compare electric consumption due to HVAC system.
The graphs and table below shows simulation parameters and outputs.

Simulation building parameters

Geometry	
A_{floor} - Total floor area of the zone [m²]	13580
n_{storey} - Number of storey of the zone [-]	16
h_{zone} - Ceiling height of the zone [m]	3,85
EXTWFR - External walls to floor ratio [m²/m²]	0,28
WINWR - Windows to walls ratio [m²/m²]	0,92
INTWFR - Internal walls to floor ratio [m²/m²]	0,52
Ventilation & Gains	
$ACH_{ventilation}$ - Nominal mechanical ventilation rate [Air Change per Hour]	0,9
$X_{out,min}$ - Minimal fresh air fraction [-]	0,5
$ACH_{infiltration}$ - Infiltration rate [Air Change per Hour]	0,1
$IGFR_{appl}$ - Plug loads density [W/m² of floor]	18
$IGFR_{light}$ - Lighting density [W/m² of floor]	12
$Metab_{occ}$ - Occupants total metabolic rate [W/occ]	135
$n_{occ,max}$ - Maximal number of occupants [occ]	844
Temperature & Humidity Setpoints	
$t_{a,in,heating,min}$ - Night/WE indoor heating setpoint [C]	17
$t_{a,in,heating,occ}$ - Occupancy indoor heating setpoint [C]	20
$t_{a,in,cooling,occ}$ - Occupancy indoor cooling setpoint [C]	26
$t_{a,in,cooling,max}$ - Nighr/WE indoor cooling setpoint [C]	28
$RH_{in,min}$ - Humidification indoor relative humidity setpoint [-]	0,4
$RH_{in,max}$ - Dehumidification indoor relative humidity setpoint [-]	0,6

Simulation HVAC system parameters

Heating Terminal Units (HTU) — **Zone 1**

$type_{HTU}$ - Heating Terminal Units type [0 to 5]: 3

(1) Heating Fan Coil Unit (HFCU - k_{aux} = 0.045)
(2) Heating Induction Unit (HIU - k_{aux} = 0)
(3) Heating Radiant Ceiling Panels (HRCP - k_{aux} = 0.01)
(4) Radiator (RAD - k_{aux} = 0)
(5) Terminal Reheat Box (no CTU - k_{aux} = 0)

$t_{hw,su,HTU,n}$ - Supply hot water temp. [C]: 40
$\Delta t_{hw,HTU,n}$ - Hot water temp. variation [K]: 20
$k_{aux,HTU}$ - Specific auxiliary consumption [W/W]: 0,01

Design factor (e.g. 1.15 = 15% oversized heating capacity)

$F_{sizingHTU}$ = 1,1 [-]

Cooling Terminal Units (CTU) — **Zone 1**

$type_{CTU}$ - Cooling Terminal Units type [0 to 5]: 3

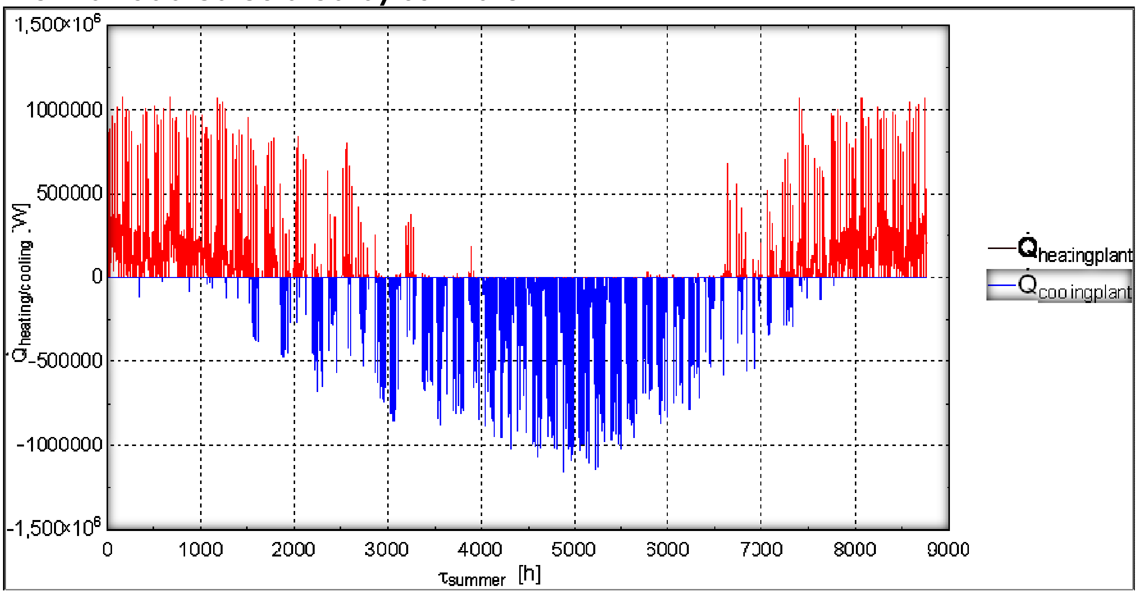
(1) Cooling Fan Coil Unit (CFCU - k_{aux} = 0.025)
(2) Cooling Induction Unit (CIU - k_{aux} = 0)
(3) Cooling Radiant Ceiling Panels (CRCP - k_{aux} = 0.01)

$t_{cw,su,CTU,n}$ - Supply chilled water temp. [C]: 7
$\Delta t_{cw,CTU,n}$ - Chilled water temp. var. [K]: 5
$k_{aux,CTU}$ - Specific auxiliary consumption [W/W]: 0,01

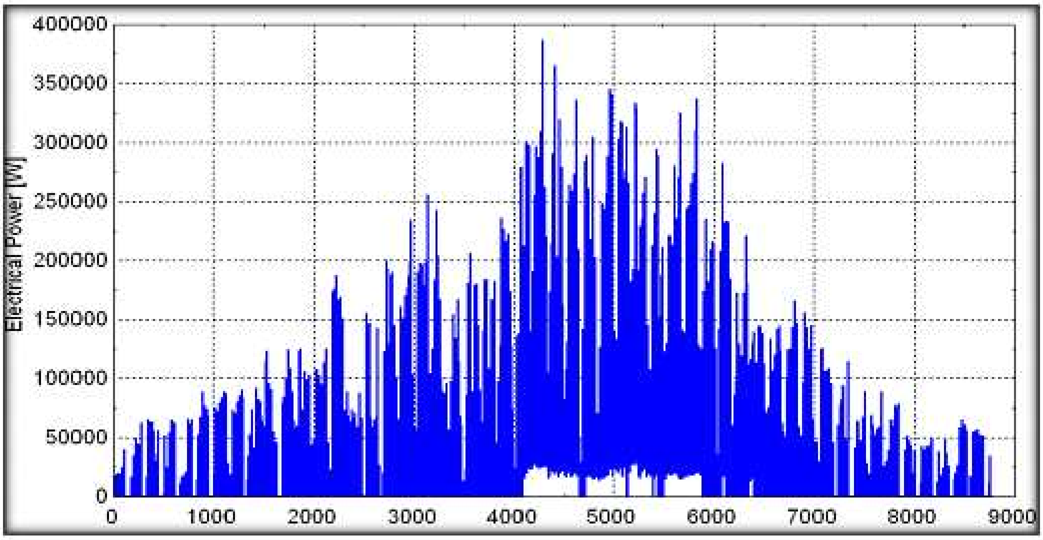
Design factor (1.15 = 15% oversized heating capacity)

$F_{sizingCTU}$ = 1,22 [-]

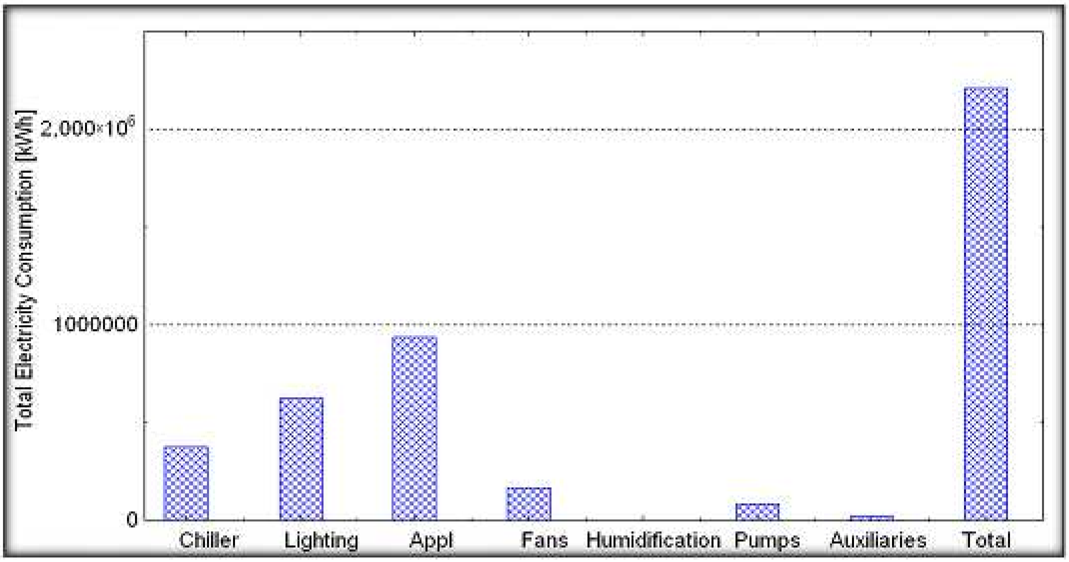
Thermal load calculated by software



Electric consumption of chiller calculated by software

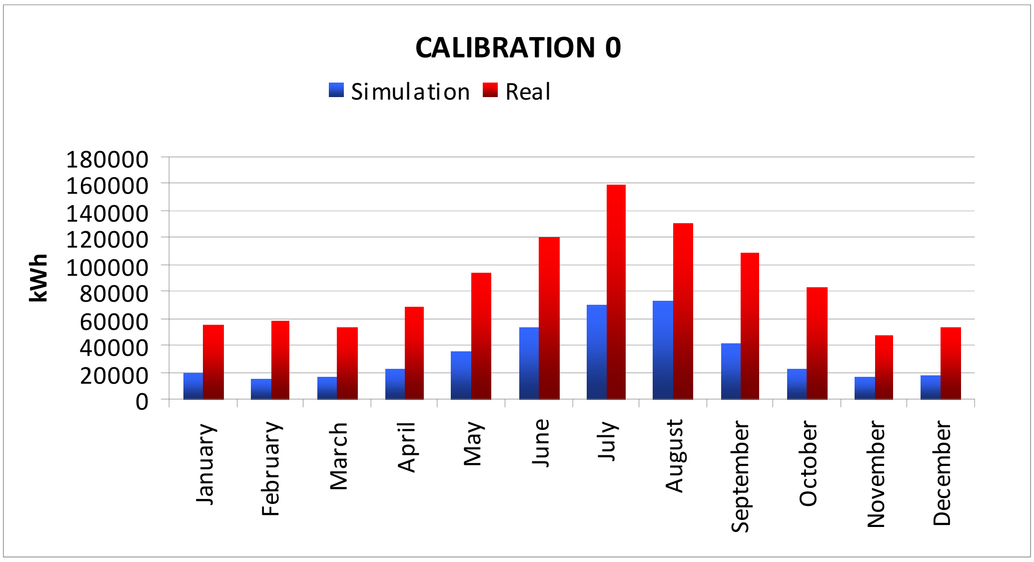


Electric consumption of different loads calculated by software



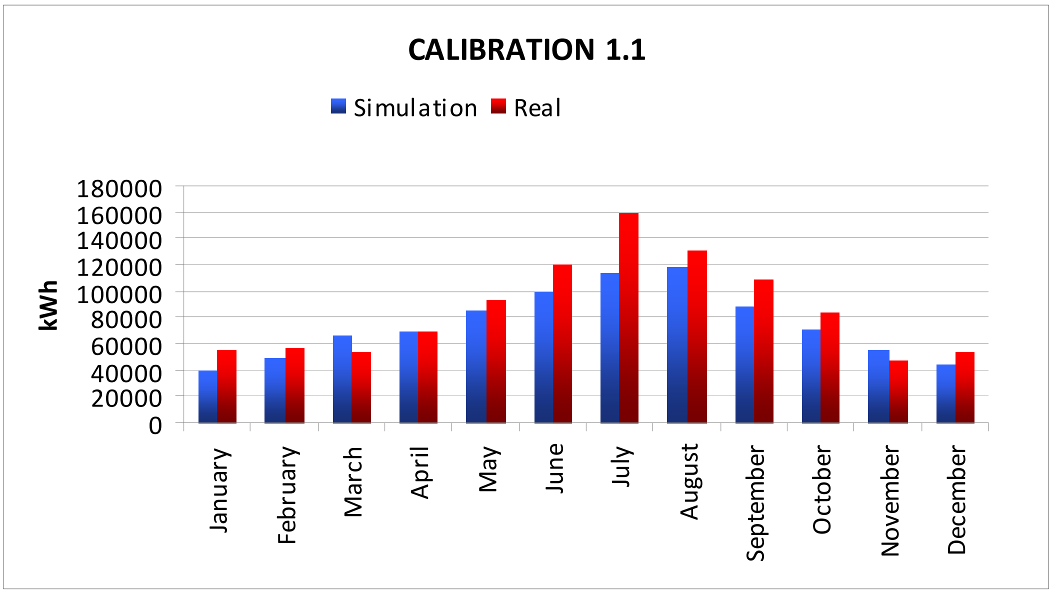
Simaudit calibration

According to the Harmonac tools, a set of subsequent calibration was produced. The **"Calibration 0"** is the first output of the software, resulting in an underestimation of electric consumption in all the months of the year, especially in summer season.



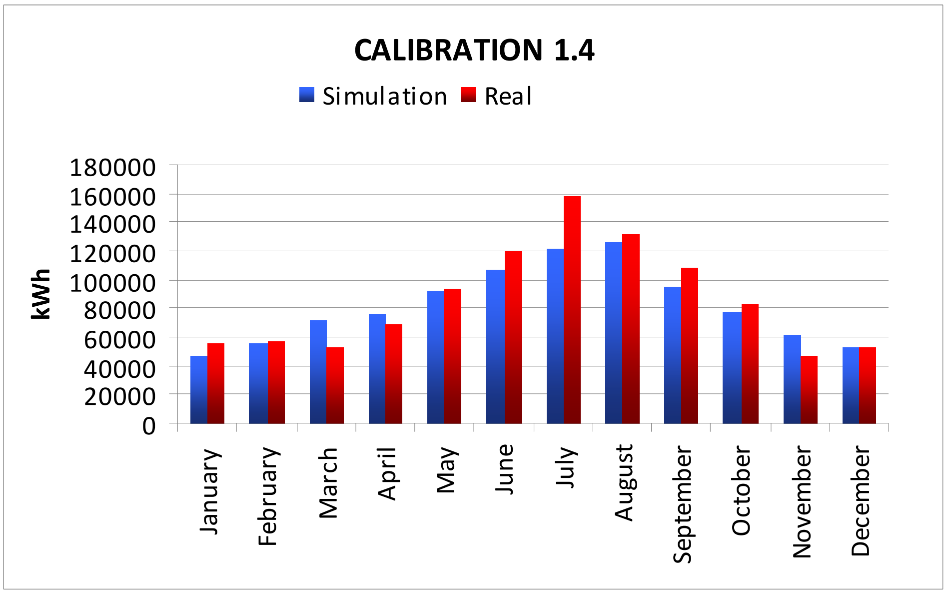
Calibration 1.1 was performed adjusting internal set point parameters, especially internal temperatures during summer season. Data provided by internal conditions survey were used (see "Monitoring observations for environmental parameters" section for furthers details).
Input changed form calibration n°0 to n°1:

- Raised internal temperature by 0.1 °C;
- Adjusted schedule of HVAC system in summer season (7:00-17:40 instead of 7:30-17:30), according to HVAC system manager);
- Increase of electric appliance utilization factor during work time (from 90% to 100%)



This calibration shows a good overall result, but significant errors affect the data: difference between simulation and real monthly consumption varies from -40% to +15%.

Other calibrations were made; after 4 steps the simulation shows the best fitting to real consumption data. The graph clearly shows a good overall fitting on almost all the year, excluding on July, the hottest month of the year.
This should be explained by some inefficiency in the HVAC system at full load. The fixed air-to-air heat recuperator mounted on the AHUs causes some over consumption, especially on the first hours of the day, when the HVAC system starts. In this situation internal temperature is often higher than external temperature, and the heat recuperator causes inefficiency. This should be avoided with a by-pass system on the intake air of the AHUs.



Environment parameters

Description of the environment design conditions, Heating/cooling loads, design temperatures (from UNI EN 10349).
Climatic data was provided by ARPA Liguria, the regional environmental protection public agency.

Outdoor Environment Parameters	Design	Measure/observe - Winter/Summer (average)
Outdoor air temperature [°C] Winter/Summer	**N.A./24.6** mean, **0/29.9** design Temp	**8.6** / **24.4** average min **0** / max **33.3**
Outdoor Relative Humidity [%] Winter/Summer	**80** /**60** UNI 10339	**62.7**/ **67.3** average
Max. Solar Radiation [W/m²]		**940**

Zone ID:	**1**
Activity type	**Office**

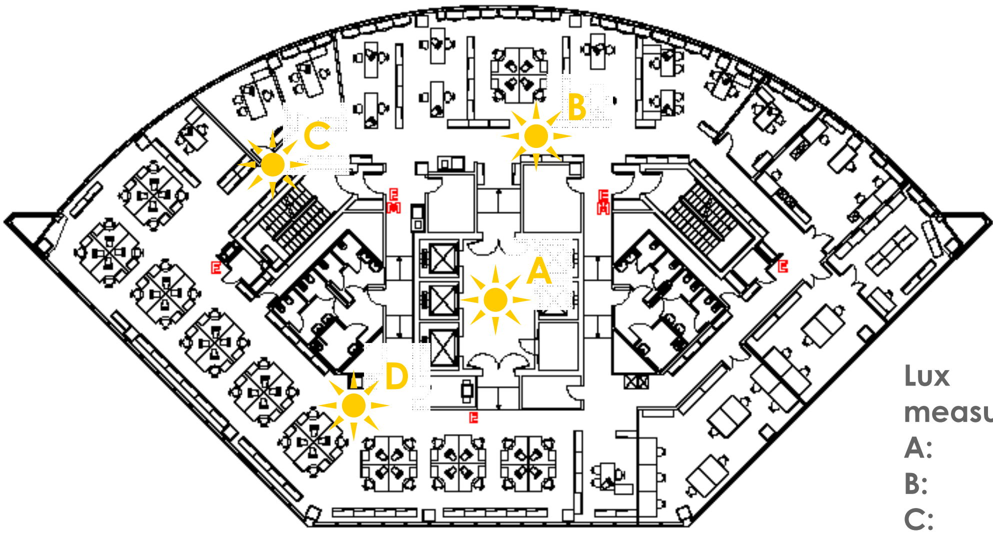
Indoor Environment Parameters per zone	Design	Measure/observe - Winter/Summer (average)
Ventilation Rate [ach]	0.5	
CO_2 threshold / CO_2 measured [ppm]		
Indoor Relative Humidity [%]	50	**40.6**/**49.9** average
Indoor air Temperature [°C] – Winter/Summer (state whether air temperature or operative temperature)	20/	**20.9**/**26.4** average air temperature
Lighting [lux]		A: 200 B: 400 C: 130 D: 220 see figure below

Monitoring observations for environmental parameters

The interior lighting level was measured using a photoelectric cell. Measures were made on storey n°12, in four different points, named A, B, C, D on 12 April 2009.
Photographs of interior spaces were limited due to the policy of the building owner: no pictures of the work stations were allowed.

Interior picture of daylight situation

Interior picture of artificial light situation



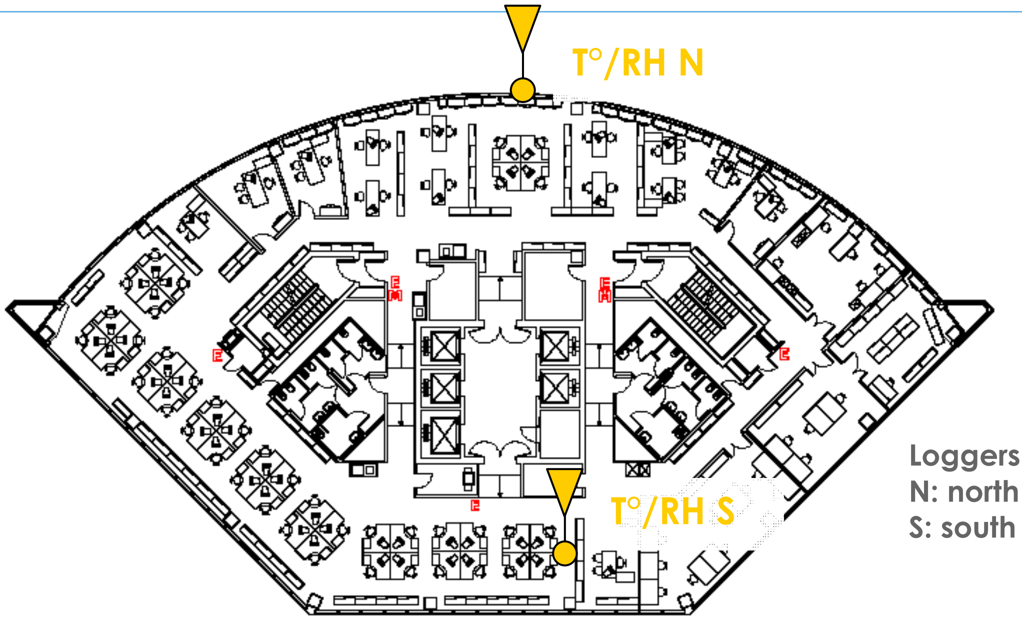
Localization of measurement points of interior light

Lux measured

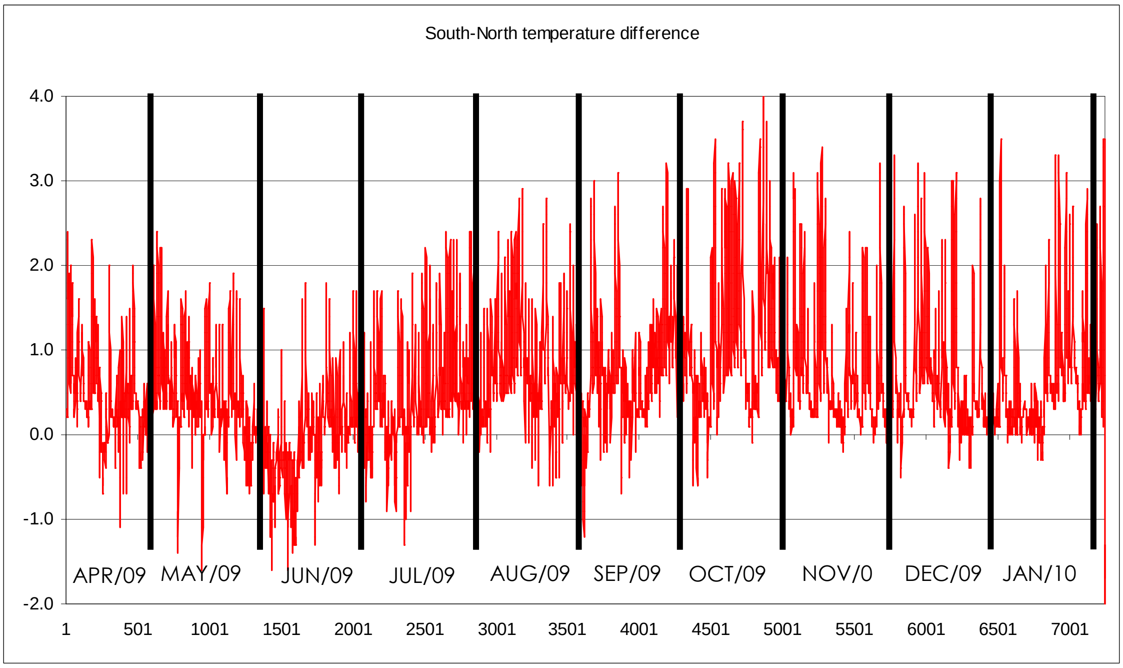
A:	**200**
B:	**400**
C:	**130**
D:	**220**

The BEMS installed in the building provides logs of internal temperature. However, such data show a low reliability. For this reason two self powered RH/T loggers were installed. The HVAC system manager reported that occupants often comply about temperature control. Particularly, occupants working on the south part of the building reported low temperature in Winter and high temperature in Summer. For this reason the loggers were installed in the office zone, close to the north and south facade, on the 12th storey. The survey was conducted from April 2009 to February 2010.

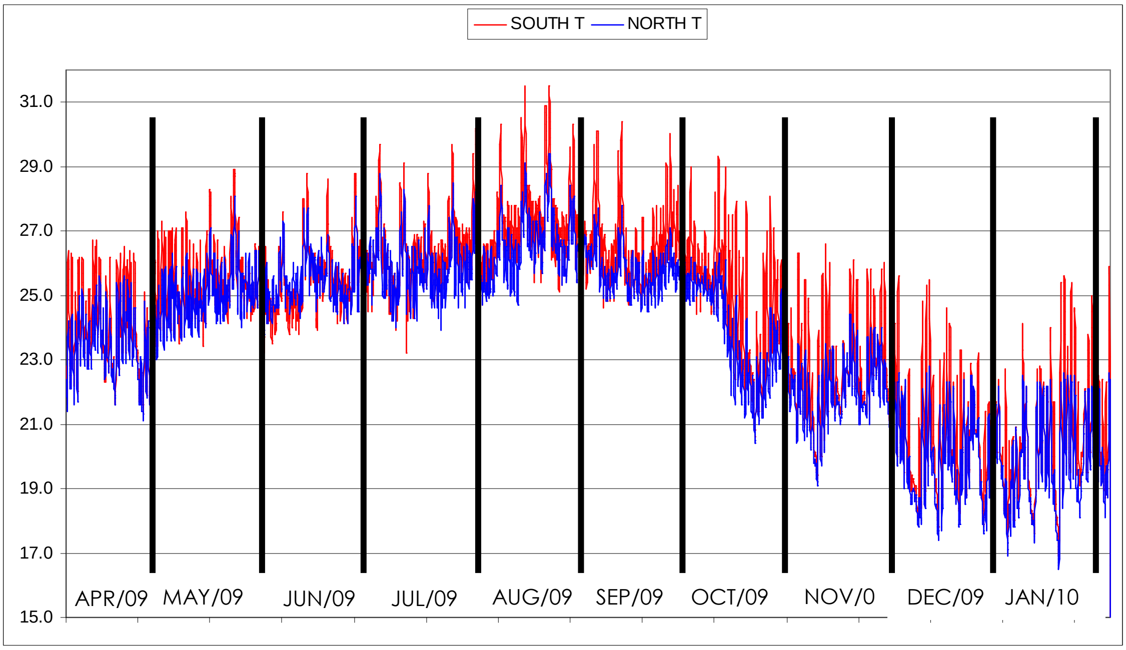
Results show that temperature difference is around 1°C in middle Season and goes above 4°C in Summer and Winter.



Localization of measurement points of Temperature and Relative Humidity

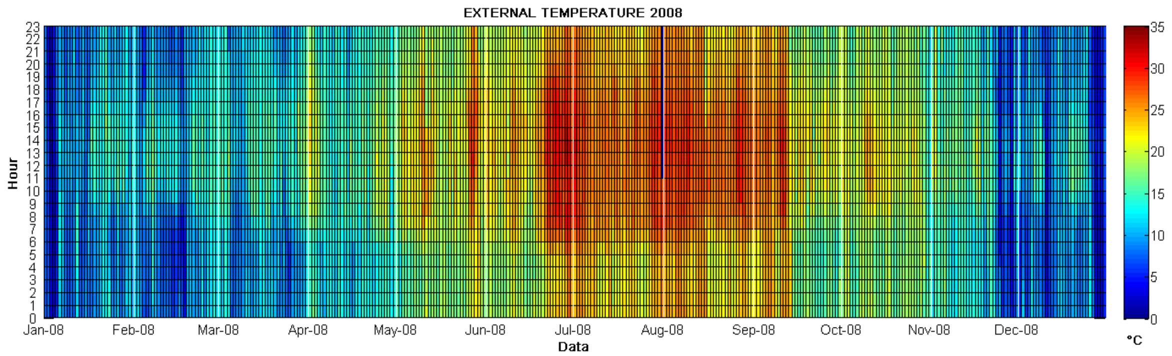


As visible in the graph, the temperature difference between northern and southern part of the building is distributed along the whole year. For almost all the months, this difference has a positive sign: this obviously implies that the south part of the building is always hotter than the north part.
Nevertheless, an interesting aspect of survey is that the maximum difference of temperature occurs during winter months. This behaviour is caused by the lower inclination of the sun on the horizon during the winter season. In addition the internal temperature control of HVAC system is based on a single probe for a whole storey: this implies that it is almost impossible to provide comfort conditions to all the occupants. Actually, the system manager manually adjusts the set point temperature day by day, depending on discomfort situation (typically hot on the south part and cold on the north part).

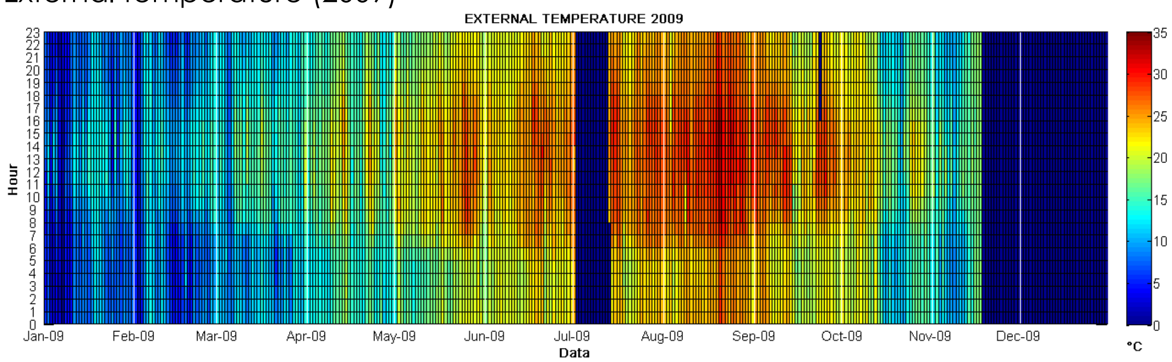


Climatic data were provided by ARPA Liguria, the regional environmental protection agency, whose main climatic station is located within a 3 km radius from the building analysed.

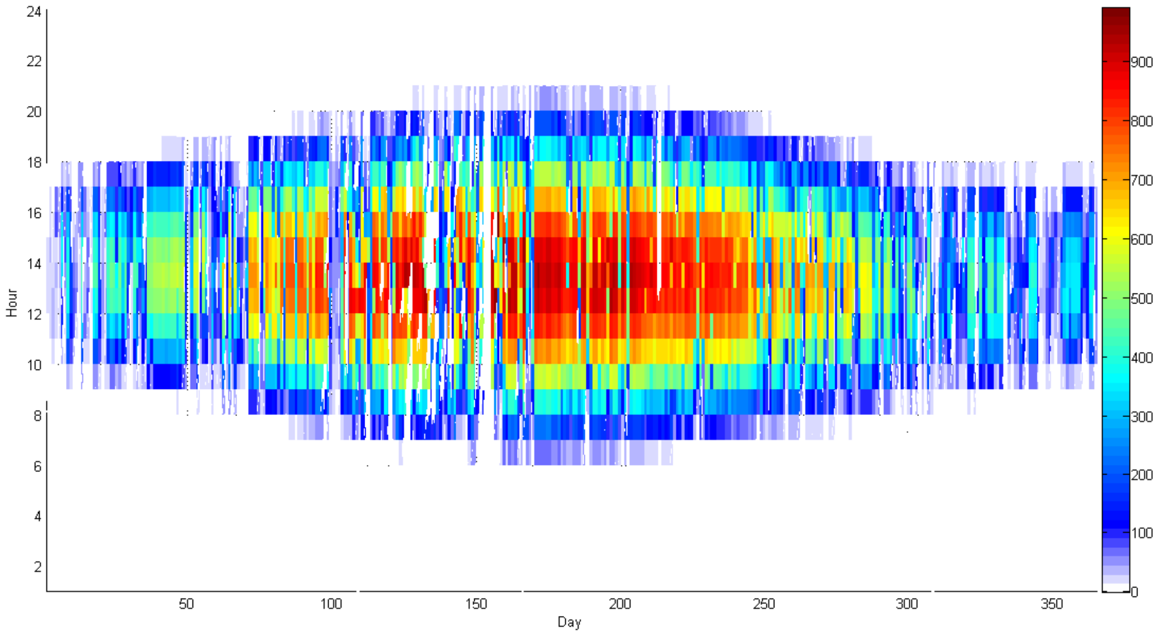
External temperature (2008)



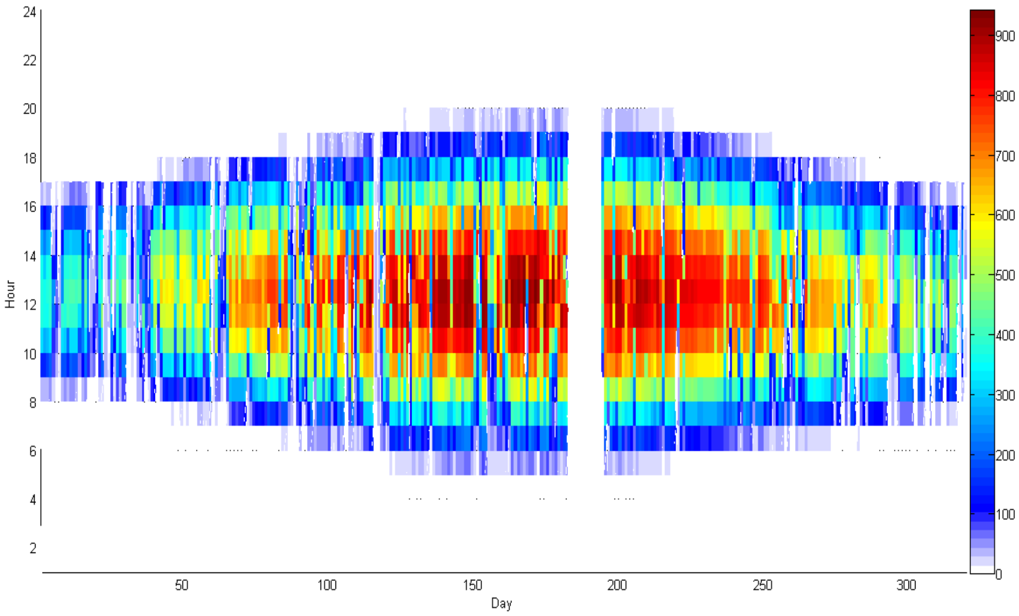
External temperature (2009)



Solar Irradiance (2008)



Solar Irradiance (2009)



The structure, in steel and concrete, has an intrinsically high permeability to air, compared to conventional brickwork structures.
Some complaints by the users revealed a non perfect sealing of some voids. Particularly some users complain about smells originated in the underground garage that are perceptible in the office area at the upper storeys. This is a clear sign that some void was not properly sealed.
Other comfort problems were encountered at the ground storey: in this area the HVAC system manager measured on a Winter Monday a temperature about 10°C at 50 cm from the floor. This should indicate an inefficient insulation of ground slab.

Air Flows Rates Environment Parameters per zone	**Design**	**Measure (average during operation)**
Total air flow rate supplied to the zone [h^{-1}]	**0.5 ACH**	
Total air flow rate extracted from the zone [m^3/h]or[h^{-1}]	**0.48 ACH**	
Minimum outside air supplied to zone [$m^3/(h.m^2)$]	**100% external air**	

HVAC system components

The HVAC system is supported by district heating and screw compressor chiller. The heating water is circulated on a primary circuit by 2 x 3 kW pumps. The hot water is circulated by 2 pumps, rated at 1.1 and 4 kW each.

The chilled water produced by these generators is distributed in a primary circuit by 3 x 15 kW fixed speed pumps. Condenser heat rejection is achieved with a water loop, including two water-to-air heater exchangers and 3 x 18,5 kW fixed speed pumps.

The Case Study considers each of the components of the system individually in the following order:

- Heating systems (heat exchangers) and pumps
- Cooling systems (cold generators) and pumps
- Heat rejection and pumps

Heat Exchangers and Pumps

Boiler Identification (X2)	
Manufacture/Model	Pacetti PHE
Year	2004
Equipment Type	water-to-water plates heat exchanger

Performance Data	
Nominal Heating Capacity [kW]	850
Installed Heating Capacity /m² GIA	215.3
Nominal Efficiency [%]	N.A.
Hot side water temperature [°C]	100-70
Cold side water temperature [°C]	65-80

Electrical data	
Power supply [V/Ph/Hz]	N.A.
Start-up amps [A]	N.A.

Auxiliary Equipment	
Fan Electrical Demand [kW]	
Pumps Electric Demand [kW]	65
Other	


Figure – Heat exchanger


Figure – District heating connection

Figure – Pumping system


Figure – motorised valves

Monitoring observations

Inspection	
Maintenance status	**Satisfactory**
Previous inspection/maintenance Reports	**No**
Operation time estimated [h]	**2500**
Thermal Insulation (Visual)	**Satisfactory**
Water leaks	**No**
Sensors calibration records	**No**
Meter readings data	**available**

Field measurements	
Thermal consumption [kWh]	**2211 MWh (2008 data)**

Figure – Heating consumption meter

Figure – Temperature of district heating network inlet

Cold Generator

Chiller Identification (X2)	
Manufacture/Model	McQuay WHS 266.2 ST
Year	2004
System Type	vapour compression
Compressor Type	screw
Fuel Type	el. energy

Performance Data	
Nominal Cooling Capacity [kW]	934
Installed Cooling Capacity /m² GIA	217.4
Nominal Electric Power [kW]	207
COP	4.52
SEER	
Refrigerant Gas	R134a

Electrical data	
Power supply [V/Ph/Hz]	380/3/50
Start-up amps [A]	1148

Figure – Equipment pictures


Figure – Cold generator Plant

Auxiliary Equipment	
Fan Electrical Demand [kW]	22 (evaporative tower fans)
Pumps Electric Demand [kW]	55.5 (heat rejection circuit)
Other	


Figure – heat rejection circuit pumping system


Figure – evaporative towers

Monitoring observations

Inspection	
Maintenance status	**Satisfactory**
Previous inspection/maintenance Reports	**Yes Data of last: april 2008**
Operation time estimated [h]	
Operating mode	
Thermal Insulation (Visual)	**Satisfactory**
Vibration eliminators	**Satisfactory**
Worn couplings	**Satisfactory**
Equipment cleanliness	**Satisfactory**
Compressor oil level	**Satisfactory**
Compressor oil pressure	**Satisfactory**
Refrigerant temperature	**Satisfactory**
Refrigerant pressure	**Satisfactory**
Chilled water systems leaks	**No**
Sensors calibration records	**No**
Refrigerant leaks	**No**
Location of the equipment	**Indoor**

Field measurements	
Electricity consumption [kWh]	**253.011 kWh (annual 2008 data)**
Electric voltage [V]	N.A.
Electric current [A]	N.A.

Heat Rejection System

Heat Rejection Identification	
Manufacture/Model	Baltimore aircoil
Year	2004
Cooling method	evaporative
Type	ev. tower

Performance Data	
Nominal Cooling Capacity [kW]	1200
Installed Cooling Capacity /m² GIA	
Nominal Electric Power [kW]	22
Total Heat Rejection [kW]	1200
Water flow rate [m³/h]	206
Water Pressure Drop [kPa]	N.A.

Electrical data	
Power supply [V/Ph/Hz]	380/3/50
Start-up amps [A]	N.A.


Figure – Equipment pictures

Auxiliary Equipment	
Fan Electrical Demand [kW]	22
Pumps Electric Demand [kW]	55.5
Other	

Monitoring observations

Inspection	
Maintenance status	**Satisfactory**
Previous inspection/maintenance Reports	**No**
Operation time estimated [h]	
Operating mode	
Thermal Insulation (Visual)	**Satisfactory**
Equipment cleanliness	**Satisfactory**
Operating water level (sump)	**Satisfactory**
Fan shaft bearings lubrification	**N.A.**
Drive system belt condition and tension	**N.A.**
Heat transfer section cleanliness	**Satisfactory**
Refrigerant leaks	**No**
Water systems leaks	**No**
Sensors calibration records	**No**
Correct rotation of the fan	**Yes**
Bleed rate [l/s]	**N.A.**

Control systems

The control system is based on a BEMS that allows the control of Temperature and Relative humidity in different zones of the building. As seen in "Monitoring observations for environmental parameters" section the zone temperature control presents a low degree of freedom. In fact each storey is treated as one thermal zone, provided with a single temperature probe. This implies some discomfort, especially during Summer and Winter.

Energy consumption data

Metering information

A complete energy metering system was installed in the building.

Data logged at 15 mins intervals are:

- Global electrical income
- Chilled water pumps electrical consumption
- Chillers electrical consumption
- AHU electrical consumption
- Total thermal energy to the building (from district heating)
- Thermal consumption for space heating
- Thermal consumption for DHW
- Total water consumption
- Evaporative towers water consumption

The monitoring survey refers to data from 01 January 2008 to 20 November 2009.

Monitoring observations

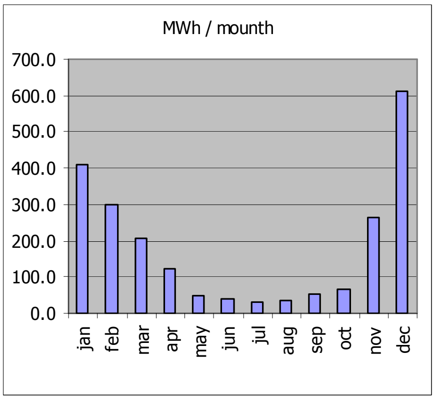
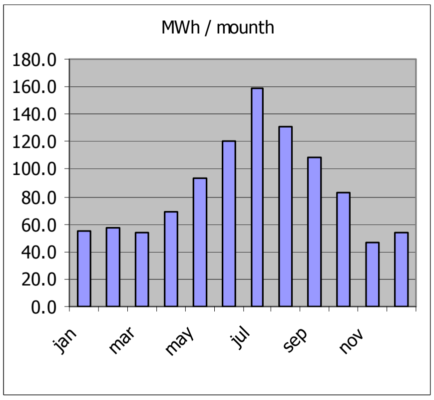
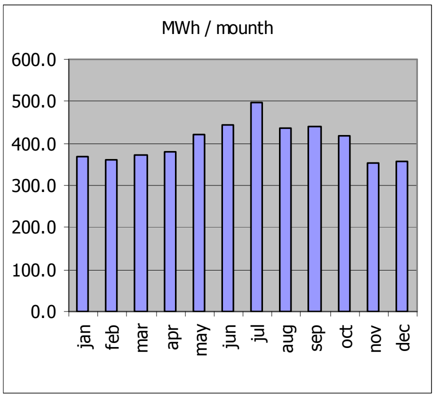
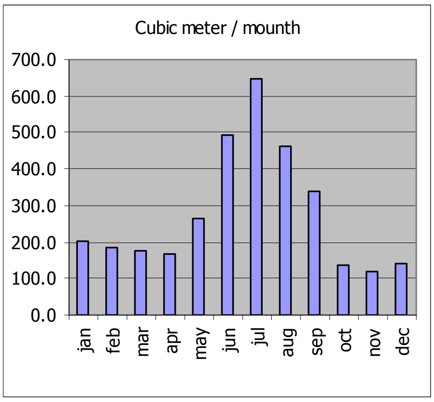
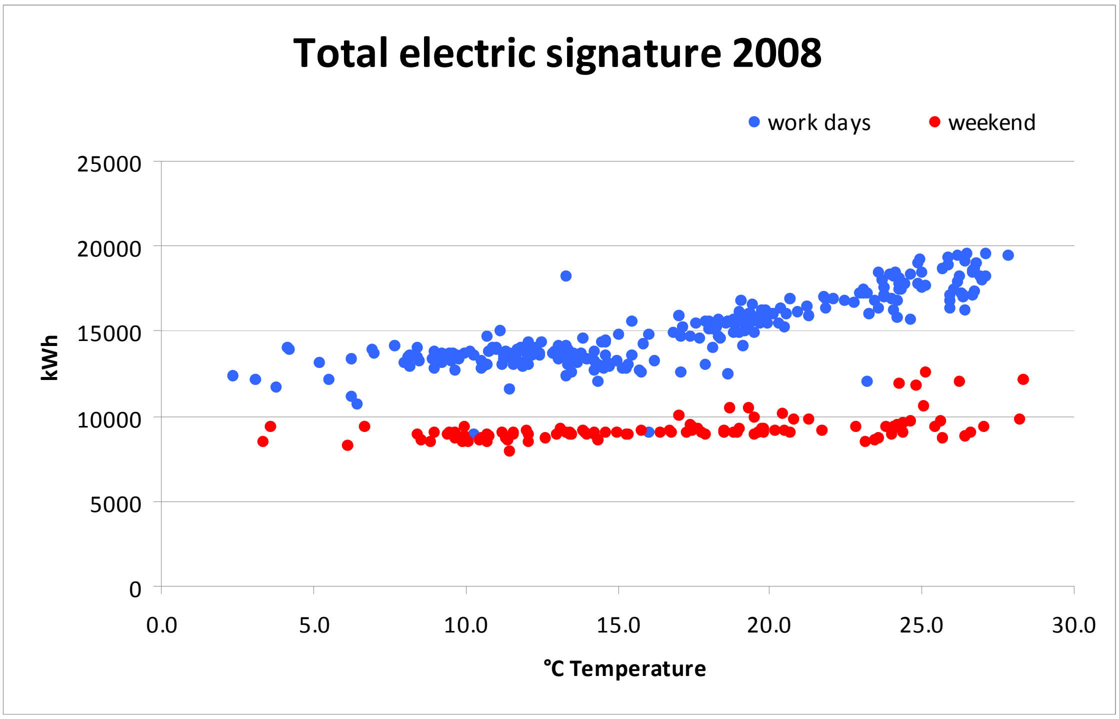
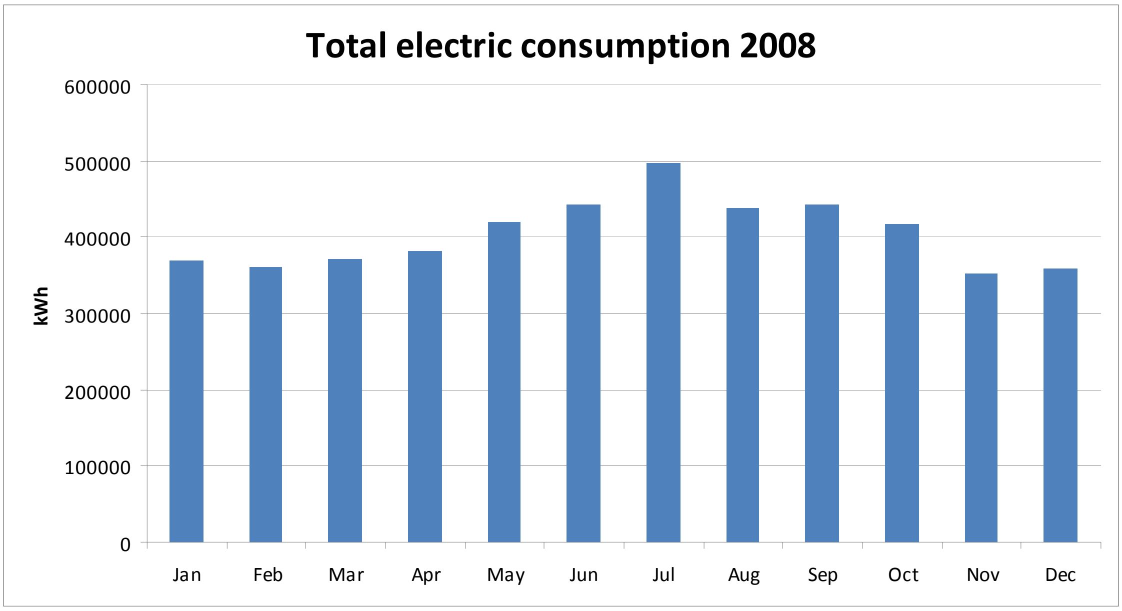
Heating [MWh]	HVAC el. consumtption [MWh]
	
Electricity [MWh/year]	HVAC Water [m³/year]AHUs + ev. towers
	

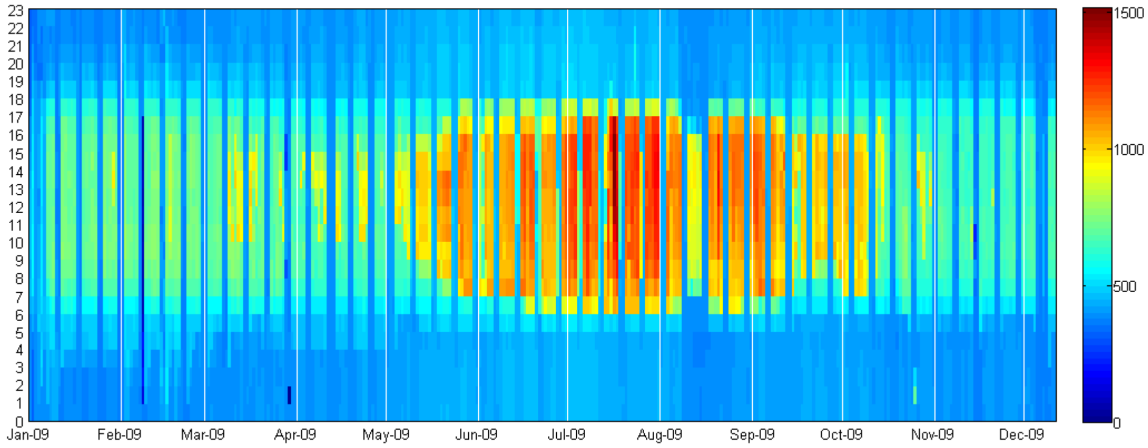
Fig: Summary of heating, cooling, electricity, gas and water consumption per month over the measurement period.

The building energy consumption is significant. The value of 564 kWh/m² per year is the highest value among Italian Case studies and field trials. An important part of this consumption is due to appliances installed in the building. As seen in the "Total electric signature" graph the electric consumption remains almost constant up to 15-16°C. This means that lighting power influence is low, compared to total appliance loads: there is not a decrease in electric consumption associated with increase of temperature (and also solar irradiation). Almost 120 kWh/m² is due to HVAC system.


Total electric signature 2008
work days
weekend
25000
20000
15000
10000
5000
0
kWh
0.0
5.0
10.0
15.0
20.0
25.0
30.0
°C Temperature


Total electric consumption 2008
600000
500000
400000
300000
200000
100000
0
kWh
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

The increase of electric consumption during summer is clearly seen in the graphs. The carpet plot shows that, from the first week of May to the second week of October, total hourly electric consumption is almost 50% higher than during the rest of the year. This is due to electric chillers, evaporative towers and cool water pumps, as shown in the further graphs on HVAC consumption.



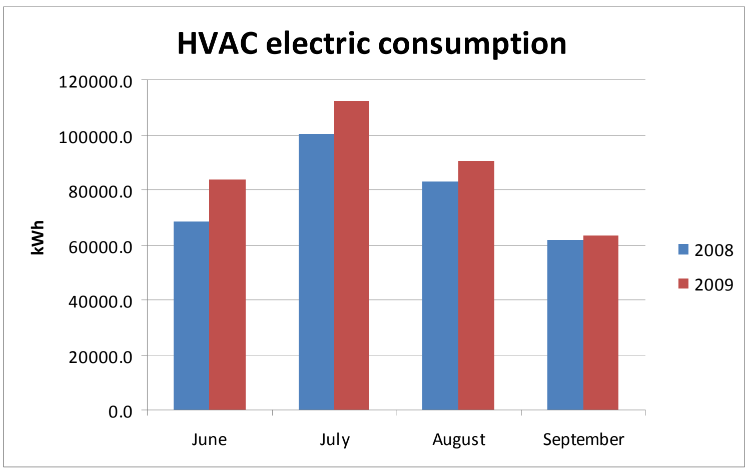
HVAC Consumption

The HVAC consumption presents an almost flat profile during winter, due to AHUs and pumps.

In summer season the consumption increases noticeably (about 50%) due to the electric chillers and evaporative towers.

The first part of the analysis shows the summer HVAC consumption comparison between 2008 and 2009 summer season, while the second part shows the different loads concurring on HVAC consumption.

The HVAC consumption between 2008 and 2009 is increased. This was due to the climatic conditions, as explained in furthers graphs.



The furthers graphs show electrical consumption of HVAC system (electric chillers+ AHUs+ evaporative towers+ pumps) just for the summer season. For the correlation with external enthalpy, the latter was calculated with the following formula (Ashrae 2009, Fundamentals) as a function of external temperature, relative humidity and air pressure:

$$h = 1.006t + W(2501 + 1.86t)$$

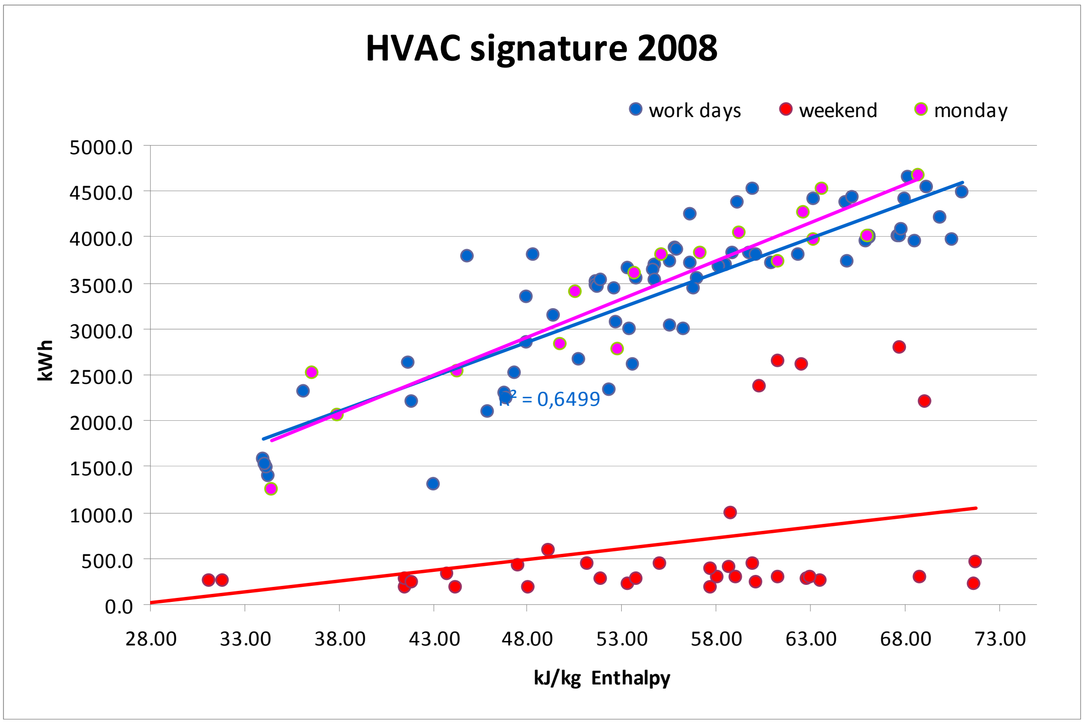
$$W = 0.621945 \frac{p_w}{p - p_w}$$

$$p_w = RH \cdot p_{ws}$$

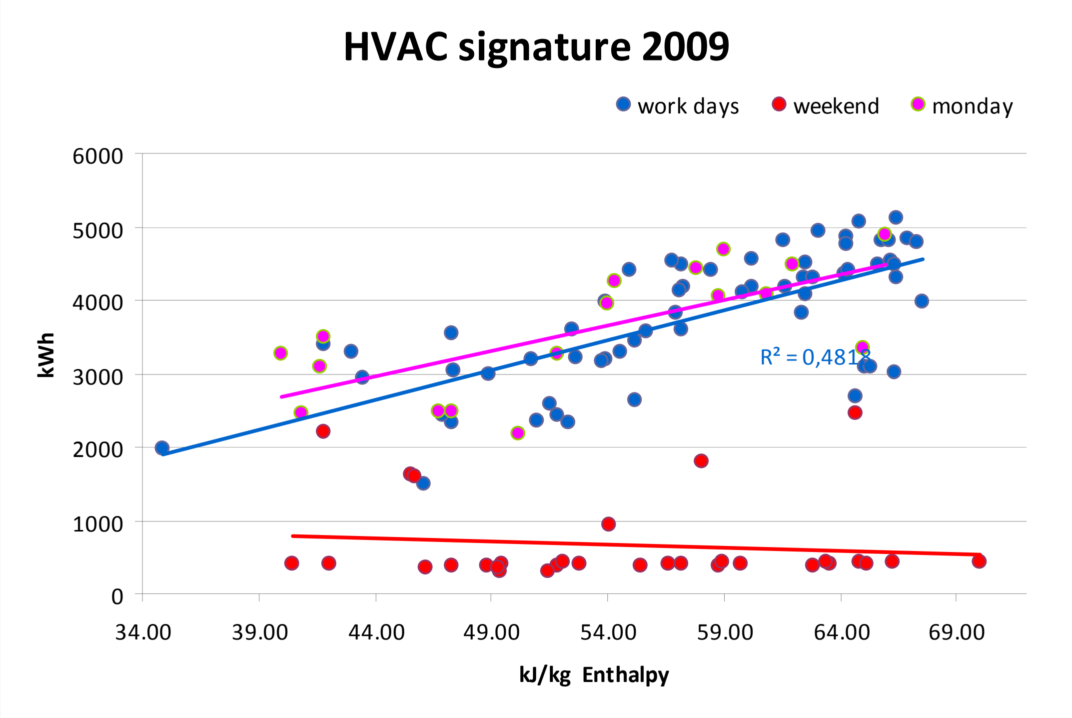
$$\ln(p_{ws}) = \frac{C8}{T} + C9 + C10T + C11T^2 + C12T^3 + C13\ln T$$

With:

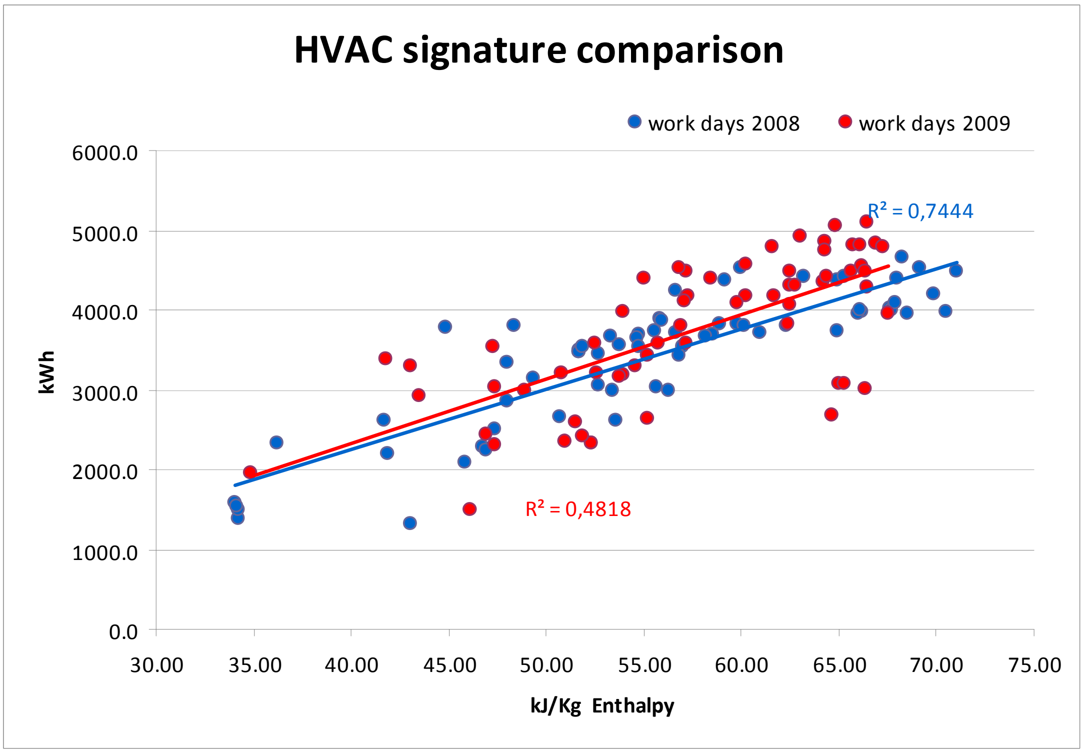
h	=	air enthalpy
t	=	ait temperature (°C)
Pw	=	vapour pressure
Pws	=	saturated vapour pressure
RH	=	relative humidity
C9-C13	=	constants



The profiles of the two years seem almost equal, on Monday the consumption is always a bit higher than in other workdays. On the other hand, weeks end days show a flat profile over air enthalpy: this implies that HVAC system is correctly turned off during non-working days.

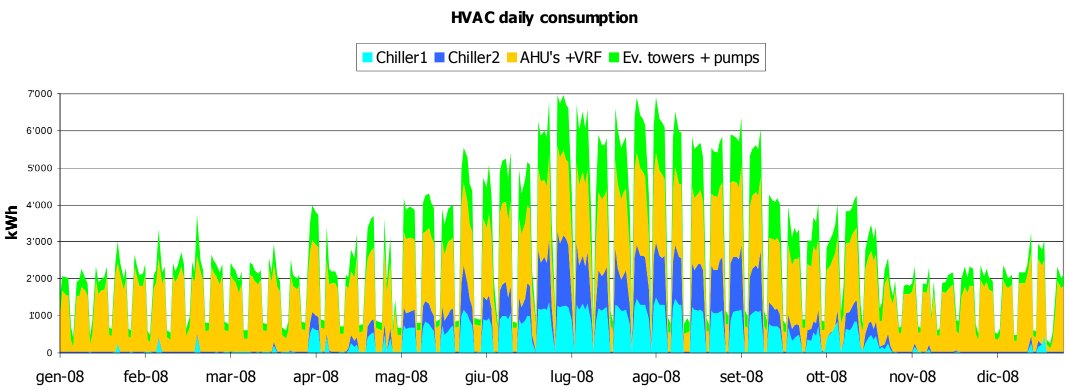


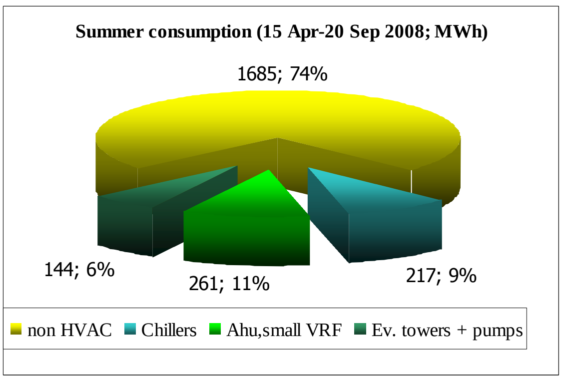
Focusing on working days, a comparison between 2008 and 2009 summer season could be done. The 2009 consumption data (red dots) appear to be more concentrated in the upper right corner of the graph, compared to 2008 data (blue dots). This means that in 2009 air enthalpy was higher than in 2008, on an average basis. The two regression lines appear really close and almost parallel; nevertheless a small increase on 2009 correlation is appreciable.

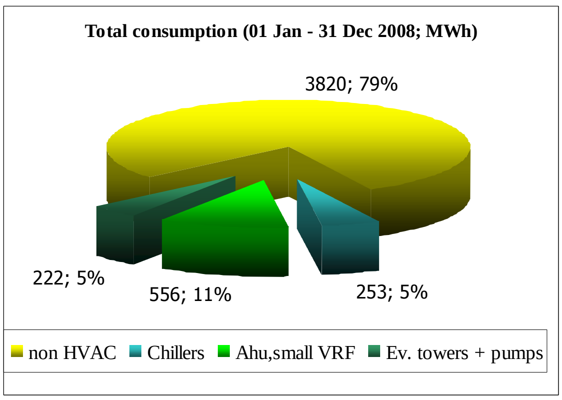


HVAC electrical loads

The electric power metering system installed in the building allows a specific analysis on different HVAC equipment consumption.



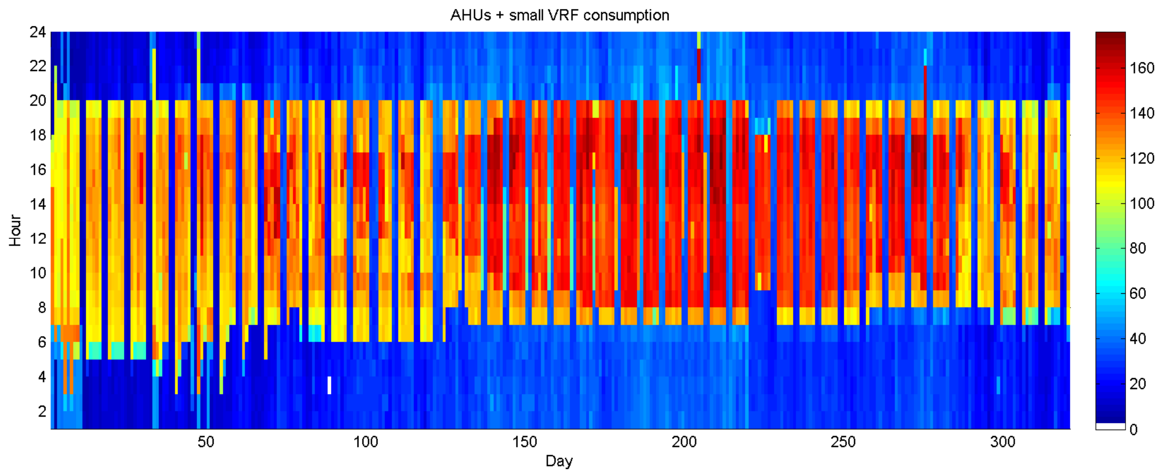




AHUs

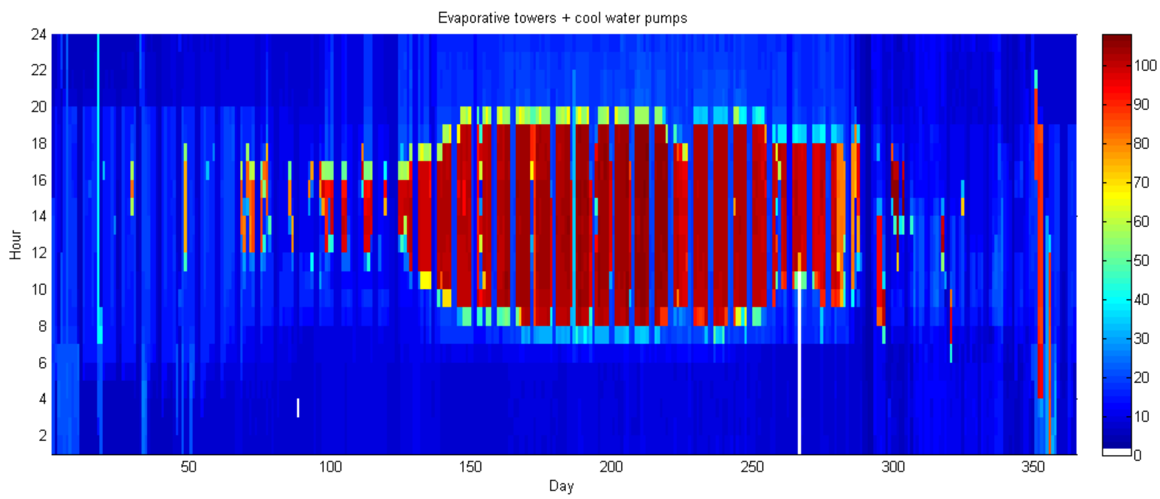
As seen in the graph below the AHUs and VRF systems consumption is almost constant during a typical work with some differences depending on the season:

- more operation hours in winter
- higher peak load in Summer



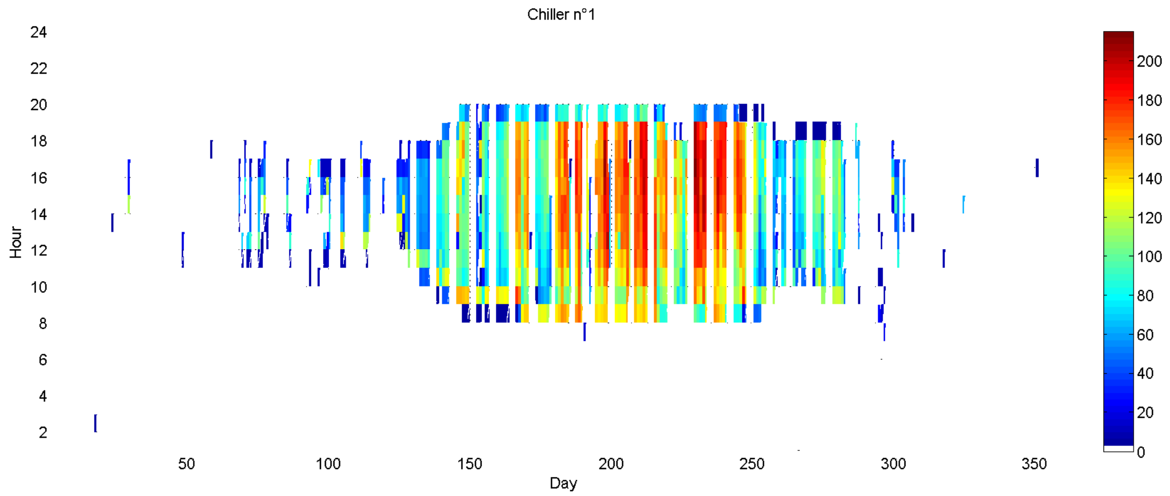
Evaporative towers and cooling water pumps

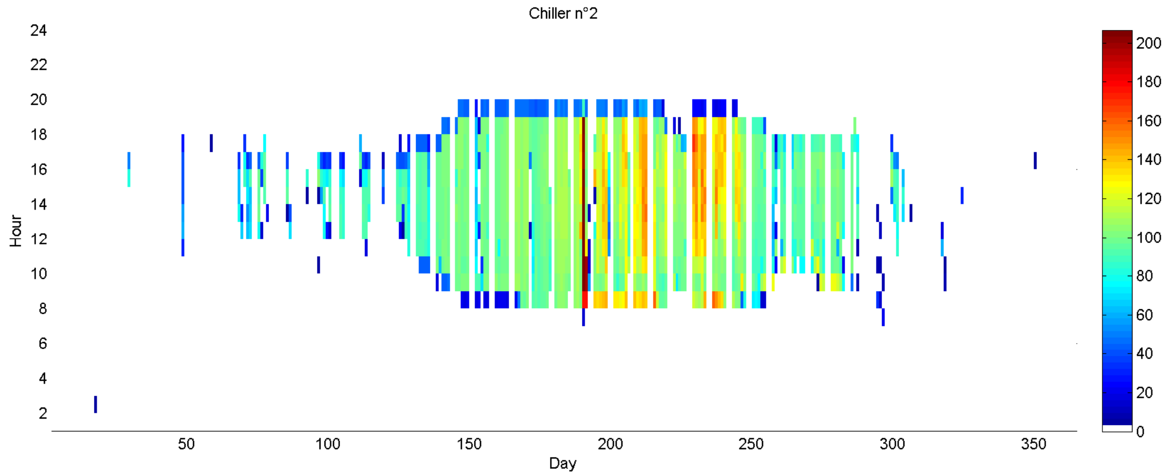
The evaporative towers and cooling water pumps show a typical profile of consumption for equipment that is turned on just on summer season. Clearly the consumption is quite constant along the day and no particular difference is noticeable between different days: all the equipment work at fixed power: maybe an inverter solution should be considered.



Chillers

The electric chillers show a correct operation schedule; nevertheless the chiller n°1 presents a higher consumption during almost all the season compared to chiller n°2. It seems that the switching between the two chillers, to prevent premature wear out of one piece of equipment, was not working properly.





Timing table for first inspection

Inspection Item	Short Description	Time (mins)	Savings	Notes
PI1	Location and number of AC zones	24		
PI2	Documentation per zone	40		
PI3	Images of zones/building	15		
PI4	General zone data/zone	14		
PI5	Construction details/zone	17		
PI6	Building mass/air tightness per zone	12		
PI7	Occupancy schedules per zone	9		
PI8	Monthly schedule exceptions per zone	3		
PI9	HVAC system description and operating setpoints per zone	35		
PI10	Original design conditions per zone	10		Complete documentation available
PI11	Current design loads per zone	28		
PI12	Power/energy information per zone	10		
PI13	Source of heating supplying each zone	4		
PI14	Heating storage and control for each zone	15		
PI15	Refrigeration equipment for each zone	5		
PI16	AHU for each zone	10		
PI17	Cooling distribution fluid details per zone	10		
PI18	Cooling terminal units details in each zone	10		
PI19	Energy supply to the system	1		
PI20	Energy supply to the building	1		
PI21	Annual energy consumption of the system	5		The Building is provided with a complete monitoring system, that allow to obtain data about electrical consumption
PI22	Annual energy consumption of the building	5		The Building is provided with a complete monitoring system, that allow to obtain data about electrical consumption
	TOTAL TIME TAKEN (minutes)	**283**		
	TOTAL (seconds/m^2)	**1.97**	Area (m^2)	8600

Centralized system inspection

Inspection Item	Short Description	Time (mins)	Savings	Notes
PC1	Details of installed refrigeration plant	35		
PC2	Description of system control zones, with schematic drawings.	15		
PC3	Description of method of control of temperature.	15		
PC4	Description of method of control of periods of operation.	2		
PC5	Floor plans, and schematics of air conditioning systems.	16		
PC6	Reports from earlier AC inspections and EPC's	0		not available
PC7	Records of maintenance operations on refrigeration systems	4		
PC8	Records of maintenance operations on air delivery systems.	8		
PC9	Records of maintenance operations on control systems and sensors	0		not available
PC10	Records of sub-metered AC plant use or energy consumption.	5		The Building is provided with a complete monitoring system, that allow to obtain data about electrical consumption
PC11	Commissioning results where relevant	0		not available
PC12	An estimate of the design cooling load for each system	50		
PC13	Records of issues or complaints concerning indoor comfort conditions	0		not available
PC14	Use of BMS	12		
PC15	Monitoring to continually observe performance of AC systems	5		The Building is provided with a complete monitoring system, that allow to obtain data about electrical consumption
C1	Locate relevant plant and compare details	40		
C2	Locate supply the A/C system and install VA logger(s)	0		not necessary
C3	Review current inspection and maintenance regime	15		
C4	Compare system size with imposed cooling loads	15		
C5	Estimate Specific Fan Power of relevant air movement systems	4		on label data
C6	Compare AC usage with expected hours or energy use	25		compare mesures of BMS with expected occupancy
C7	Locate refrigeration plant and check operation	15		
C8	Visual appearance of refrigeration plant and immediate area	5		

C9	Check refrigeration plant is capable of providing cooling	8		
C10	Check type, rating and operation of distribution fans and pumps	13		already done in C1
C11	Visually check condition/operation of outdoor heat rejection units	15		
C12	Check for obstructions through heat rejection heat exchangers	10		
C13	Check for signs of refrigerant leakage	10		
C14	Check for the correct rotation of fans	0		not possible
C15	Visually check the condition and operation of indoor units	10		radiant ceiling
C16	Check air inlets and outlets for obstruction	10		
C17	Check for obstructions to airflow through the heat exchangers	10		
C18	Check condition of intake air filters.	10		
C19	Check for signs of refrigerant leakage.	10		
C20	Check for the correct rotation of fans	10		
C21	Review air delivery and extract routes from spaces	21		
C22	Review any occupant complaints	0		not available
C23	Assess air supply openings in relation to extract openings.	12		
C24	Assess the controllability of a sample number of terminal units	15		
C25	Check filter changing or cleaning frequency.	12		
C26	Assess the current state of cleanliness or blockage of filters.	10		
C27	Note the condition of filter differential pressure gauge.	10		
C28	Assess the fit and sealing of filters and housings.	30		
C29	Examine heat exchangers for damage or significant blockage	10		
C30	Examine refrigeration heat exchangers for signs of leakage	10		
C31	Note fan type and method of air speed control	2		
C32	Check for obstructions to inlet grilles, screens and pre-filters.	7		
C33	Check location of inlets for proximity to sources of heat	2		
C34	Assess zoning in relation to internal gain and solar radiation.	15		
C35	Note current time on controllers against the actual time	10		
C36	Note the set on and off periods	6		
C37	Identify zone heating and cooling temperature control sensors	5		per floor
C38	Note zone set temperatures relative to the activities and occupancy	13		per zone

C39	Check control basis to avoid simultaneous heating and cooling	6		
C40	Assess the refrigeration compressor(s) and capacity control	210		with climacheck
C41	Assess control of air flow rate through air supply and exhaust ducts	15		
C42	Assess control of ancillary system components e.g. pumps and fans	10		
C43	Assess how reheat is achieved, particularly in the morning	0		not available
C44	Check actual control basis of system	8		
	TOTAL TIME TAKEN (minutes)	**841**		
	TOTAL (seconds/m^2)	**5.87**	Area (m^2)	8600

Overall conclusions

This case study concerns a new building with extremely high internal loads and high solar gains. The HVAC system shows good performance and control strategy; nevertheless, some design limitations are evident: the AHUs do not have any by pass on the heat recovery. This implies that is often impossible to provide free-cooling and, particularly in the first hours of Monday morning, the system is inefficient.
On the other hand the building envelope seems to have poor thermal quality: there is a high probability that some voids were not properly sealed during construction. For such reasons the consumption of the system is really high: **299** kWh/m² of thermal energy for heating and almost **120** kWh/m² of electric energy for cooling are high values for a new building.
Talking about comfort, the control system, which handles each storey as a single thermal zone, could not provide adequate comfort.

In summary, this case study shows that:

1. **Simplification of system control (minimum number of thermal zone), to economize investment costs, decreases dramatically internal comfort.**

2. **Sub-systems to provide free-cooling are relatively cheap if installed during the construction phase, while they are really expensive if installed later.**

3. **In large system/buildings the presence of an Energy manager assisted by an expert HVAC system technician is absolutely necessary to guarantee correct operation and system efficiency.**

4. **The HVAC system for this kind of building should be accurately designed in conjunction with the building designer.**

5. **Building with much glazed surfaces should include automatic lighting control and/or effective solar shading devices.**

HARMONAC

IT Case Study 5:
Office – VRF HP SYSTEM

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DENER, Politecnico di Torino
IT

September 2010

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CASE STUDY: Regione Piemonte Headquaters - Office building with VRF HP system

The case study presents a XVII century building that passed trough a radical refurbishment of HVAC system in 2006.
The A/C system installed is a VRF (Variable refrigerant flow) reversible heat pump system (air to air) with fan coils. Mechanical ventilation is provided to some areas only. Air cooled water chillers and condensing gas fired boilers supply respectively cold and hot water to AHUs.

Building Description

Country & City	Italy, Turin
Building Sector /Main Activity	Office
Net Area[m²]	9500

Installed Plant

Parameter	Installed electrical load / kW	Floor area served / m² GIA	Installed capacity W/m² GIA	Annual consumption kWh	Average annual power W/m²	Annual use kWh/m²	Average annual power (% FLE)
Total Chillers nominal cooling capacity (cooling output) [e]	550.0	9'500.0	57.9				
VRF electrical demand (cooling)	258.0	9'500.0	27.2	135'200.0	1.6	14.2	6.0
Total CW pumps	NA	NA	-		-	-	-
Total fans	11.0	9'500.0	1.2	22'150.0	0.3	2.3	23.0
Total humidifiers	NA	NA	-		-	-	-
Total boilers	NA	9'500.0	-		-	-	-
Total HW pumps	NA	9'500.0	-		-	-	-
Total HVAC electrical	269.0	9'500.0	28.3	572'650.0	6.9	60.3	24.3
Total Building Elec kWh		9'500.0		1'383'968.4	-	145.7	
VRF electrical demand (heating)	258.0	9'500.0	27.2	354'156.0	4.3	37.3	15.7

Energy savings

ECO CODE	DESCRIPTION	ACTION	Saving
O2.2 WINTER	Shut off A/C equipments when not needed	Define a schedule strategy, operating on BEMS	-26.7% (-94.5 MWh) on winter VRF consumption (354.1 MWh)
O2.2 SUMMER	Shut off A/C equipments when not needed	Define a schedule strategy, operating on BEMS	-49.9% (-67.5 MWh) on summer VRF consumption (135.2 MWh)
O2.6 SUMMER	Implement pre-occupancy cycle	Define a pre-occupancy strategy, operating on BEMS	-53.7% (-72.6 MWh) on summer VRF consumption (135.2 MWh)

Overview of building and system

The Regione Piemonte Headquarters are located in a XVII century building that was almost entirely rebuilt after World War II. In 2006, a radical refurbishment of the building services has been completed.
The A/C system monitored in this building is a VRF (Variable refrigerant flow) reversible heat pump system with fan coils. Mechanical ventilation is provided to some areas only. An air cooled water chiller and a modular condensing gas fired boiler supply hot/cold water to AHUs.

A BEMS provides complete monitoring and management of the building services (HVAC, fire prevention, camera and access, lighting); in particular the lighting system includes daylight and PIR control.

The modular VRF system employs 16 roof-mounted air-cooled external units. An inverter drives one of the two scroll compressors present in each module, in order to continuously vary the cooling output according to the actual demand. Rated power values are:

- heating: 600 kW (VRF system); 505 kW (condensing boiler for DHW)
- cooling: 550 kW (VRF system); 223 kW (water chiller for AHU)
- electrical: 258 kW (VRF external units)

The AHU provide humidity control (steam humidification), heat recovery system with 60 % efficiency is present.

The ground floor and the three top floors of the building are equipped with a two-pipe system, in which the refrigerant fluid is distributed by a single main loop to the internal units that operate either in heating or cooling regime, according to a seasonal changeover scheme.

At the second floor, a three-pipe system allows simultaneous indoor heating and cooling, with a heat recovery strategy: the outdoor unit operation is varied in order to match the refrigerant fluid state (liquid, low-pressure / temperature vapour, high –pressure / temperature vapour) with the internal units demand.

The central Building Monitoring System (BMS) allows monitoring of the internal / external units using the building Ethernet network from a remote PC. Features include: remote internal unit set-point control, alarm handling, energy consumption recording, fire prevention system monitoring, monitoring of window opening / closing, lighting system and PC on / off switching (internal heat load monitoring). Energy performance data acquired by the BMS have been recorded and stored since 2005.

The metering currently available are:
- Main electrical incomer
- Global consumption of the VRF system
- Internal temperature

Summary of building and systems

The following table summarises the main aspects of the building:

Building Description	
Building Sector /Main Activity	Office
Gross net Area[m²]	9500
Max number Occupants	200
N° Zones	1

Zone Description

Zone ID	Activity Type	Gross net Area	N° Occupants
1	Office	9500	300

Heating/Cooling Production		Normalised/m² GIA	Notes
Conditioned net Area	9500 [m²]		
VRF system nominal cooling capacity	550 [kW]	**57.9** W/m²	
VRF system nominal heating capacity	600 [kW]	**63.2** W/m²	
VRF system nominal electrical demand	258 [kW]	**63.2** W/m²	
Chillers nominal electrical demand	256 [kW]	**27.2** W/m²	the chiller supplies cool water for the AHUs

Measured annual performance

		Normalised/ m² GIA	Notes
Total Building Electrical Consumption	**1383.9** [MWh]	**145.7** [kWh/m²]	2008 data
• HVAC Equipment	**572.6** [MWh]	**60.3** [kWh/m²]	2008 data
•VRF system electrical demand (cooling season)	**135.2** [MWh]	**14.2** [kWh/m²]	Summer 2008 data
•VRF system electrical demand (heating season)	**354.1** [MWh]	**37.3** [kWh/m²]	Winter 2008/09 data

Case study details - Building Description

Plan of the fourth floor, in blue the VRF tubes circuit

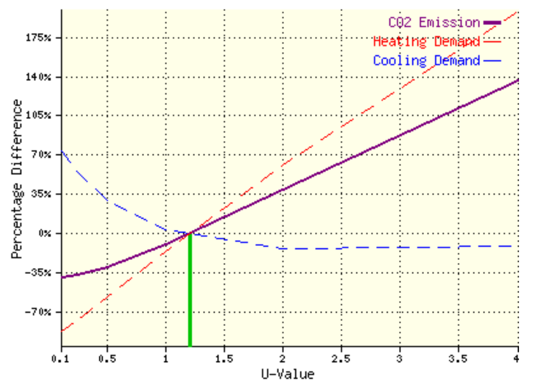
General building data

Country/City	Italy – Turin
Latitude/Longitude[°]	45°4'41''16 N- 07°40'33''96 E
Elevation [m]	240
Cooling Degree Days	2617
Building Sector/Main Activity	Office
Total net floor area [m²]	11500
Ceiling height [m²]	3,1
Number of floors	5

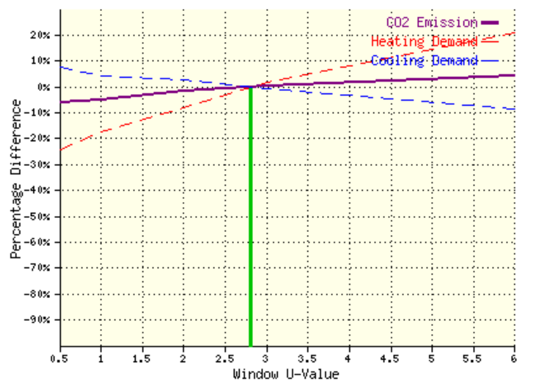
Case study details - Constructions details

Envelope – Heat Transfer Coefficient [W/m².K]	
External wall (predominant)	1.2
Floor (predominant)	1.0
Intermediated floor (predominant)	1.3
Roof (predominant)	1.6

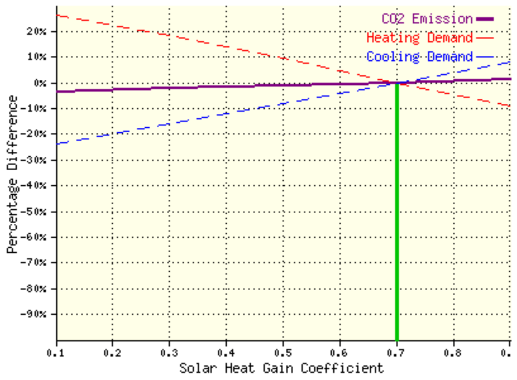
Windows	
U- value (predominant) [W/m².K]	2.8 (new)
Window type	double
Window gas	air
Solar Factor	0.7
Solar Protection Devices	
Window Overhangs	**none**
Shading Device	**venetians**



CAT Graphs Wall U-value



CAT Graphs Windows U-value

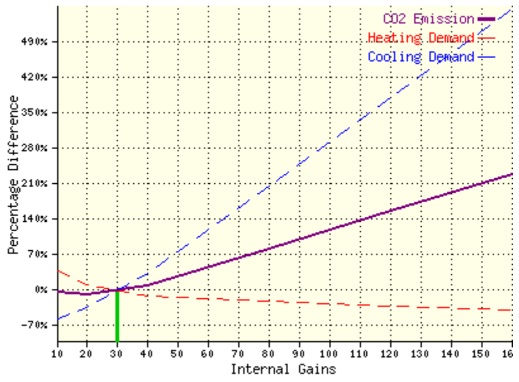


CAT Graphs Solar heat gain

Internal gains and operation schedules per zone

Zone ID:	
Activity type	

Equipment electric loads/Schedules	**Design**	**Measure/observe - Winter/Summer (average)**
Office equipment [W/m²]	15	17
Working schedule	8:00-17:00	9:00-18:00
Permanent/variable occupancy	400	n.a.
Cleaning staff schedule	-	-
Lighting [W/m²]	15	14
Type of lighting	fluorescent	fluorescent
Lighting control	PIR	PIR
Lighting schedule	8:00-17:00	variable

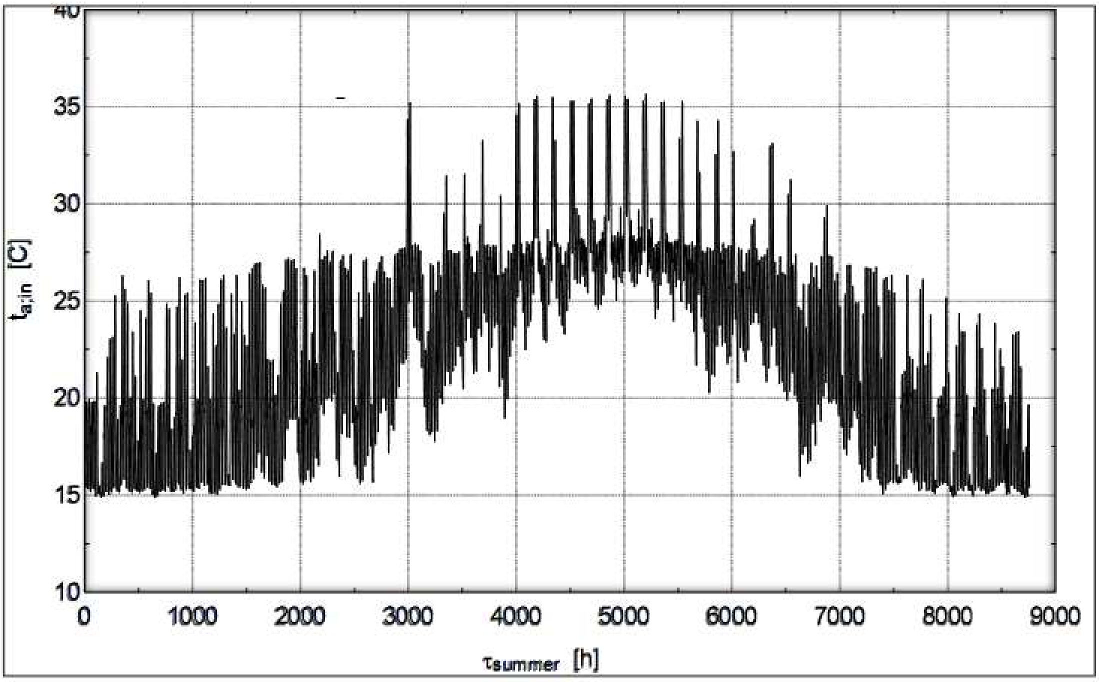


CAT Graphs internal gains

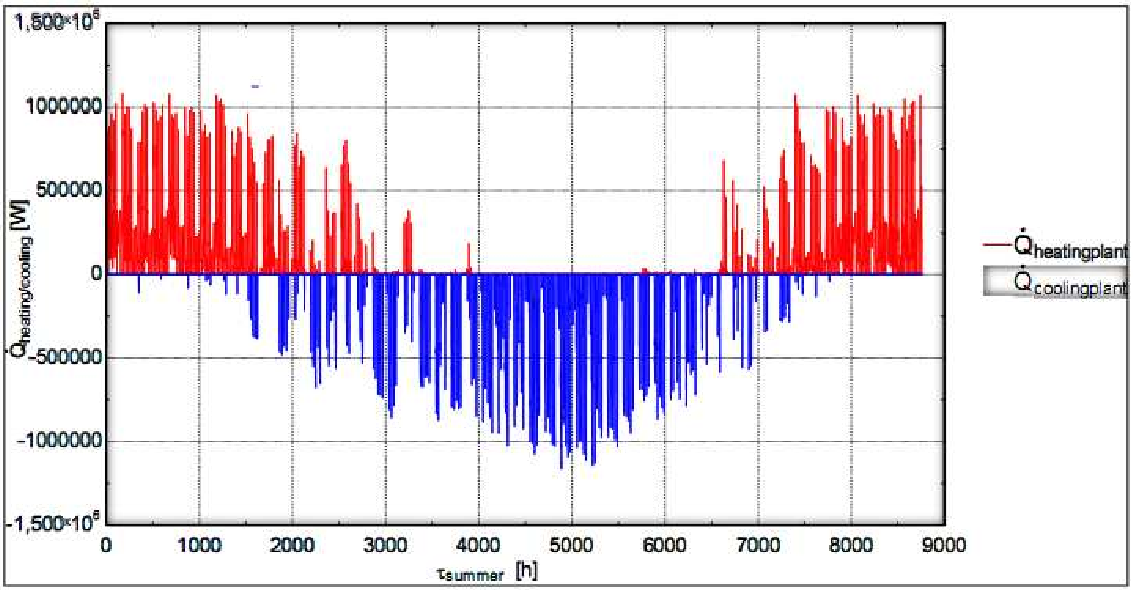
Monitoring observations for internal gains

Benchmark and Simaudit tools were used on the case study just to evaluate thermal loads. Since the software does not allow the HP system implementation, no calibration was made on this case study.

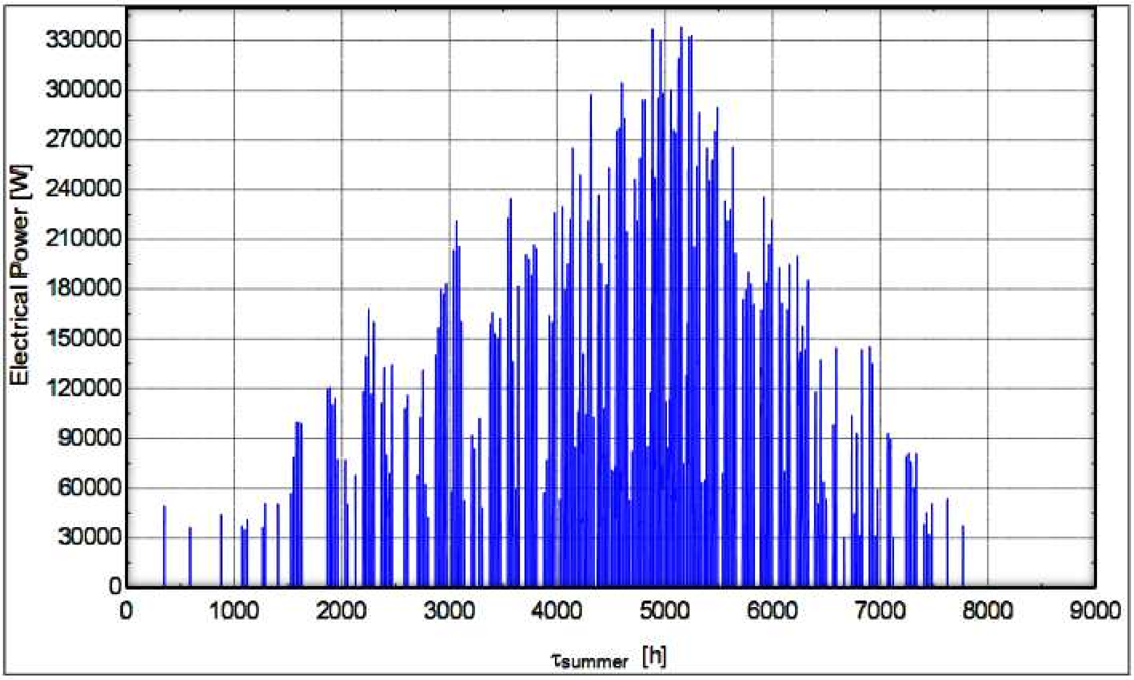
Internal air temperature calculated by software



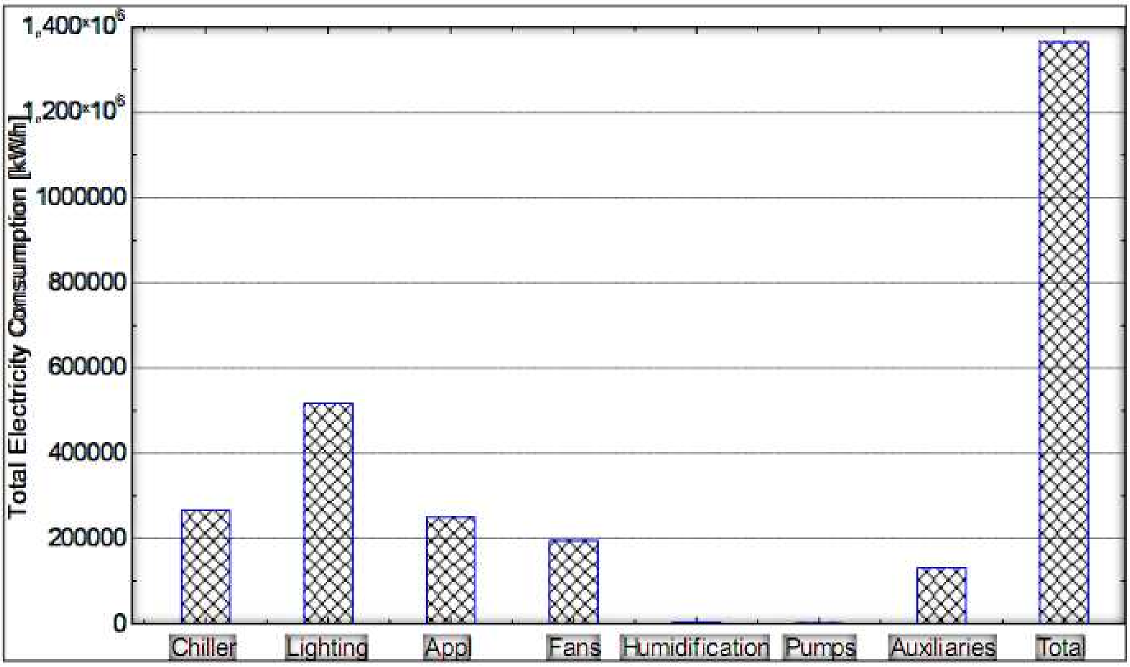
Thermal load calculated by software



Cooling system consumption (for an equivalent centralized system)



Electric energy consumption calculated by software.



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Environment parameters

Description of the environment design conditions, Heating/cooling loads, design temperatures (from UNI 10349).

Outdoor Environment Parameters	**Design**	**Measure/observe - Winter/Summer (average)**
Outdoor air temperature [°C] Winter/Summer	-8 / 30.7	min -3 / max 36.4 avg: 6.1/ 25.3
Outdoor Relative Humidity [%] Winter/Summer	85% / 46%	77/ 61.6
Max. Solar Radiation [W/m²]		max 1119 (10.06.2008) avg : 63.6 / 203.1 (on 24h)

Zone ID:	**1**
Activity type	**Office**

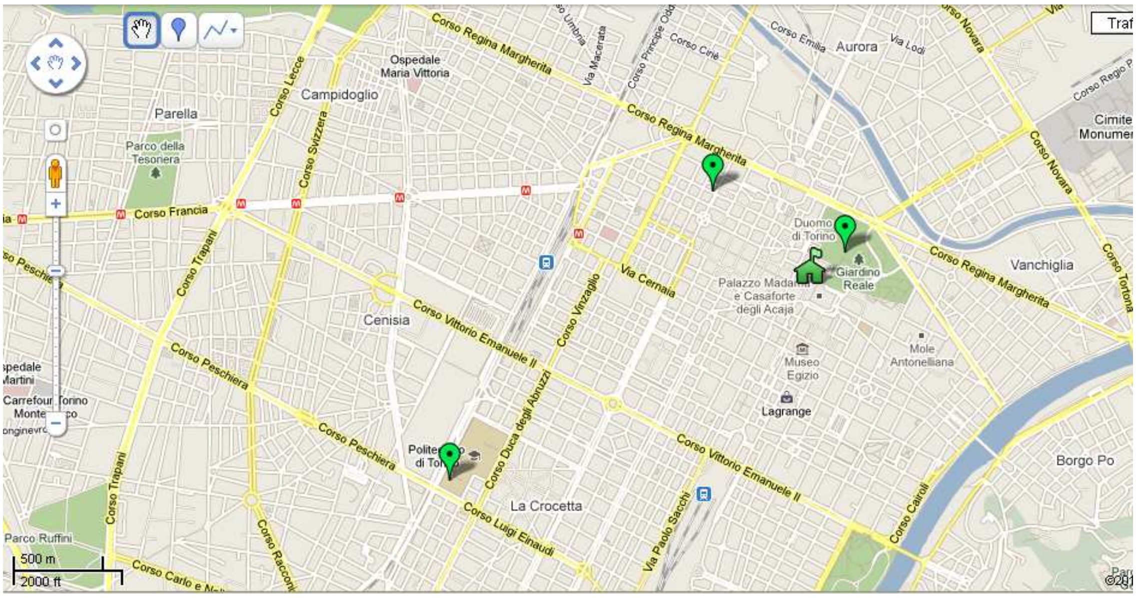
Indoor Environment Parameters per zone	**Design**	**Measure/observe - Winter/Summer (average)**
Ventilation Rate [ach]	1.5	32.000 m³/h 1 ach
Indoor air Temperature [°C] – Winter/Summer (air temperature)	20/N.A.	21/22-26

Monitoring observations for environmental parameters

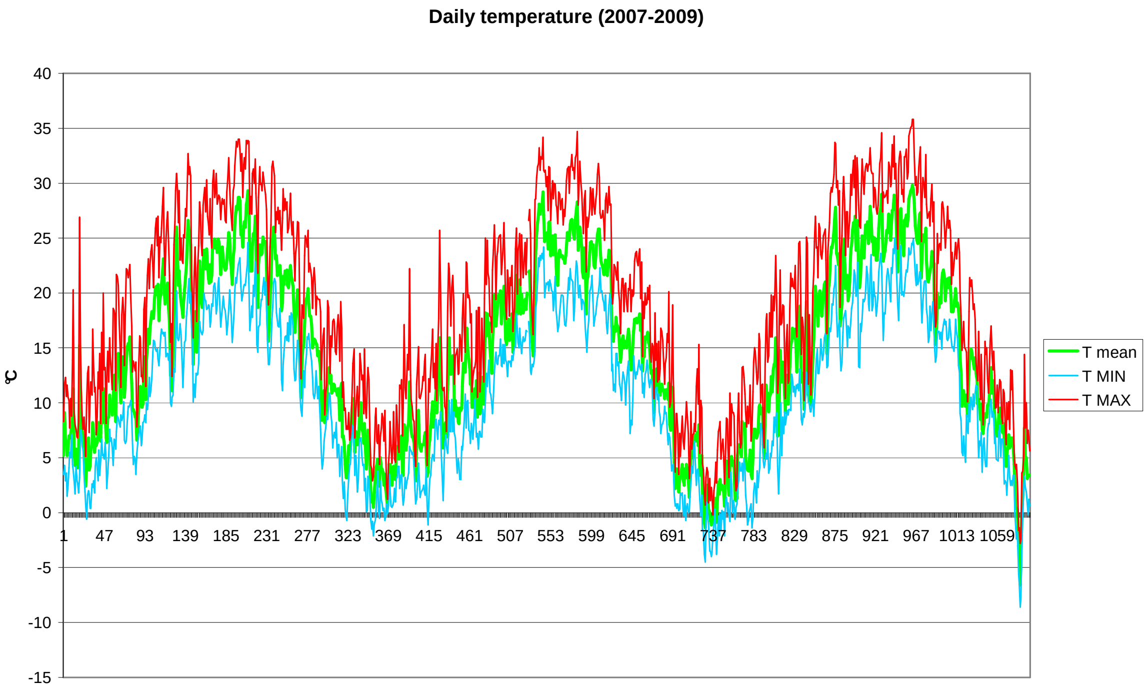
The meteo data for Torino were provided by three different sources:

1. meteo station installed on the roof of the building
2. meteo data provided by NEMEST project (station installed at Politecnico di Torino)
3. meteo data provided by ARPA Piemonte, the regional environmental protection agency

For the consumption and statistical analysis ARPA data were used. Such data, in fact, showed statistical robustness, provided by 3 meteo stations, one of which really close to the building (almost 500 meters).



The green house represents Regione Piemonte Headquaters building, while the three green pointers represent the 3 meteo station.



Carpet plot of external temperature are provided for different years (2008, 2009). Air enthalpy was calculated with the following formula (ASHRAE 2009, Fundamentals) from external temperature, relative humidity and air pressure:

$$h = 1.006t + W(2501 + 1.86t)$$

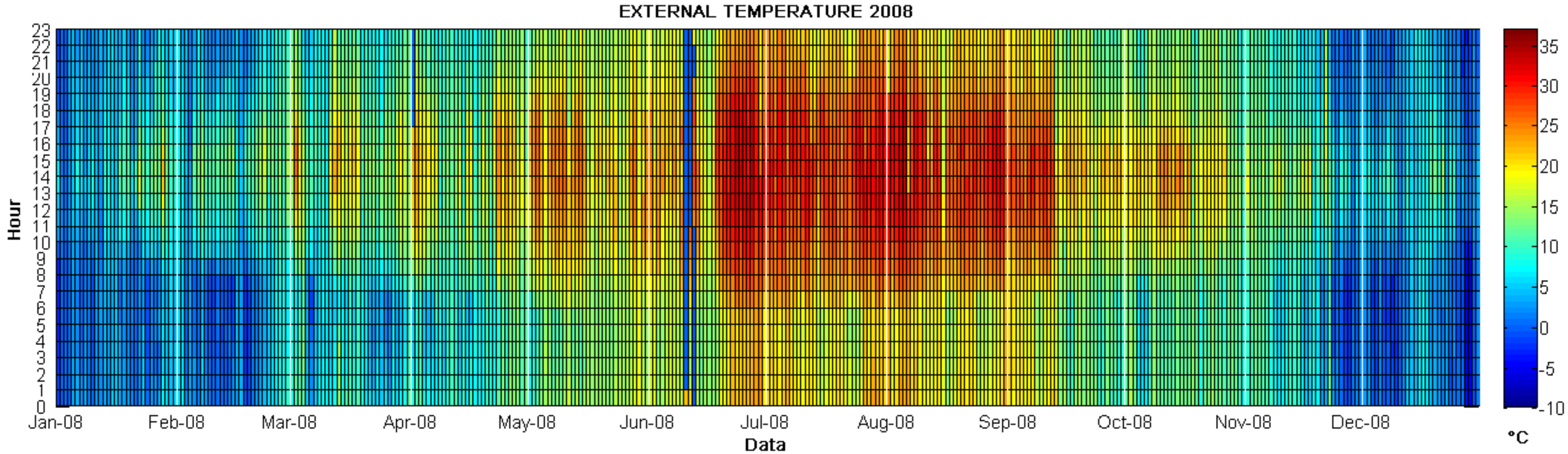
$$W = 0.621945 \frac{p_w}{p - p_w}$$

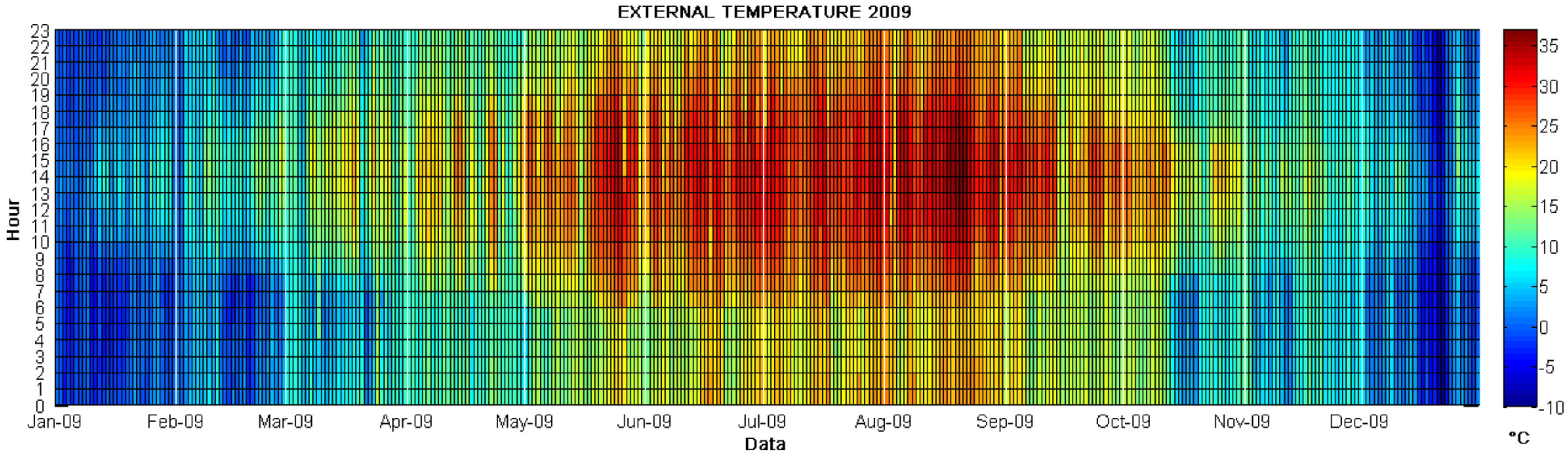
$$p_w = RH \cdot p_{ws}$$

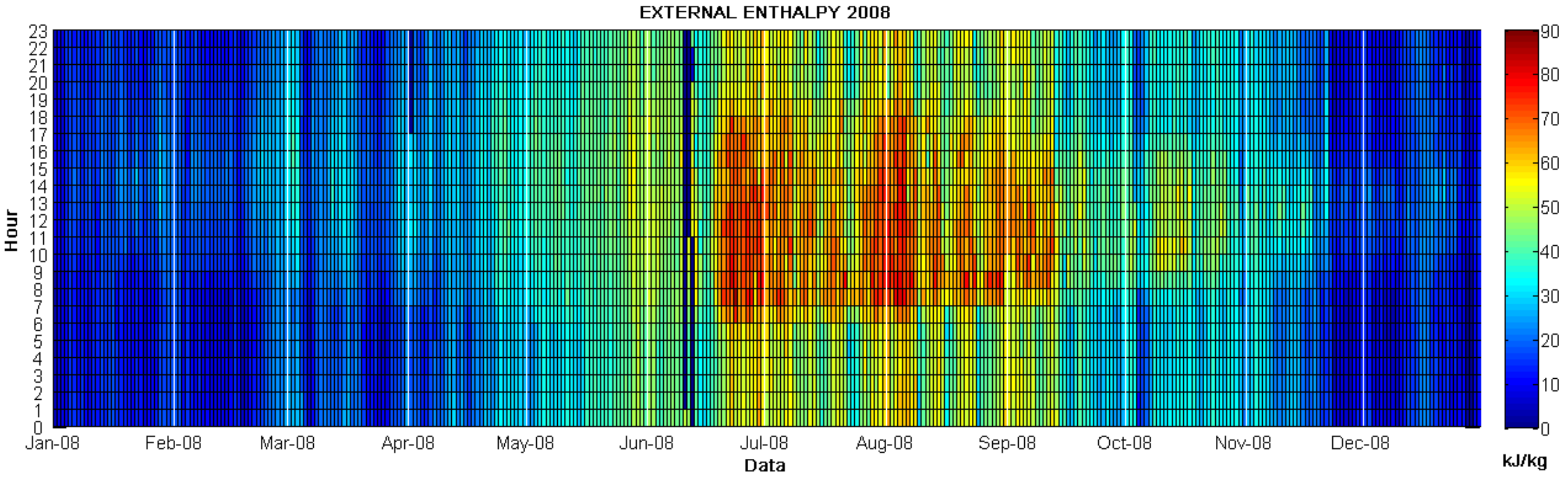
$$\ln(p_{ws}) = \frac{C8}{T} + C9 + C10T + C11T^2 + C12T^3 + C13 \ln T$$

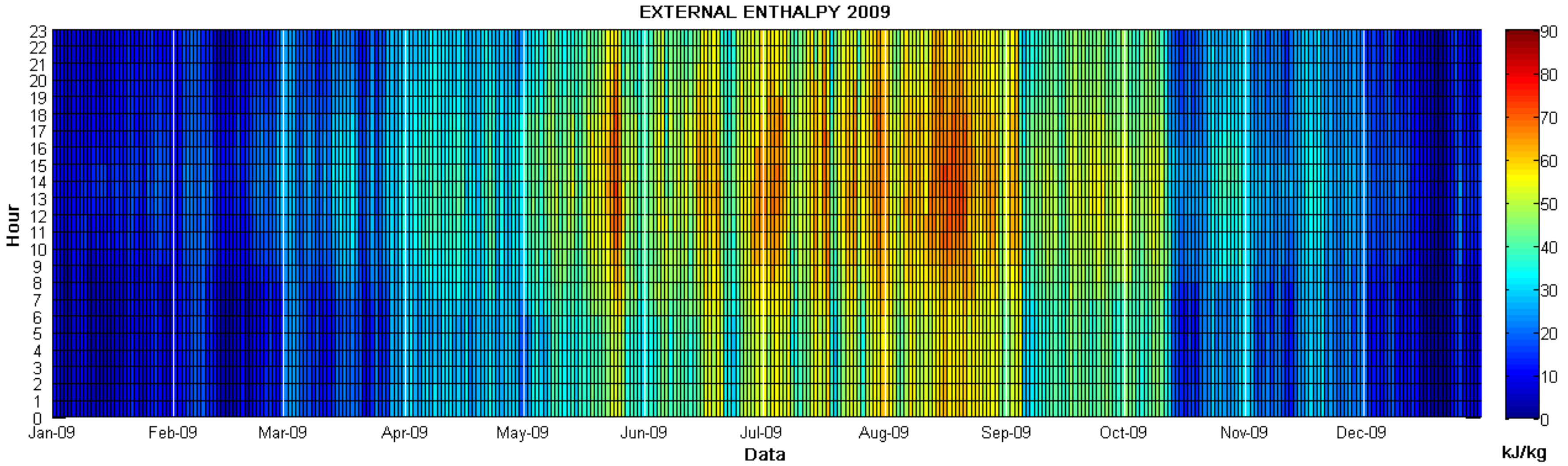
With:

h	=	air enthalpy
t	=	ait temperature (°C)
Pw	=	vapour pressure
Pws	=	saturated vapour pressure
RH	=	relative humidity
C9-C13	=	constants

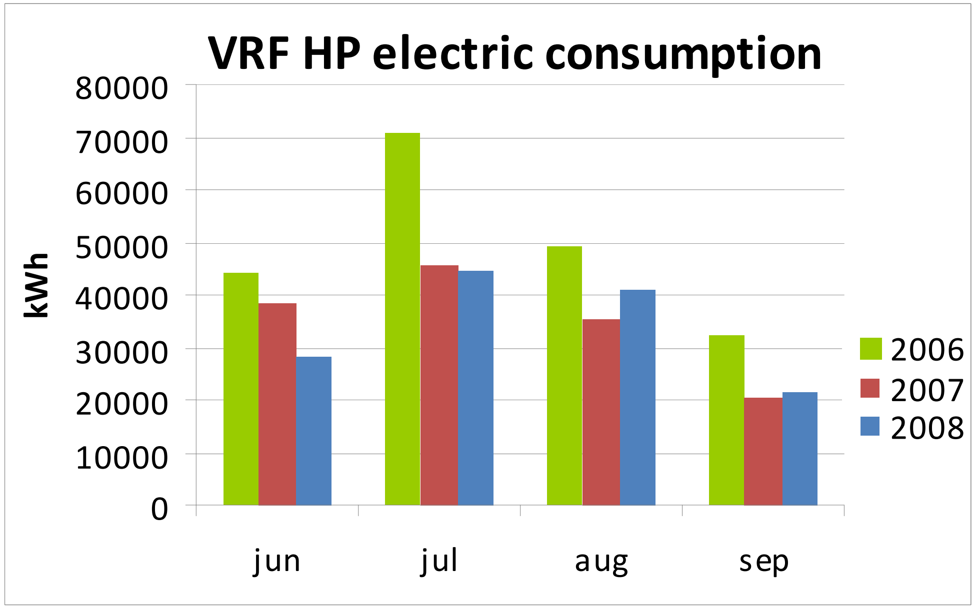

EXTERNAL TEMPERATURE 2008
Hour
Data
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
°C


EXTERNAL TEMPERATURE 2009
Hour
Data
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
°C


EXTERNAL ENTHALPY 2008
Hour
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Data
90
80
70
60
50
40
30
20
10
0
kJ/kg

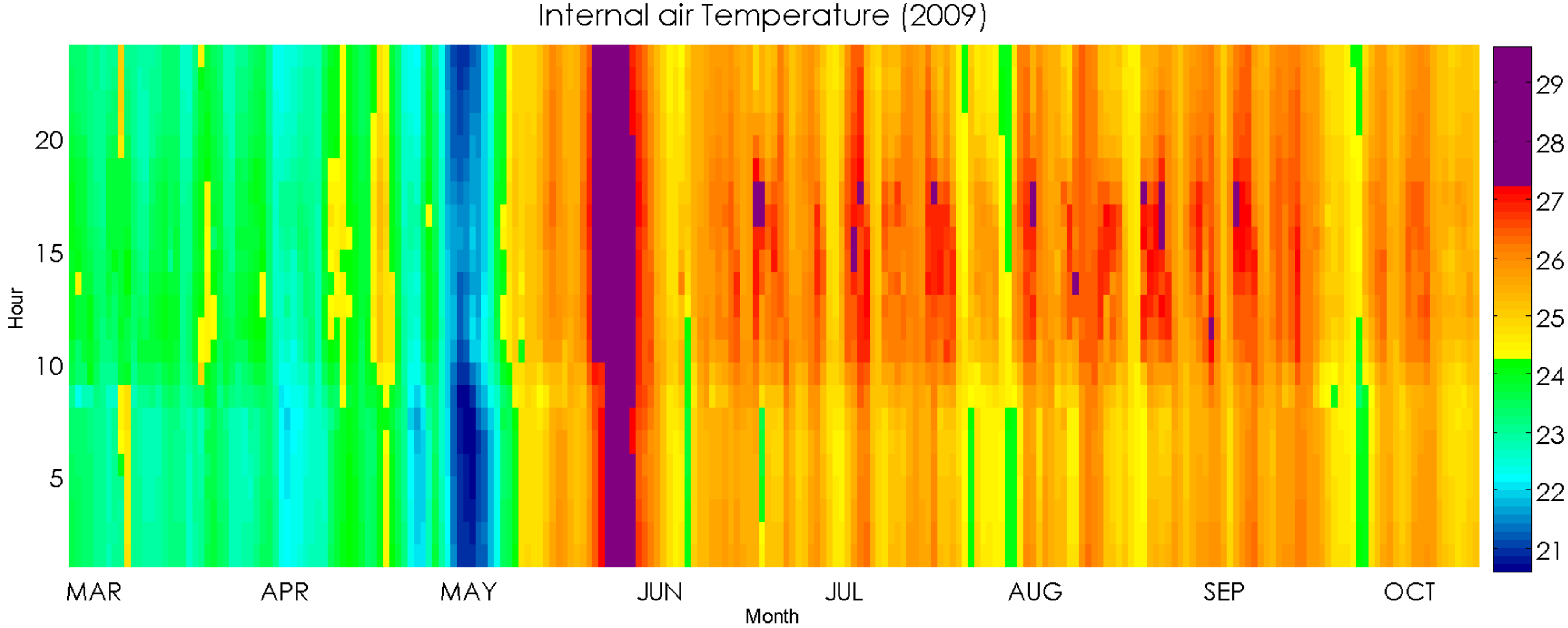

EXTERNAL ENTHALPY 2009
Hour
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
Data
90
80
70
60
50
40
30
20
10
0
kJ/kg

The 2009 season was characterized by external air temperature higher that 2008 season. This implies, on a first analysis, a higher load for the cooling system. Nevertheless it is interesting to notice that air enthalpy in 2009 season is lower than in 2008; this implies that for those system with mechanical ventilation, probably 2008 season was characterized by higher consumption.
Unfortunately, the metering system of the analyzed building stopped its operation at the beginning of 2009, as explained in the ECO 2.2 paragraph. The graph below shows the electric consumption of VRF HP system. Along the years the consumption decreased: this is due to changes in system operation strategy.



Internal temperature logging

In 2009 internal temperature loggers were installed. The graph following show that internal temperature does not follow any trend connected to work hours. This is probably due to the system schedule, not properly set. In May it is clearly seen the changeover of the system. When the HP VRF was set on cooling mode, for at least a week the system over cooled the zone, with an internal temperature about 21°C. These data show a bad operation strategy, with repercussions on energy consumption and internal comfort.



HVAC system components

The modular VRF system employs 16 roof-mounted air-cooled external units. An inverter drives one of the two scroll compressors present in each module, in order to continuously vary the cooling output according to the actual demand. Rated power values are:

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- electrical: 258 kW (VRF external units)

The AHU provides humidity control (steam humidification); heat recovery system with 60 % efficiency is present.

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The metering currently available are:

- Main electrical incomer
- Global consumption of the VRF system

Heat Pump

General Identification	
Manufacture/Model	Daikin VRV II
Year	2005
Type	VRF air to air

Performance Data	
EER – Cooling mode	3.1
COP – Heating mode	3.57
SEER	
Nominal Cooling Capacity [kW]	550 (all units)
Nominal Heating Capacity [kW]	600 (all units)
Refrigerant Gas	R410A
Electrical data	
Power supply [V/Ph/Hz]	380/3/50
Start-up amps [A]	52 (single unit)

Figure – External units

Figure – Internal unit in a inefficient position

Monitoring observations

Inspection	
Operating Mode	**Automatic**
Maintenance status	**Unsatisfactory**
Maintenance reports	**No**
Equipment cleanliness	**Satisfactory**
Pressure status	**Satisfactory**
Sensors calibration records	**No**
Previous inspection reports	**No**

Operating time estimated [h/year]	**8000 (24 hours-7/7 operating)**
Air filter cleanness	**N.A.**
Thermal insulation (Visual)	**Unsatisfactory**

During winter inspection, in February 2009, the external units presented signs of ice formation on thermal exchange battery. This implies that units operate numerous defrosting cycles. These cycles are responsible for impressive operational life decreasing of scroll compressors. In fact, on the system analyzed some compressors had to be replaced. Replacing compressors after 3 years of operation is not usual for market high end heat pumps, as Daikin VRV II. This problem is in part due to continuous operation of the machines, especially during winter nights.
The heat pumps control system allows to set how the de-frosting cycle should works:

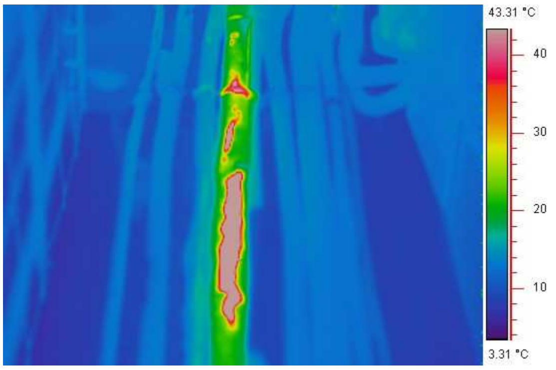
- with a complete stop of the compressors for 5 minutes
- without stop of the compressors

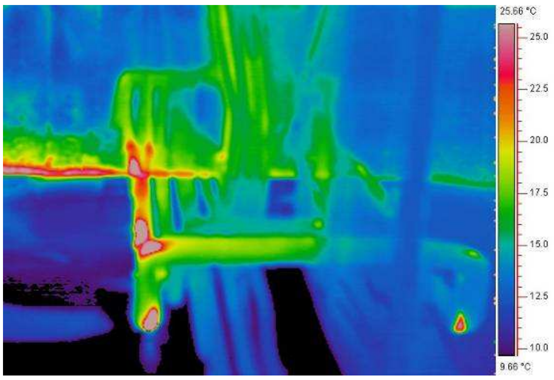
In the system analyzed the set up of de-frosting cycle was without compressors stop. This had consume compressors components and sealing.

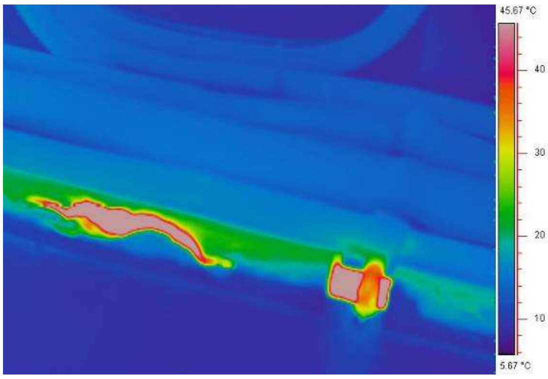
Ice formation on the external units

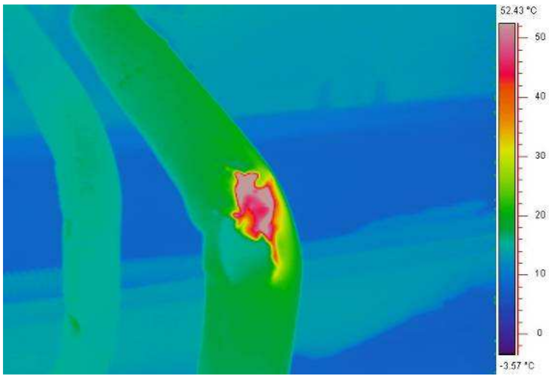
Thermo-graphic analysis of insulation

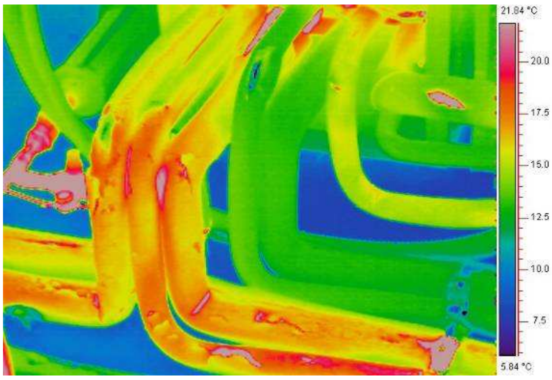
The insulation of refrigerant fluid pipes appeared to be inadequate, on one hand because its thickness seemed insufficient to provide adequate thermal insulation, on the other hand because the insulation was not protected against mechanical shock.
A visual inspection is sufficient to determine where the insulation is damaged, while the thermo-graphic analysis shows numerous points where the insulation is in visual good state, but inadequate to avoid thermal losses.

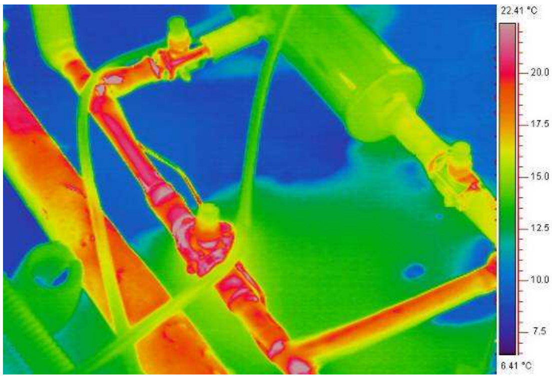


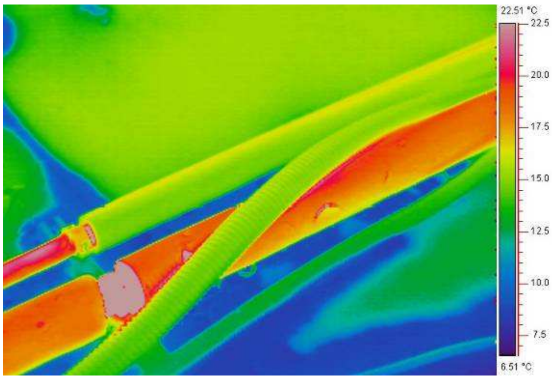


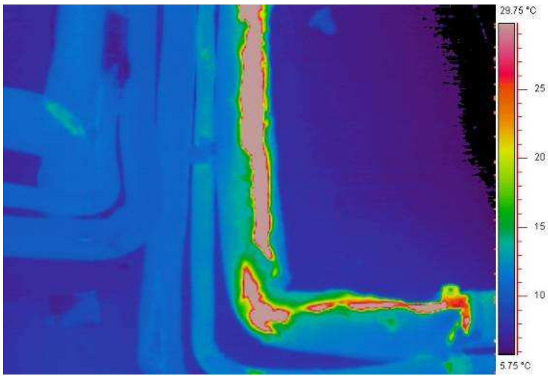

45.67 °C
40
30
20
10
5.67 °C

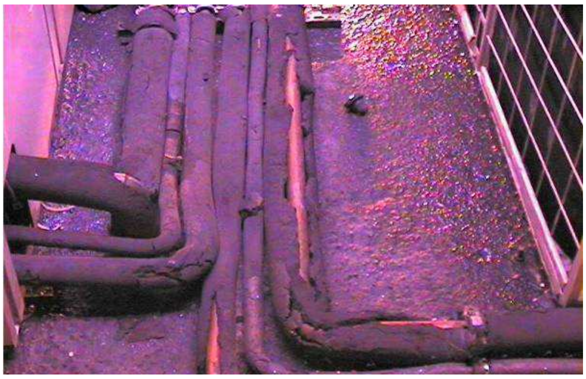

52.43 °C
50
40
30
20
10
0
-3.57 °C

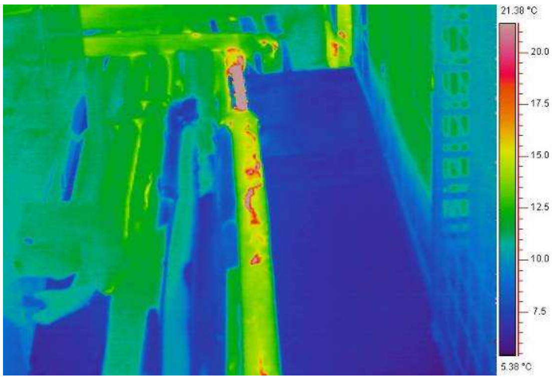

21.84 °C
20.0
17.5
15.0
12.5
10.0
7.5
5.84 °C


22.41 °C
20.0
17.5
15.0
12.5
10.0
7.5
6.41 °C


22.51 °C
22.5
20.0
17.5
15.0
12.5
10.0
7.5
6.51 °C


29.75 °C
25
20
15
10
5.75 °C



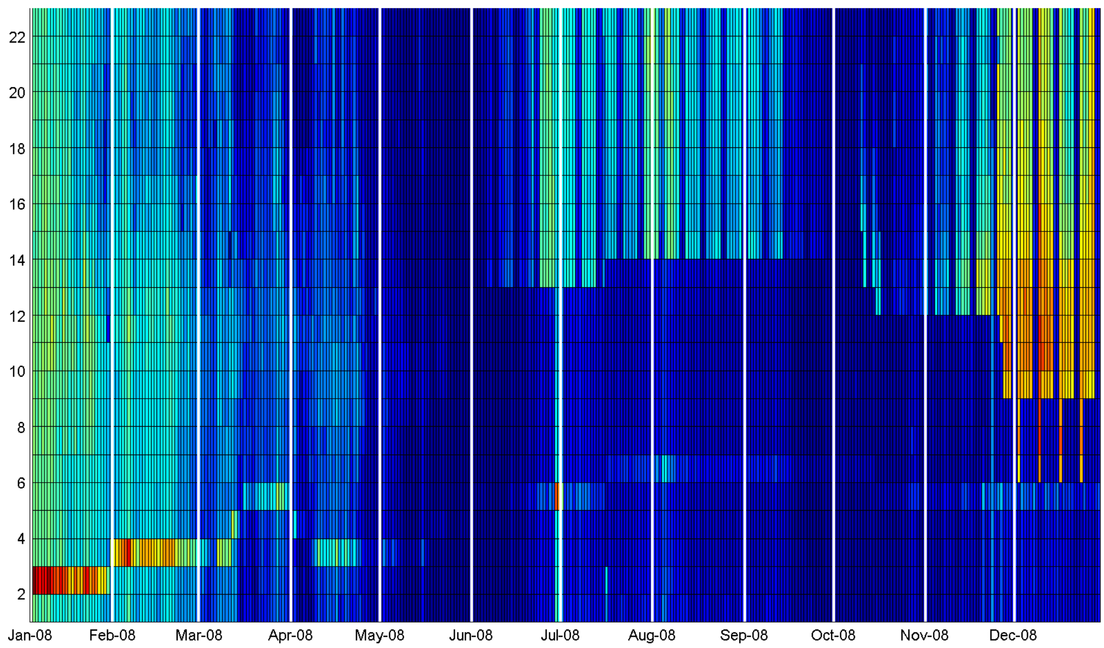

21.38 °C
20.0
17.5
15.0
12.5
10.0
7.5
5.38 °C

Energy consumption data

Metering information

As explained in the overview, the HP VRV system is composed by internal and external units. The internal units are characterized by a really small electric input; the single part that has a significant electric load is the fan motor, about 60 Watts. The main electric input is due to external units, where the fluid compressors is installed (each compressor has an electric input of about 2 kW). In addition the external units are connected to two main electric control panels, while each internal unit is connected to a different panel.
For this reason the HVAC manager decide to install two electric power meters on the two main panels, serving external units of HP VRF system.

The data on HP VRF system consumption are available from 2006 to 2008.
The data are represented by a kWh counter, with a sampling rate of 1 hour. These data permit analyzing the seasonal consumption of the system. Daily and hourly analyses are also possible, but some data mismatch and lacks does not permit an accurate carpet plot. In addition, the system data logger registered the data considering a normal day composed by just 23 hours. This implies that the value of 2:00 AM indicates electric consumption during two hours (from 0:00 AM to 2:00 AM). The results are quite bad, as seen in the graph below.



Nevertheless the counting system used (that memorizes a summation of consumption) permits analyzing seasonal consumption without errors, along with daily analysis on selected weeks. In addition, the electric global income, registered at 15 minutes intervals without lacks, represents in a good way the VRF HP load profile.

Monitoring observations

VRF HP CONSUMPTION (Heating & Cooling) [MWh]

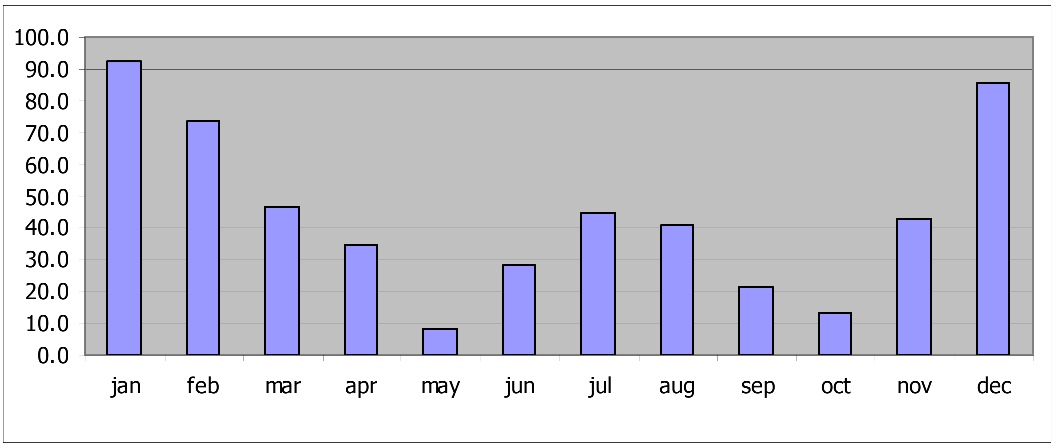


Figure – MWh/month per year

Global Electricity [kWh/year]

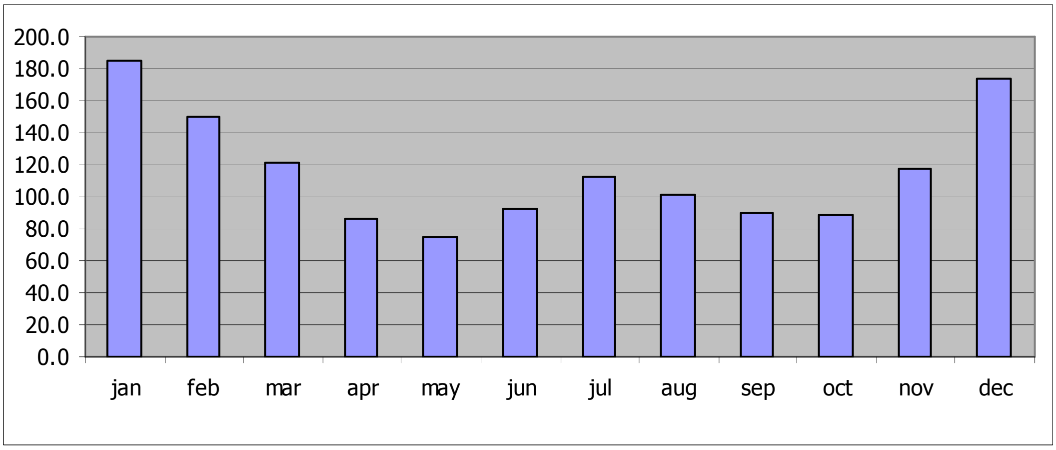
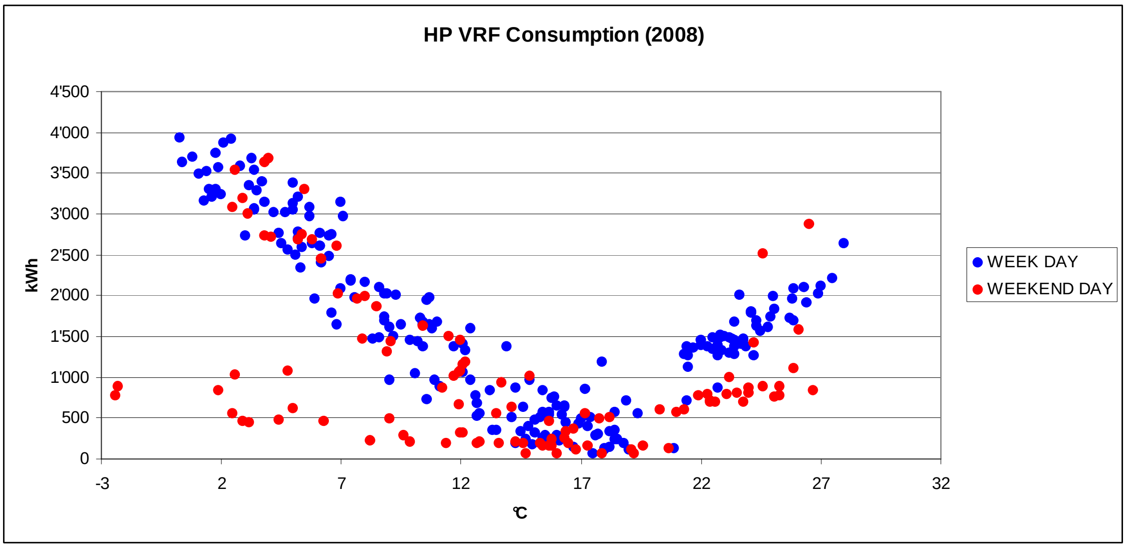


Figure – Chart

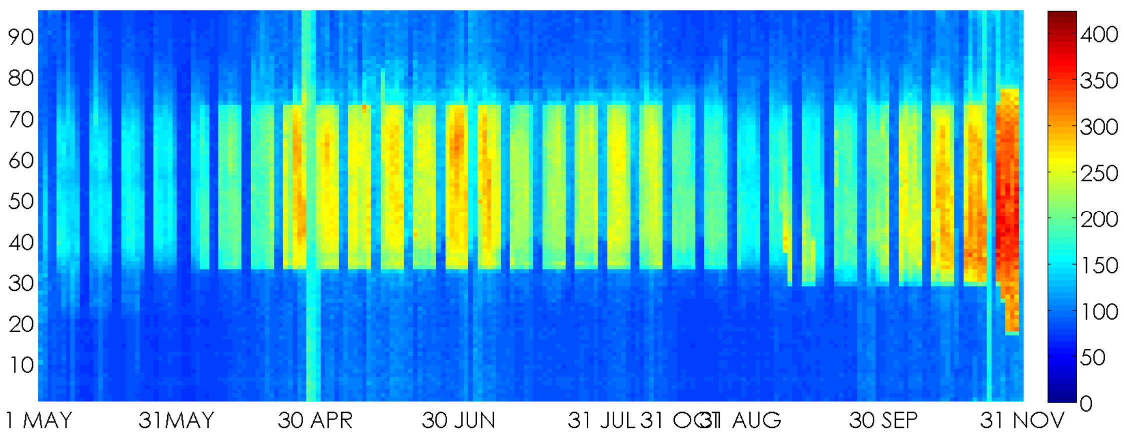
The graph below shows the daily consumption of HP VRF system during the whole year, as function of mean external temperature.
As expected, there is a strict correlation between external temperature and electric consumption: the efficiency of an air HP, in fact, is greatly influenced by the temperature of the external heat source / sink. The image also shows that system schedule was not always correctly set; in fact some non-work days show the same consumption of work days. The following graphs on total electric consumption demonstrate this theory.



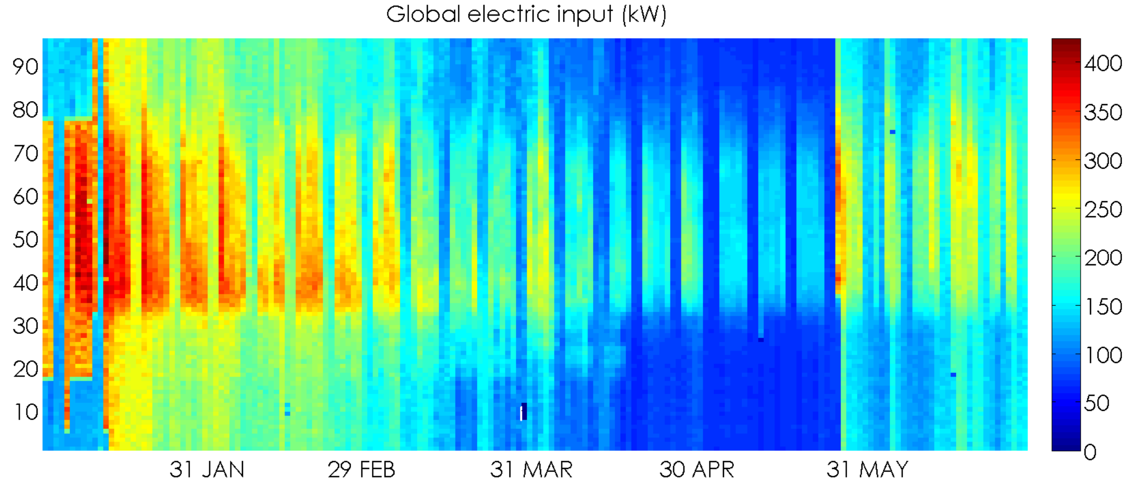
The further graphs show global electric input. After a period whit a well set system schedule, the system worked with 24 hours operation.

The first is referred to 2008 year:

Global electric input (kW)

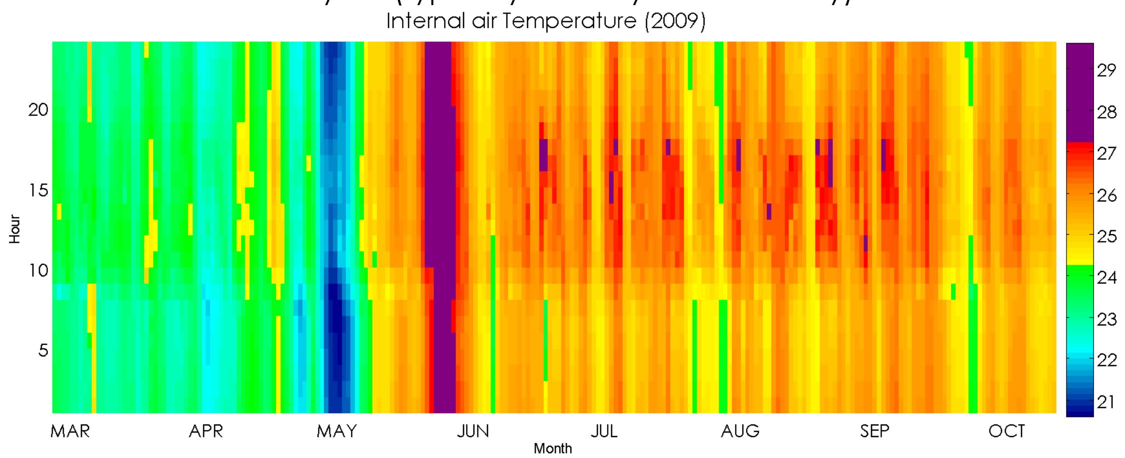


The second is referred to 2009 year:



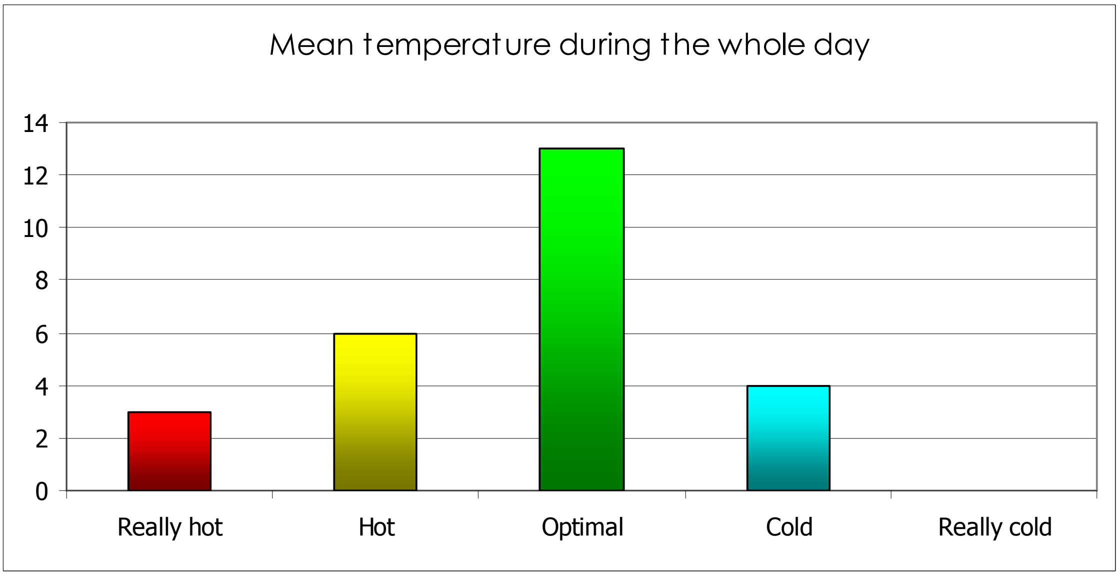
The global electric consumption in 2008 demonstrates a correct schedule of the system during the whole year. At the beginning of December the HVAC system manager decided to increase the hours of pre-heating.
In 2009, after the 31st of January the system was set on 24 hours operation, 7 days per week.

The internal temperature monitoring started on March 2009. The data show high internal temperature during winter and very low temperature during the beginning of cooling season (May). The internal temperature in March was always between 23° and 24° degree. We should conclude that internal temperature set point is in generally too high during winter, especially in the coldest months of the year (typically January and February).

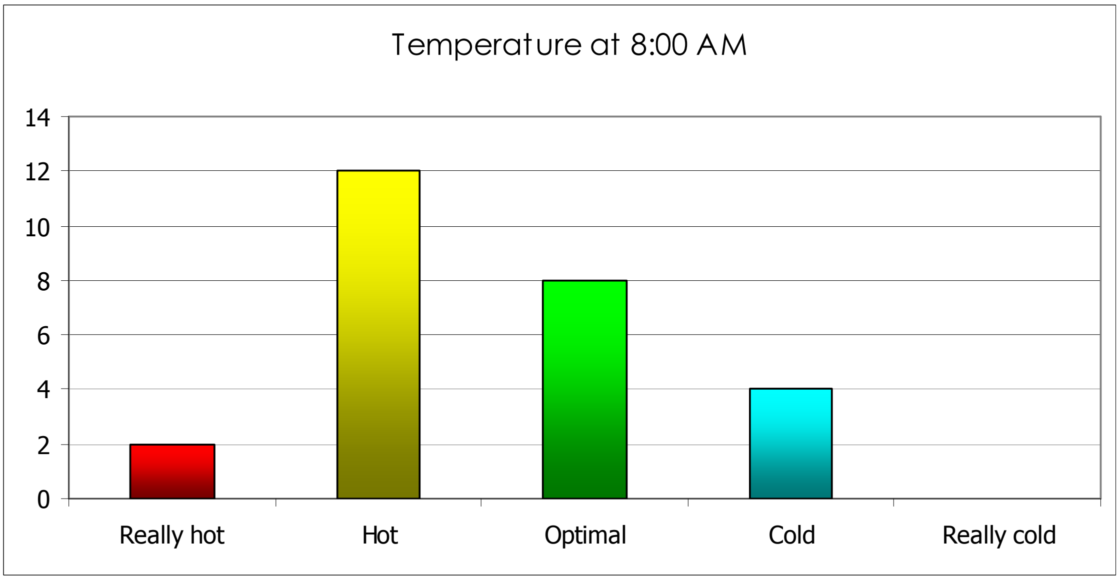


A survey, conducted in 2009/2010 Winter season on a 26 people sample, showed that the high set point definitely decreases the internal comfort; the following graphs show the results of this survey.
The occupants were asked to choose between 5 possible perceived levels of internal temperature of the offices during a work day:

- Really hot
- Hot
- Optimal
- Cold
- Really cold



In addition, the participants were asked to define the temperature when they started to work, at 8:00 o'clock.



The perception of internal temperature is hot, especially in the first hours of the morning: the occupants often change set point during the day and/or switch off internal units, but every nights the units provide too much heat to the building, before work time.
The 24 h operation consume huge amount of energy and does not provide sufficient comfort.

Main Eco's identified

ECO CODE	DESCRIPTION	ACTION	Saving
O2.2 WINTER	Shut off A/C equipments when not needed	Define a schedule strategy, operating on BEMS	-26.7% (-94.5 MWh) on winter VRF consumption (354.1 MWh)
O2.2 SUMMER	Shut off A/C equipments when not needed	Define a schedule strategy, operating on BEMS	-49.9% (-67.5 MWh) on summer VRF consumption (135.2 MWh)
O2.6	Implement pre-occupancy cycle	Define a pre-occupancy strategy, operating on BEMS	-53.7% (-72.6 MWh) on summer VRF consumption (135.2 MWh)

ECO O 2.2, Shut off A/C equipments when not needed

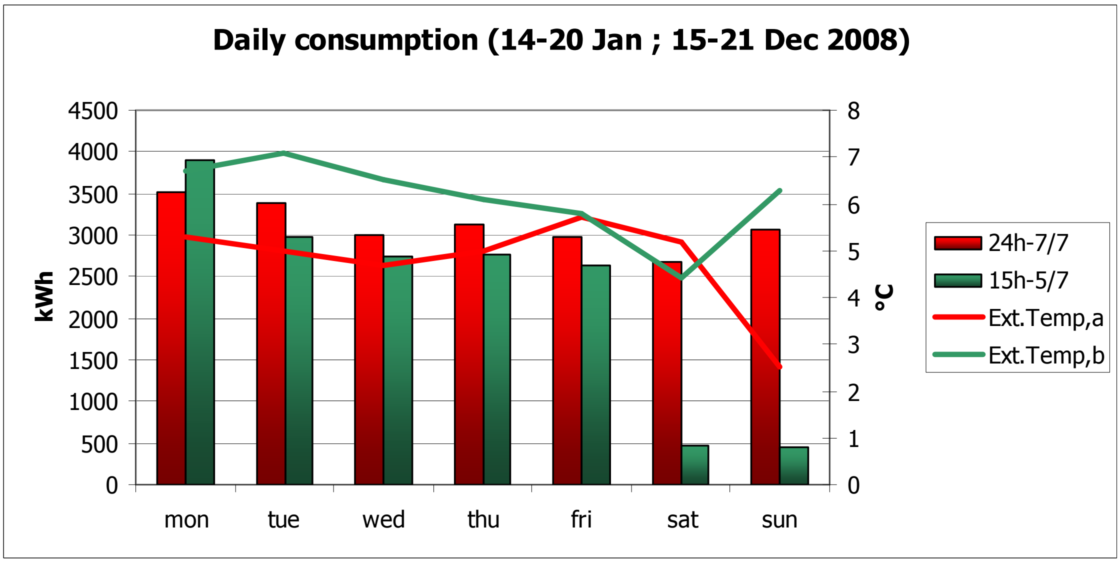
WINTER

The system considered was built in 2004. An electric meter was installed: it logs the VRF external units consumption.
The table below shows the VRF system specific electrical consumption (kWh/m^2).

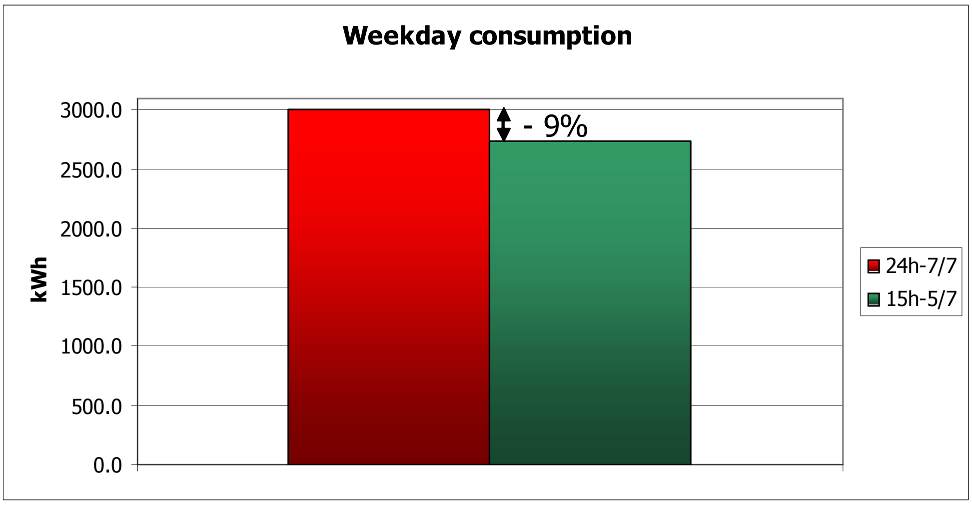
Season	Annual	Heating Oct-Apr	Cooling May-Sep
2005 - 2006	65	47	18
2006 - 2007	48	35	13
2007 - 2008	49	37	12

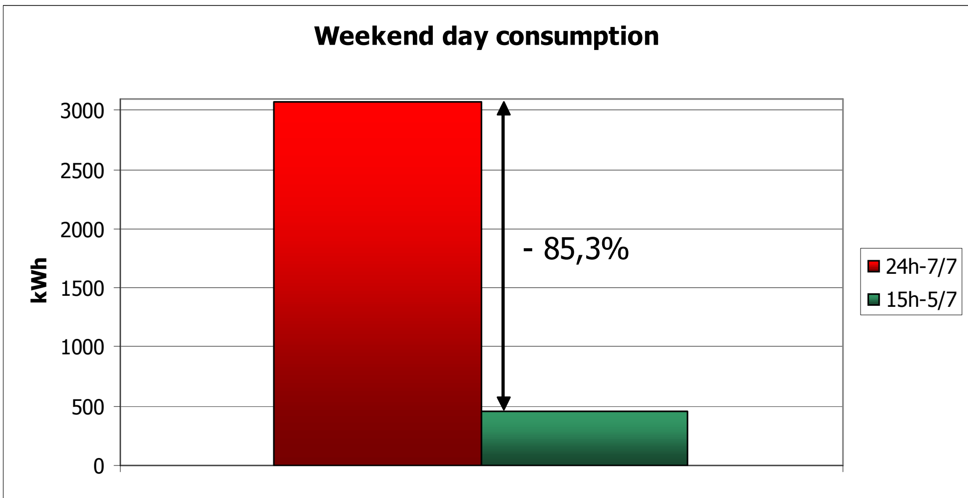
These values indicate that the HVAC system consumption was optimized, after the first year of operation. During 2007-2008 season, the operational schedule was changed, from 24/24 hours, 7 day per week, to 15 hours, 5 days per week.

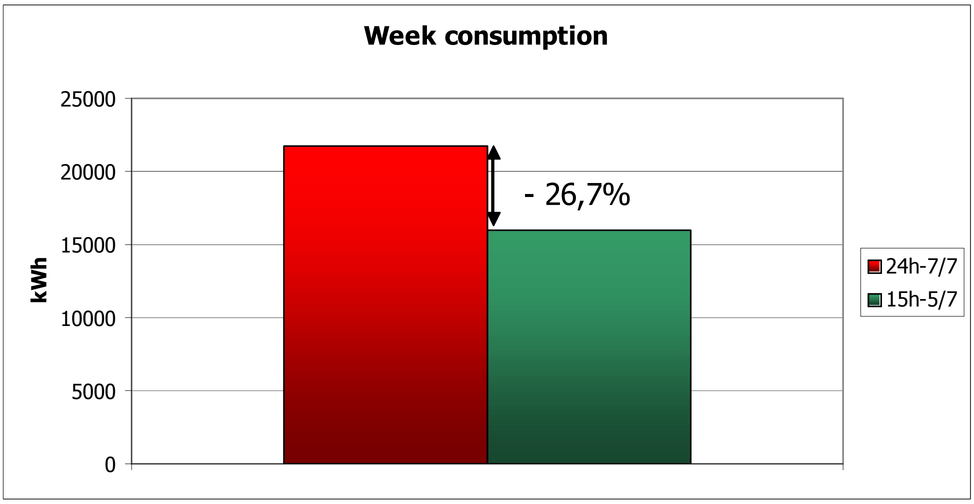
The variation of consumption is clearly seen in graph below.



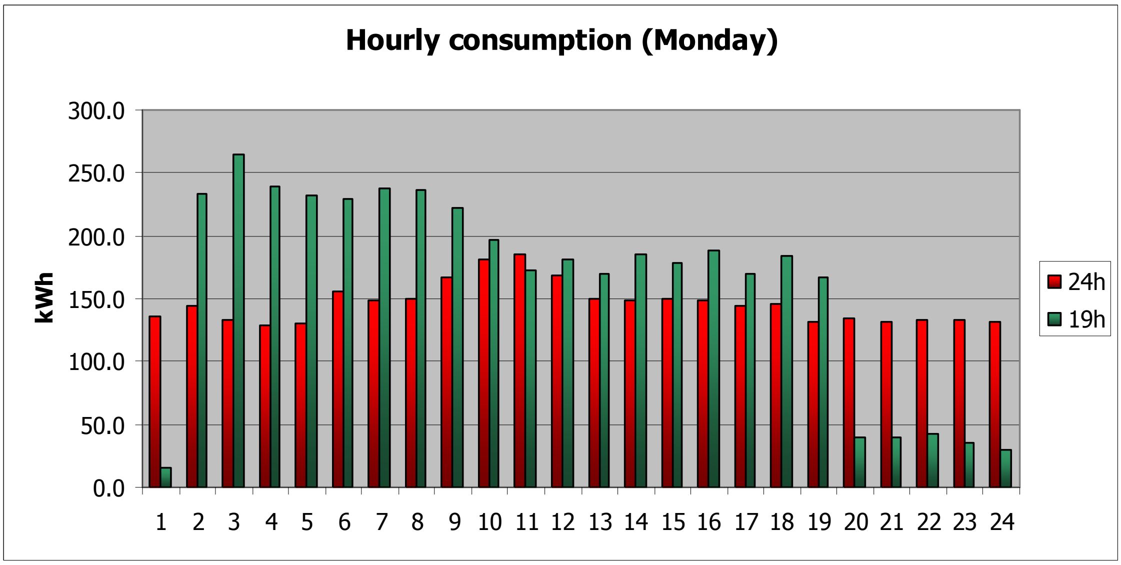
It is clear that a different schedule affects dramatically the weekend consumption, while work-day consumption sees a limited but constant decrease, with exception of Monday. The high thermal capacity of the building explains this behaviour.







An hourly analysis of Monday consumption reveals that the HVAC system works at full load for some hours before reaching partial load.



The values presented demonstrate the energy savings on the week considered, during winter season:

- **26,7% on overall week consumption of HVAC external units consumption, composed by:**
  - **9% on work day**
  - **85% on week-end**

SUMMER

After ten years of contract, the ESCO was changed in December 2009. This fact implied a reset of HVAC system control.
When we made a new inspection, in Spring 2010, it was clear that VRF HP system was running 24 hours a day, 7 days per week. Furthermore, the electric consumption monitoring system, connected to BEMS, was totally inoperative. For this reason we started a metering campaign on a small part of the building. We also proposed to change the system parameters (set point and operation hours) to improve system efficiency.
To compare the optimized consumption to a standard basis, two parts of the building were considered. The north part of 4th floor, served by HP called MC3 and the north part of the 3th floor, served by the HP called MC5. The MC3's operation strategy was improved, while on the MC5 schedule no changes were made.
To estimate the energy savings the energy signature method was used (ASHRAE GUIDELINE 14-2002).
The experimentation started on 18 July and finished on 30 August.

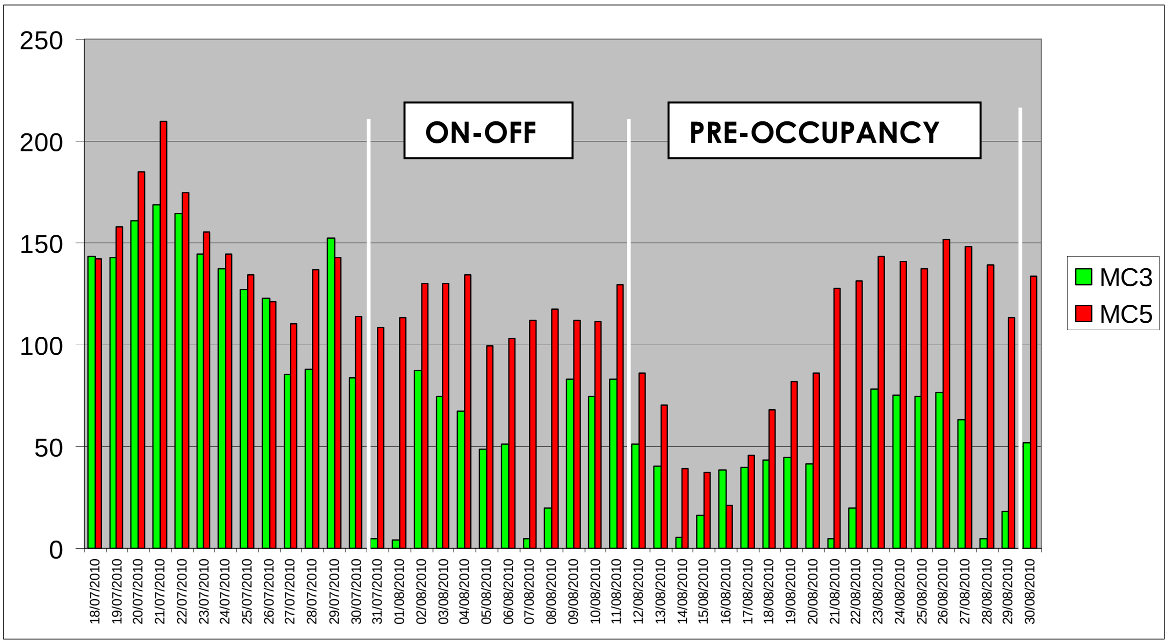
During the first week a normal ON-OFF strategy was implemented, with a set-point of 24.5°C and this schedule:

MON	04:00-12:30	13:30-16:30
TUE-FRI	06:30-12:30	13:30-16:00
SAT	OFF	
SUN	OFF	

The result of this schedule changing was a net electric energy saving:

- -32.9% on daily consumption during workdays
- -95.3% on daily consumption during weekend
- -49.9% on weekly overall consumption

The graph below show, in kWh, the daily consumption of the two HP considered.



ECO O 2.6, Implement pre-occupancy cycle

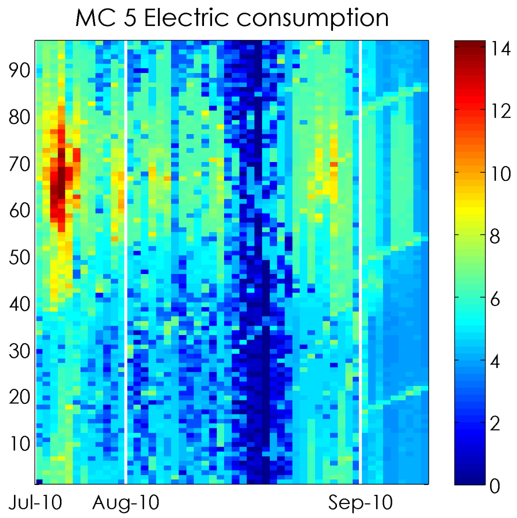
As a part of the experimentation described above, on 11 August 2010 the schedule was changed, implementing a pre-occupancy cycle. The occupancy set point was the same: 24.5°. The new operational schedule was:

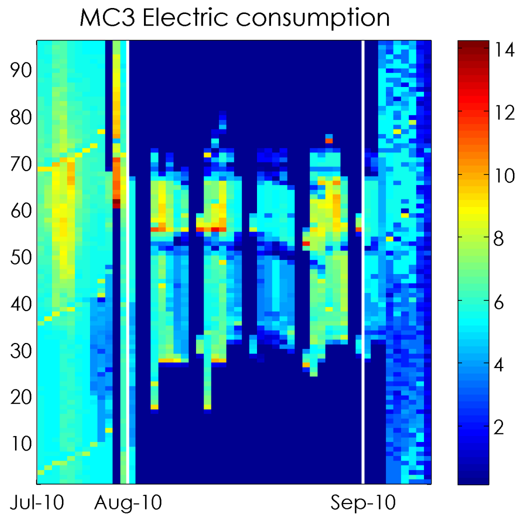
MON	06:45-16:30
TUE-FRI	07:45-16:30
SAT	OFF
SUN	OFF

During the operation time, pre-occupancy cycle, with a set-point of 26.5, was implemented, with the following schedule:

MON	06:45-08:30	12:30-13:30
TUE-FRI	07:45-08:30	12:30-13:30

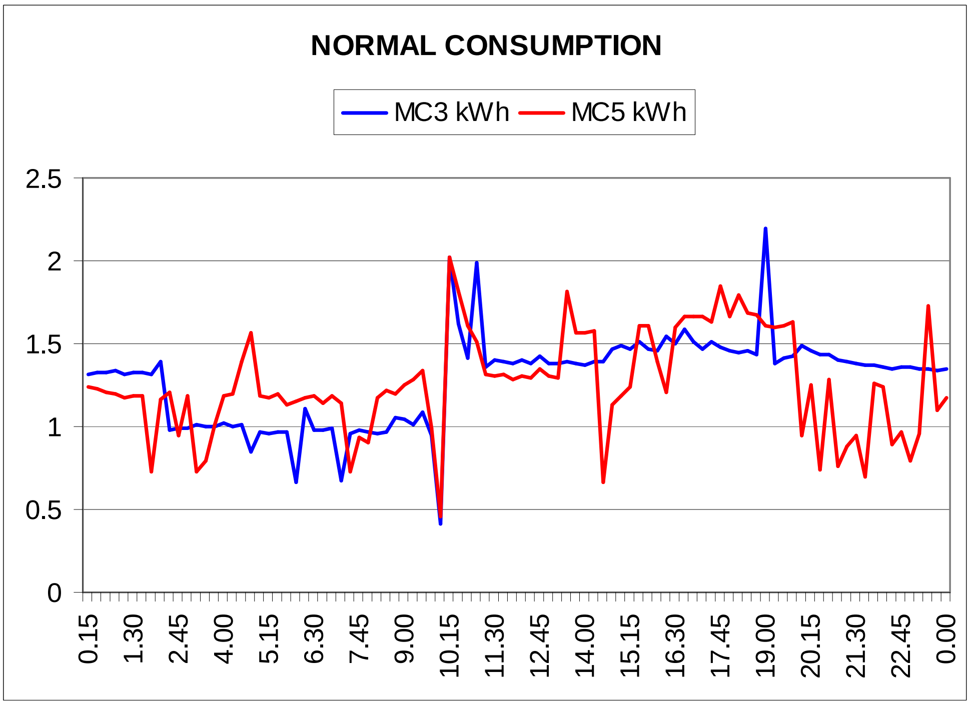
The graph below show the carpet plot of electric mean power; data are expressed in kW, with a sampling rate of 15 minutes.



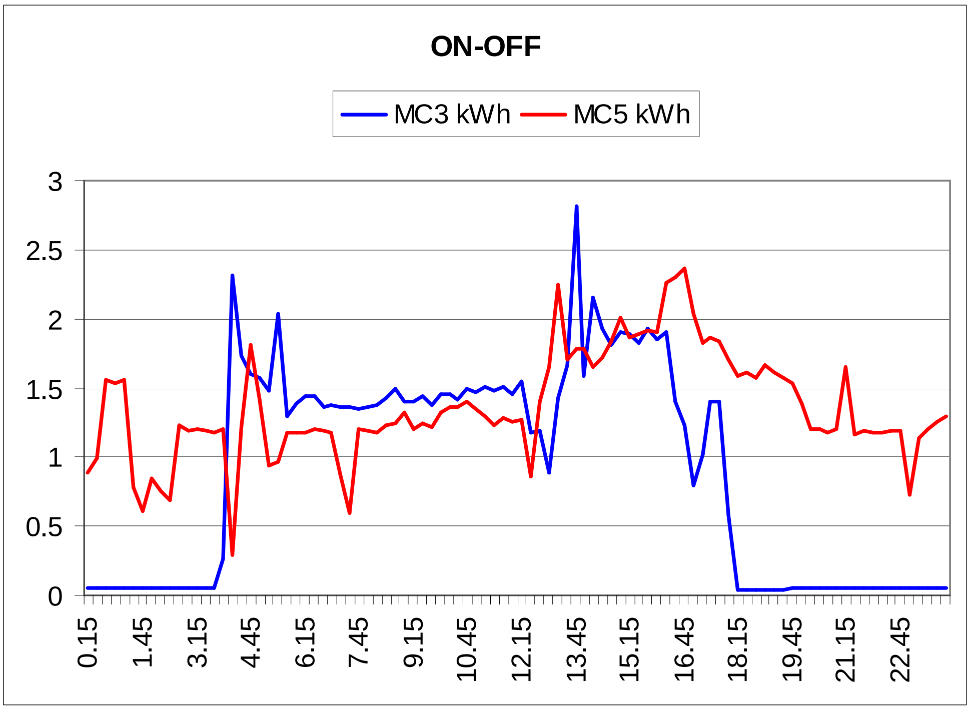


The following graphs present Monday hourly consumption of the HP VRF considered (MC3) in the different operation strategies. As described above, the MC5 HP worked for all the surveys 24 hours a day, 7 days per week.

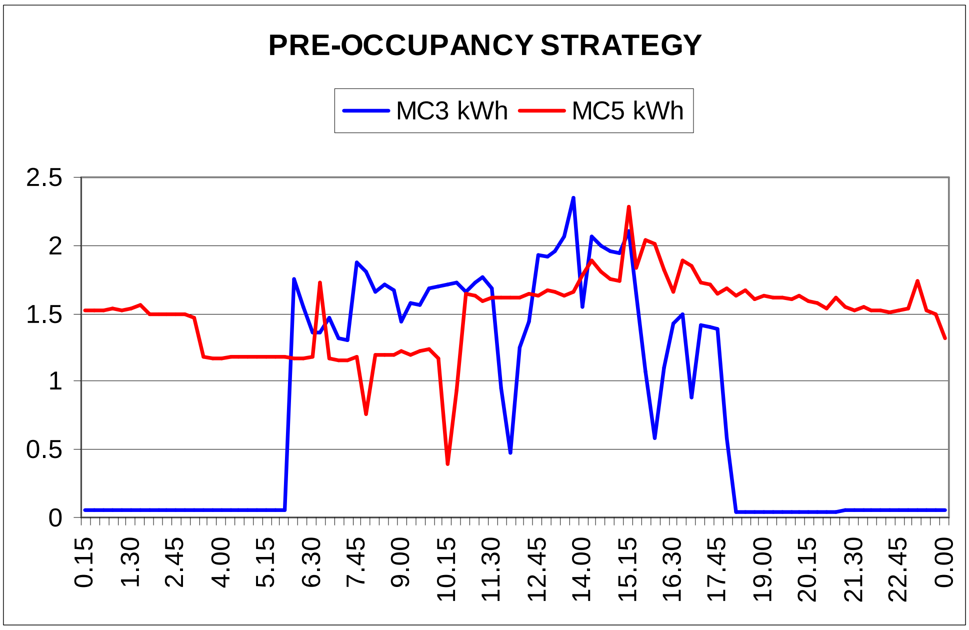
26 JUL 2010



2 AUG 2010



23 AUG 2010



MC3 HP, in pre-occupancy strategy presents overall consumption less than half of its theoretical consumption with 24 hours operation schedule.
The savings, result of pre-occupancy implementation, was calculated as difference on the normal VRF HP behaviour before the experiment (using ASHRAE GUIDELINE 14-2002).

The calculated saving are:

- **-37.9% on daily consumption during workdays**
- **-92.2% on daily consumption during weekend**
- **-53.7% on weekly overall consumption**

Timing table for first inspection

Inspection Item	Short Description	Time (mins)	Savings	Notes
PI1	Location and number of AC zones	5		
PI2	Documentation per zone	10		
PI3	Images of zones/building	15		
PI4	General zone data/zone	15		
PI5	Construction details/zone	8		
PI6	Building mass/air tightness per zone	10		
PI7	Occupancy schedules per zone	5		
PI8	Monthly schedule exceptions per zone	1		
PI9	HVAC system description and operating setpoints per zone	13		
PI10	Original design conditions per zone	10		
PI11	Current design loads per zone	60		
PI12	Power/energy information per zone	5		
PI13	Source of heating supplying each zone	2		
PI14	Heating storage and control for each zone	1		
PI15	Refrigeration equipment for each zone	4		
PI16	AHU for each zone	4		
PI17	Cooling distribution fluid details per zone	6		
PI18	Cooling terminal units details in each zone	2		
PI19	Energy supply to the system	2		
PI20	Energy supply to the building	1		
PI21	Annual energy consumption of the system	0		
PI22	Annual energy consumption of the building	5		
	TOTAL TIME TAKEN (minutes)	**184**		
	TOTAL (seconds/m²)	**1.16**	Area (m²)	9500

Packaged system inspection data

Inspection Item	Short Description	Time (mins)	Savings	Notes
PP1	List of installed refrigeration plant	8		
PP2	Method of control of temperature.	3		
PP3	Method of control of periods of operation	5		

PP4	Reports from earlier AC inspections and EPC's	5		
PP5	Records of maintenance operations	14		
PP6	Records of maintenance (control systems and sensors)	0		n.a.
PP7	Records of sub-metered air conditioning plant (use or energy)	25		
PP8	Design cooling load for each system	5		
PP9	Description of the occupation of the cooled spaces	25		
P1	Review available documentation from pre-inspection	30		
P2	Locate the plant and compare details with pre-inspection data	30		
P3	Locate supply to the A/C system and install VA logger(s)	70		
P4	Review current inspection and maintenance regime	12		
P5	Compare size with imposed cooling loads	18		
P6	Compare records of use or sub-metered energy with expectations	45		
P7	Locate outdoor plant	5		
P8	Check for signs of refrigerant leakage.	15		
P9	Check plant is capable of providing cooling	3		
P10	Check external heat exchangers	10		
P11	Check location of outdoor unit	2		
P12	Assess zoning in relation to internal gain and orientation	12		
P13	Check indicated weekday and time on controllers against actual	220		1 minute per each internal unit, there are 220 internal unit
P14	Note the set on and off periods	5		
P15	Identify zone heating and cooling temperature control sensors.	1		in the internal unit
P16	Note set temperatures in relation to the activities and occupancy	1		assessing with P13
P17	Provision of controls or guidance on use while windows open	15		
P18	Type, age and method of capacity control of the equipment	2		
P19	Write report	60		
	TOTAL TIME TAKEN (minutes)	**646**		
	TOTAL (seconds/m^2)	**4.08**	Area (m^2)	9500

Overall conclusions

This case study represents in some ways the typical Italian building stock. It is an ancient building, passed through a war, completely reconstructed and merged with another building.
In this kind of architectural panorama, the HP VRF solution is quite interesting, thanks to its minimum impact on internal walls and the modularity of its installation, which permits having the external units distributed in several small zones, instead of two large centralized cooling and heating stations.
The performance of the system assessed is quite good, in comparison to other Italian case studies. Nevertheless, different inspection conducted in different seasons of the year revealed that schedule control was not optimized, the system ran 24 hours a day, 7 days per week. In addition the internal comfort was lower than expected with such kind of system.

In summary, this case study shows that:

1. **HP VRF SISTEM may be a suitable alternative to centralized system, in some buildings. The effect of HP COP at low temperature should be well assessed and evaluated in cold climatic zones.**

2. **Possible freezing problem on the external units (typically occurring around 8°C) has to be evaluated in the design phase of the system. Defrosting system of HP air to air should compromise the components life: operational settings of the units have to be well defined to avoid that.**

3. **Inefficient BEMS is like no BEMS. Data storage and schedule control must be of primary importance in the HVAC management.**

4. **Surveys on occupants should help to understand the comfort perception inside the building.**

5. **Occupants education campaigns to utilize internal units should be made at least once every two years. Occupants education as well should help building manager to decrease energy consumption.**