

POLITECNICO DI TORINO

DEPARTMENT OF ENERGY

Master's degree in Industrial Engineering



MASTER'S THESIS IN INDUSTRIAL ENGINEERING

ENERGY AUDIT OF THE BELLVITGE UB HEALTH SCIENCE CAMPUS THROUGH DESIGN BUILDER

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To my family and friends,

Abstract

The following document presents a Master's Thesis that pretends to carry out an Energy Audit of the Bellvitge UB Health Science Campus using the software Design Builder.

The aim of the thesis is to identify the main weaknesses of the building under study, in order to develop a proposal for improvements to reduce the associated energy consumption.

In first place, there is a preface, where the main reasons to develop this project are explained. In second place, the objectives of the thesis and its scope are defined.

Afterwards, an introduction to the studied building from the constructive point of view is made. Once this explanation has been completed, the process by which the architectural modelling of the Campus has been carried out can be found.

Below it is described the current technical building system. This study has allowed understanding its mode of operation in order to have the widest information for its modelling through Design Builder.

From this point on, the HVAC model is presented. In this description, one can find the justification of the introduced simplifications, which have been made in order to solve the limitations caused by the used software. Once justified, the obtained results from the annual hourly simulations are shown.

These results have been compared with the real consumption values of the Campus in order to evaluate the calibration process and thus assess its validity. Based on its analysis, the main problem of the building has been identified, its high interior lighting consumption.

Two measures for improvement are proposed below to reverse the current situation. The first of them consists on replacing the current lighting with a LED system, and secondly (chained to the obtained scenario after applying the first proposal) the implementation of photovoltaic panels in the outdoor area located on the fifth floor of the Campus.

The application of these measures would reduce the overall consumption of the building by 31%, thus increasing its energy efficiency.

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1. Glossary

UPC	Universitat Politècnica de Catalunya
ETSEIB	Escola Tècnica Superior d'Enginyeria Industrial de Barcelona
UB	Universitat de Barcelona
CTE	Código Técnico de la Edificación
RITE	Reglamento Instalaciones Térmicas en los Edificios
DB	Design Builder
TBS	Technical Building System
XPS	Extruded Polystyrene
DHW	Domestic Hot Water
BC1	Air to Water Heat Pump 1
BC2	Air to Water Heat Pump 2
RF-HR	Air-Cooled Scroll Chiller with Heat Recovery
AHU	Air Handling Unit (CL's)
BSC	Secondary circuit Hot water Pump
BSF	Secondary circuit Cold water Pump
ESEER	European Seasonal Energy Efficiency Ratio
BTU	British Terminal Unit
VAV	Variable Air Volume
T_{ext}	External Temperature
CO	Carbon Monoxide
PC	Set point (<i>Punto de Consigna</i>)

PID	Proportional-Integral-Derivative
ASHP	Air Source Heat Pump
HVAC	Heating, Ventilation and Air Conditioning
IDA	Indoor air quality category (taken from RITE)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ITEC	Instituto de Tecnología de la Construcción
PV	Photovoltaic
PSH	Peak Sun Hours

2. Preface

In this first section it can be found the opening of the Master Thesis itself, as well as the reason and origin of this study and the motivation that brought the author to choose this field of study and theme. Furthermore, the project main goals and scope can also be read in this section.

2.1. Origin of the project

All of us are aware of the energy situation in which we are plunging the planet. With the predominant dependence on fossil fuels, new energy sources try to reverse this context and lead society towards a more sustainable model.

Compared to other industrial sectors, the construction field is one of the areas with the highest natural resource consumption (wood, minerals, water and energy): in fact, it is responsible of 25-40% of total energy consumption, 20-30% of raw material consumption, 30-40% of greenhouse gas emissions and 30-40% of solid waste generation.

As a response to these numbers, there was the need to implement the concept of sustainable development in the construction field. Many international commissions were held to lay these groundwork (Bruntland Report, Kyoto Protocol, Rio Summit, etc.).

With the issue of the 2010/31/EU in 2010, 20/20/20 objective were set: to reduce emissions by 20%, to increase the use of renewable energies by 20%, and to decrease energy consumption by another 20%, all with the target of being met by 2020.

In line with these objectives, energy audits and certifications of buildings allow, on one hand, to provide information to the user about the buildings consumption, and to define measures to be implemented to improve the current situation. This search for the improvement of energy efficiency is a crucial element in the transition towards a new economic and social model.

Within the Master Thesis project, the carrying out of an energy audit of the Bellvitge Health Science Campus of the University of Barcelona aims to identify the greatest weaknesses of the case study and the improvements required to increase its energy efficiency.

Since the case study is a public building (with high traffic of students and staff), of large dimensions and recently built (2012), identifying these weaknesses and the ways they can be reversed is thus challenging.

2.2. Motivation

The election of this theme for the Master Thesis is grounded in several arguments. Firstly, it was chosen because of the interest for the building energy management engineering field, despite the fact that the energy field is not the author's specialty.

The specialty during the Master in Industrial Engineering at the Polytechnic University of Catalonia (UPC) deals with the Management in Industrial Engineering, which has given to the author a point of view of the engineering more focused to the pursuit of a greater efficiency in the industrial productive processes, with the main goals of reducing times and production costs.

However, developing the Bachelor's Thesis (Bachelor's Degree of Industrial Engineering) concerning both constructive and energy study of a single-family house located in the Catalan Pyrenees, together with the accomplishment of an internship period in a company dedicated to the energetic management of buildings (BGC Architecture and Engineering), have allowed the author to see which fields of engineering awaken a greater interest.

This Master Thesis aims to wider the acquired knowledge about building energy management and, at the same time, to deepen the field of energy audits (learning a new software tool, Design Builder), which is a field not especially treated during the studies.

Secondly, the project was developed at the Politecnico di Torino. Even though it represents a challenge not only for the language, but also for the rigorousness that this prestigious university demands, it supposes also a fantastic opportunity to get to know other cultures, institutions and ways of working; what is of great importance in the current globalised world.

2.3. Previous requirements

This project requires basic knowledge on energy audit and building certification and how the main actual technical building systems are applied.

In this work there is applied the knowledge acquired in optional subjects taken during the Bachelor's Degree in Industrial Engineering, such as *Building Rehabilitation and Energy Efficiency* and *Construction Sustainability*, and the obligatory courses of *Constructions and Industrial Architecture* and *Technical Building Systems* of the Master's Degree in Industrial Engineering at the UPC (*Universitat Politècnica de Catalunya*).

On the other hand, during the semester in which this Master Thesis has been carried out, the course given by Professor Vincenzo Corrado of *Energy Audit and certification of*

buildings has been attended, whose classes have allowed to extend the knowledge on energy audits together with the current legislation applicable at Italian and European level.

In addition, the knowledge gained through a literary review of this research area has been also applied.

Moreover, as the project forms part of a student exchange programme, it has been written and developed in English. Therefore, it is required at least an intermediate level of English for the right elaboration of this Thesis and a good comprehension of the information obtained through books and Internet (journals, papers and news, for example).

3. Introduction

3.1. Main goals of the project

The main objective of this Master Thesis is to perform an Energy Audit of the Bellvitge UB Health Science Campus to identify its main weaknesses in order to propose measures to apply to improve the building energy efficiency.

These improvement proposals must be within a realistic framework, for which an economic assessment of each of them will be carried out to evaluate the feasibility of their application.

In order to perform the Energy Audit, it will be used as a modelling tool the software Design Builder (associated with the calculation system Energy Plus, provided by the Energy Department of the Politecnico di Torino), which usage will be new for the author of the project. For this reason, a secondary objective of the study consists on learning to dominate the mentioned software with the aim of modelling the building as closely as possible to the reality.

3.2. Project scope

This project aims to have a realistic approach both in the modelling of the studied building and in the proposal of the improvement measures to be implemented. For that purpose, two in site inspections have been made to the building together with the person in charge of maintenance, which have allowed to gather the necessary information to develop the project.

With regard to improvement measures, corresponding manufacturers and suppliers have been contacted and an economic study has been carried out to analyse their viability.

4. Site characteristics and building description

4.1. Physical environment and strategic location

In order to develop the studied building and the extension of the Bellvitge Hospital, it was decided to plan the whole of the new Health Sciences Campus of the University of Barcelona, located inside the Bellvitge Hospital grounds.

The Health Sciences Campus is a new infrastructure of the innovation and technology system created in 2011 for the University of Barcelona, the *Generalitat de Catalunya* (Government of Catalonia), the Hospitalet de Llobregat City Council and Biocat (Organization that coordinates and promotes the healthcare and life sciences sector in Catalonia).

The Campus is based on the creation of a solid network between hospitals, universities, research centres and companies, which allows the promotion of the sector and goes beyond the local level to become an international reference centre, in an environment of quality in terms of image and urban design, together with advanced services and infrastructures.

Since it is located inside the Bellvitge Hospital Complex the studied building is thus in a territory under permanent change that has turned into one of the most important metropolitan entrances due to its strategic position between the airport and the city centre of Barcelona.

The concentration and intensity of the new urban projects in this part of the city make it a new pole of central importance to guarantee the transition of the new key productive activities to contribute to the development of a new socioeconomic model.

The *Gran Via de Les Corts Catalanes* avenue is the structural support of this whole operation, going from being a fast moving road towards having an urban dimension achieved by changing the section of the street, taking the traffic of vehicles to a lower level and leaving the street level free to unite its two urban fronts.

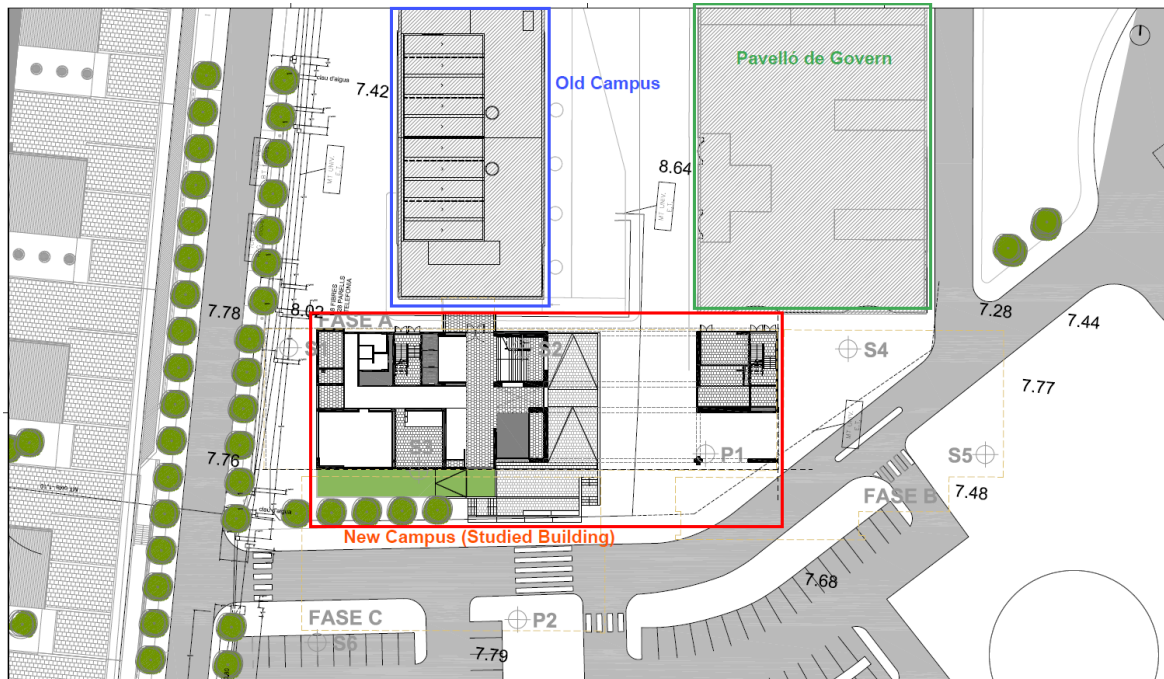


Figure 1: Bellvitge Health Science Campus

As shown in Figure 1, the expansion of the old Campus was carried out by positioning itself within the aforementioned complex in the area for teaching use, perpendicular to the old building and the *Pavelló de Govern* (Government Pavilion). This position allowed the functional connection between the old Campus and its amplification (building under study).

On the ground floor a passageway was created and it represents the continuation of the interior street, located between the old Campus and the *Pavelló de Govern*.

This step allowed the permeability of circulation between the large square and the rest of the Campus. This opening is accessible from the subway exit and serves as the entrance to the teaching area of the Campus.

4.2. Location and climatic data

As described in section 5 of the present document, at the beginning of the modelling of the building, the city of Barcelona has been assigned by means of the Design Builder software. In this way, all the climatic conditions associated with the default template of the software have been integrated.

The climatic conditions established through this template are as follows:

- Site Location:
 - Latitude: 41,28°
 - Longitude: 2,07°
 - AHRAE climate zone: 3C

- Site details:
 - Elevation above sea level: 6m
 - Exposure to wind: 2-Normal
 - Site orientation: 353°

As can be also seen in section 7.2 of the present document, the established external conditions are the following:

- Maximum summer temperature: 31°C
- Minimum winter temperature: 0°C
- Daily temperature variation: 8,4°C
- Mean relative humidity in summer: 68%

4.3. Building description

4.3.1. General configuration

The volumetric shape of the project is based on a large horizontal volume that is located on a public use area, directly related to the frontal central square.

The building envelope is mainly made of concrete walls and large glass openings with solar shading devices.

The north façade, close to the *Pavelló de Govern* and the old Campus building is characterized by a fine-grained plastered finishing and black paint on the ground and first floors. On the upper floors, the chosen coating is a white monolayer of fine grain. The shading devices are made of anodised aluminium.



Figure 2: North Façade

As regards the west façade, it is finished with the above-mentioned solar shading elements. Which consist of vertical lamellae or *brise-soleils* (made of acrylic resin and aluminium hydroxide) that give a second skin to the façade, creating an external space between the end of the built façade and the *brise-soleils*. On the other hand, as shown in Figure 3 the east façade was built from a 14 cm Gero perforated brick envelope finished with white paint.

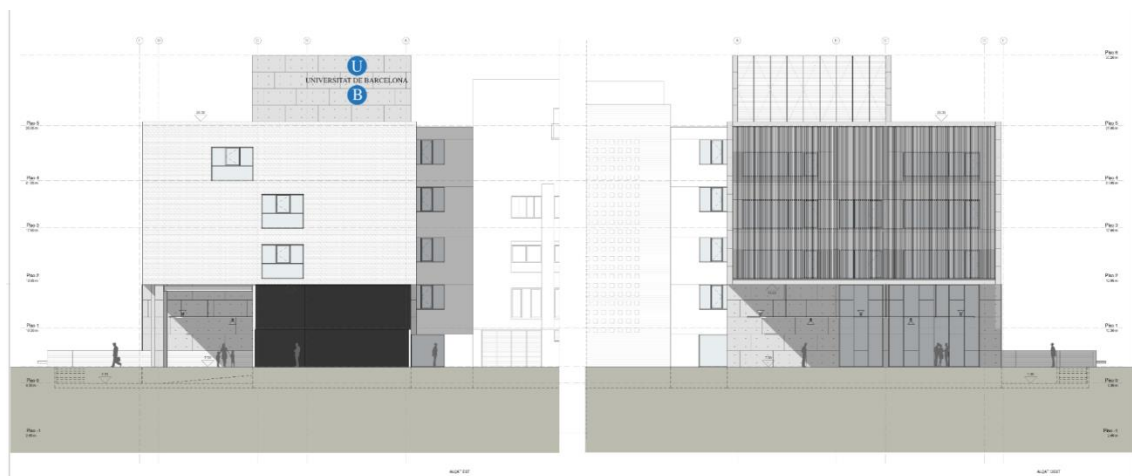


Figure 3: East and West façades

Lastly, the south façade is predominantly defined by three types of surfaces: the one formed by the *brise-soleils* elements (placed horizontally), the ground and first floors (in the area where the conference hall is located (known as *Sala de Graus*)) conferred with a brick wall surface, and finally the zone located on the left side of the Figure 4 finished with an exposed reinforced concrete wall that is part of the structural coherence of the whole that allows the cantilever of the building.

As regard the thermal properties of each constructions, the building is composed by a well-designed thermal envelope. This enclosure is mainly made up of external concrete walls composed by the pertinent thermal insulation.

As far as glassware is concerned (as can be seen in section 5.3.2 of this document together with the section 1.2 of the annex), it provides to the thermal envelope sufficient robustness thanks to the disposition and thickness of its different layers (two typologies of glazing are established: 10-12-12mm and 6-12-8mm of outer glass – air chamber – inner glass).

A deep analysis of each component has been reported in the next section 5.3.1. Also, in the annex from point 1.1.1 to 1.1.7 there can be found all the thermal and constructive information about the created constructive elements.

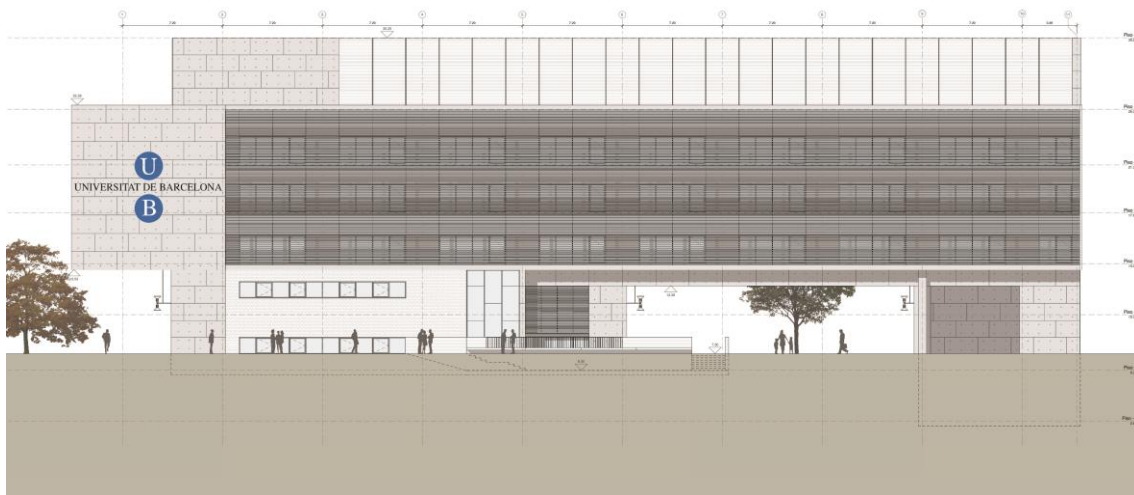


Figure 4: South Façade

As regarding the roof (fifth floor), it is divided into two types of areas:

- Technical building system area (TBS area): inverted roof finished with 15 cm of reinforced concrete compression layer, as a double ceiling to support the technical building benches.
- Outside the TBS area: inverted roof with tile over mortar.

4.3.2. Building uses and Functional Program

The studied building is made up of a ground floor, first, second, third, fourth and fifth floor (this last one used for the TBS, not habitable, and therefore not considered in the overall area calculation).

The area distribution is as follows:

BASEMENT FLOOR -1		Gross Area
Space name	Area	
Space to be defined	81 m ²	
Emergency stairs	26 m ²	
Total Area	107 m²	134,15 m²

GROUND FLOOR		Gross Area
Space name	Area	
Ventilation yard	17 m ²	
Hall (Common Area Gr. Fl.)	147 m ²	
Reception	22 m ²	
Office Gr. Fl.	8 m ²	
Conference Hall (<i>Sala de Graus</i>)	111 m ²	
Store room 0.1	18 m ²	
Store room 0.2	12 m ²	
Store room	19 m ²	
Store room	17 m ²	
Cleaning room	7 m ²	
Electrical switchboard	17 m ²	
Transformer station	36 m ²	
Men's Bathroom Gr. Fl.	8 m ²	
Women's Bathroom Gr. Fl.	8 m ²	
Adapted Bathroom Gr. Fl.	3 m ²	
Corridor (Common Area Gr. Fl.)	11 m ²	
Emergency stairs 0.1	26 m ²	
Emergency stairs 0.2	27 m ²	
Total Area	514 m²	699,42 m²

FIRST FLOOR		Gross Area
Space name	Area	
Hall (Common Area 1 st . Fl.)	147 m ²	
Classroom 1.1 (60 students)	80 m ²	
Classroom 1.2 (60 students)	77 m ²	
Store room 1 st Fl.	36 m ²	

Data (Racks) 1 st Fl.	17 m ²	
Cleaning room 1 st Fl.	7 m ²	
Men's Bathroom 1 st Fl.	8 m ²	
Women's Bathroom 1 st Fl.	8 m ²	
Adapted Bathroom 1 st Fl.	3 m ²	
Corridor (Common Area 1 st Fl.)	79 m ²	
Corridor (Common Area 1 st Fl.)	24 m ²	
Emergency stairs 1.1	29 m ²	
Emergency stairs 1.2	30 m ²	
Total Area	545 m²	711,20 m²

SECOND FLOOR	Gross Area
---------------------	-------------------

Space name	Area	
Hall (Common Area 2 nd Fl.)	128 m ²	
Classroom 2.1 (67 students)	71 m ²	
Classroom 2.2 (70 students)	76 m ²	
Classroom 2.3 (42 students)	48 m ²	
Classroom 2.4 (42 students)	48 m ²	
Classroom 2.5 (42 students)	50 m ²	
Classroom 2.6 (42 students)	46 m ²	
Classroom 2.7 (42 students)	48 m ²	
Classroom 2.8 (42 students)	48 m ²	
Computer room 2.3	75 m ²	
Computer room 2.2	73 m ²	
Computer room 2.1	70 m ²	
Men's Bathroom 2 nd Fl. (2.1)	8 m ²	
Women's Bathroom 2 nd Fl. (2.1)	8 m ²	
Adapted Bathroom 2 nd Fl. (2.1)	3 m ²	
Women's Bathroom 2 nd Fl. (2.2)	7 m ²	
Men's Bathroom 2 nd Fl. (2.2)	9 m ²	
Cleaning room	3 m ²	
Corridor (Common Area 2 nd Fl.)	148 m ²	
Corridor (Common Area 2 nd Fl.)	94 m ²	
Emergency stairs 2.1	28 m ²	
Emergency stairs 2.2	26 m ²	
Total Area	1.115,00	1.428,37

THIRD FLOOR	Gross Area
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Space name	Area
Hall (Common Area 3 rd Fl.)	244 m ²
Microscopy room (3.2)	72 m ²
Cellular Biology Laboratory 3.3	70 m ²
Genetic Immunology Laboratory 3.4	70 m ²
Biochemistry Laboratory 3.5	70 m ²
Biochemistry Laboratory 3.6	70 m ²
Common Laboratory 3.7	46 m ²
Microbiology Laboratory 3.8	74 m ²
Physiology Laboratory 3.10	71 m ²
Pharmacology Laboratory 3.9	67 m ²
Histology Laboratory 3.1	68 m ²
Men's Bathroom 3 rd Fl. (3.1)	8 m ²
Women's Bathroom 3 rd Fl. (3.1)	8 m ²
Adapted Bathroom 3 rd Fl. (3.1)	3 m ²
Women's Bathroom 3 rd Fl. (3.2)	7 m ²
Men's Bathroom 3 rd Fl. (3.2)	9 m ²
Cleaning room	3 m ²
Corridor (Common Area 3 rd Fl.)	104 m ²
Emergency stairs 3.1	28 m ²
Emergency stairs 3.2	26 m ²
Total Area	1.118,00
	1.428,37

FOURTH FLOOR	Gross Area
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Space name	Area
Hall (Common Area 4 th Fl.)	158 m ²
Hall (Common Area 4 th Fl.)	71 m ²
Hall (Common Area 4 th Fl.)	75 m ²
Classroom 4.1 (93 students)	86 m ²
Classroom 4.2 (101 students)	90 m ²
Classroom 4.4 (101 students)	110 m ²
Classroom 4.3 (101 students)	106 m ²
Office 4.1	12 m ²
Office 4.2	13 m ²
Office 4.3	13 m ²
Office 4.4	13 m ²

Office 4.5	12 m ²	
Office 4.6	13 m ²	
Office 4.7	12 m ²	
Office 4.8	13 m ²	
Office 4.9	13 m ²	
Office 4.10	13 m ²	
Office 4.11	15 m ²	
Data (Racks) 4 th Fl.	7 m ²	
Store room	14 m ²	
Maintenance 4 th Fl.	19 m ²	
Men's Bathroom 4 th Fl. (4.1)	8 m ²	
Women's Bathroom 4 th Fl. (4.1)	8 m ²	
Adapted Bathroom 4 th Fl. (4.1)	3 m ²	
Women's Bathroom 4 th Fl. (4.2)	7 m ²	
Men's Bathroom 4 th Fl. (4.2)	9 m ²	
Cleaning room	3 m ²	
Corridor (Common Area 4 th Fl.)	15 m ²	
Corridor (Common Area 4 th Fl.)	24 m ²	
Corridor (Common Area 4 th Fl.)	95 m ²	
Corridor (Common Area 4 th Fl.)	14 m ²	
Corridor (Common Area 4 th Fl.)	13 m ²	
Emergency stairs 4.1	39 m ²	
Emergency stairs 4.2	39 m ²	
Total Area	1.155,00	1.426,18
Total Area	4.554,00	5.827,69

Each classroom and laboratory has good orientation and light conditions (avoiding an excess of the latter) and all spaces are conditioned to accommodate people with mobility problems.

There are points of horizontal connection with the Old Campus building are located in the main floors: ground, first, second, third and fourth.

Vertically, the floors are connected by a large staircase that begins in the main hall of the building and by a vertical communication nucleus with three lifts. There are two emergency staircases distributed to facilitate the evacuation of the occupants.

The humid zones (bathrooms and certain laboratories with water supply) are in vertical

correspondence to rationalise the distribution of the water conductions.

The functionalities of each of the floors that compose the studied building will be briefly explained below.

4.3.2.1. Ground Floor

The public area is mainly located on the ground floor, and it is divided into two well-differentiated areas of use that result from the permeability of circulation that allows the connection between the front square and the rest of the Campus.

The west-side area of the floor contains the main entrance. A large hall serves as a reception and articulation space for the entire building. In it, the reception and the main staircase are located next to the three lifts that complement the vertical communication with the rest of the building.

The described floor also houses the Conference Hall (*Sala de Graus*). In addition, there is a storage and cleaning area, while next to the evacuation staircase there is a wet core made up of three bathrooms (men, women and an adapted one).

Finally, on the east-side of the ground floor, there are two more elements: an additional nucleus of emergency staircases and technical rooms (general low-voltage switchboard).

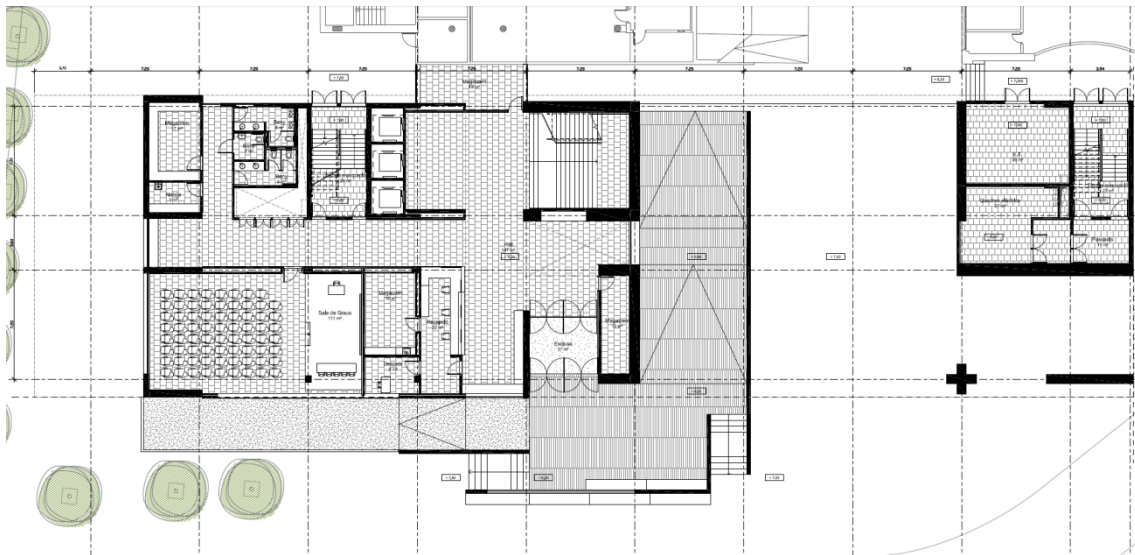


Figure 5: Ground Floor



Figure 6: Common Area Gr. Fl. (Hall)



Figure 7: Corridor Ground Floor

4.3.2.2. First Floor

The west-side of the first floor includes two classrooms for 60 students each, a maintenance storage room and a cleaning area. The wet core consists of the three baths aforementioned and it is repeated vertically.

On the east-side of the floor, the evacuation staircase and another warehouse are located.

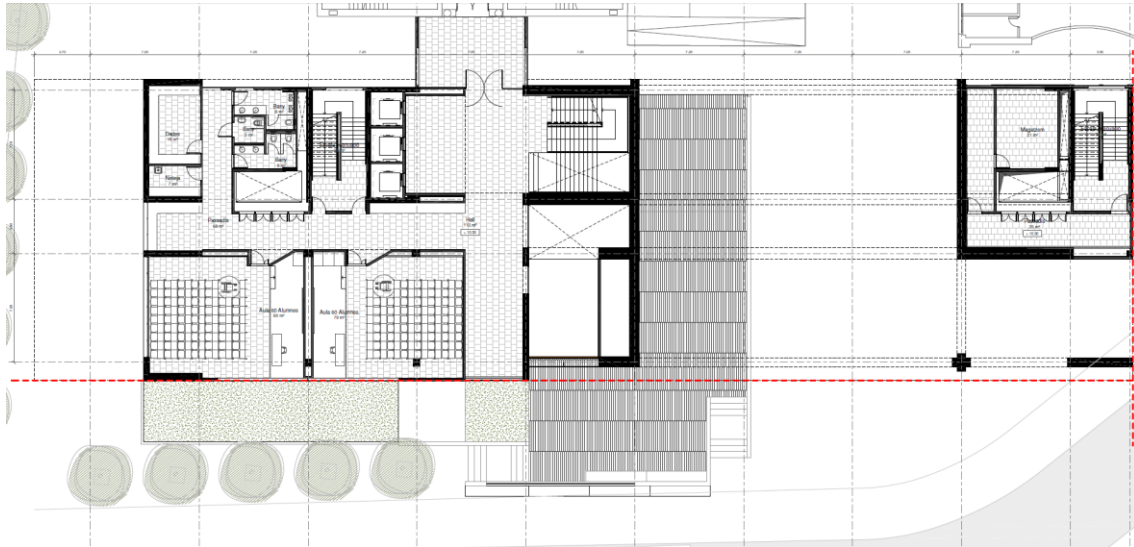


Figure 8: First Floor

4.3.2.3. Second Floor

The second floor consists of two classrooms of 70 and 67 students each, six classrooms of 42 students and three computer rooms; Two wet cores with three bathrooms each are located next to the corresponding evacuation stairs.

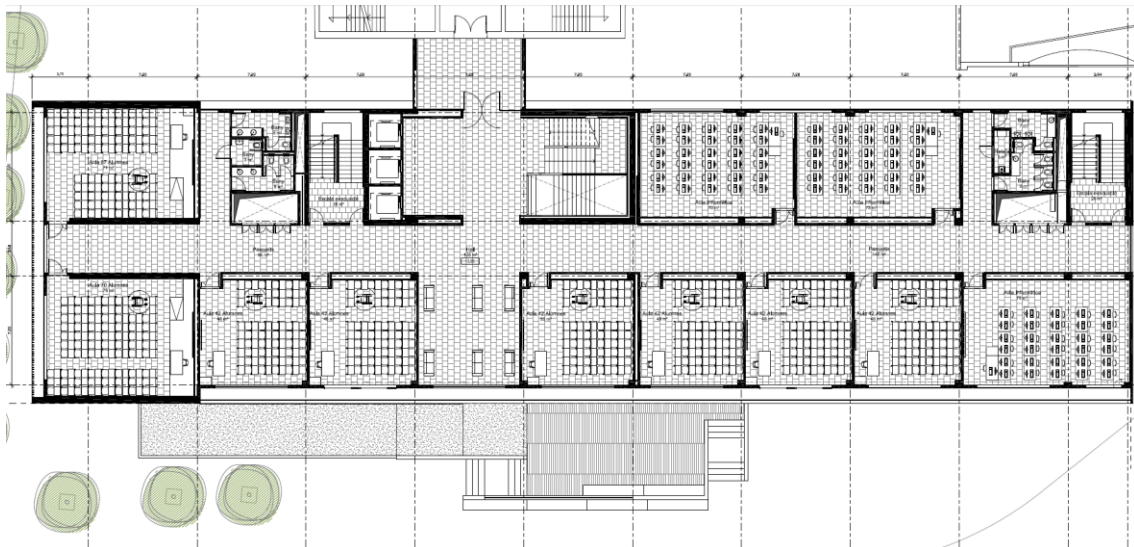


Figure 9: Second Floor

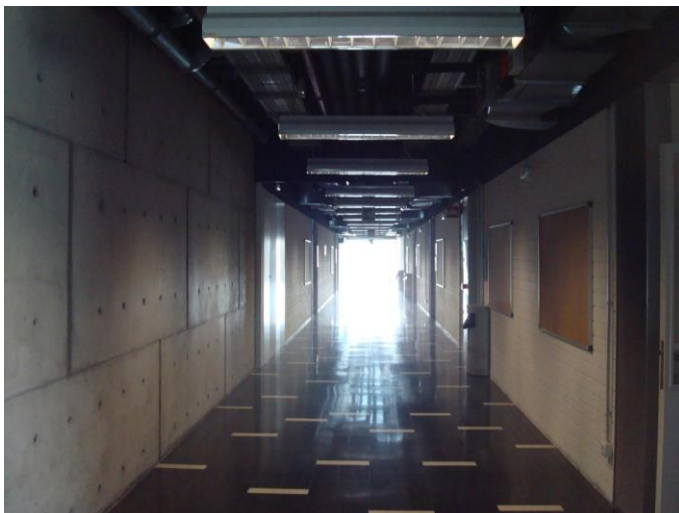


Figure 10: Corridor second floor



Figure 11: Classroom second floor

4.3.2.4. Third Floor

The third floor houses nine laboratories for 30 people and one for 20 students, dedicated to different areas of health sciences (e.g. microscopy, cellular biology, genetic immunology, biochemistry, microbiology, physiology, pharmacology, histology and common laboratory).

Some of these laboratories have smoke columns for direct evacuation to the roof. Bathroom cores are repeated in the same way as in the last floors.

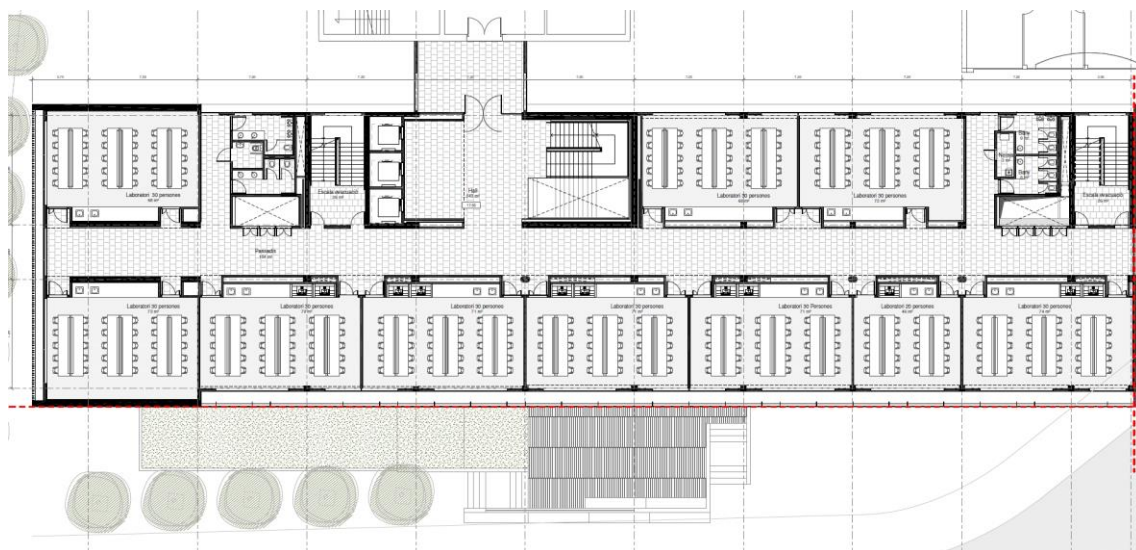


Figure 12: Third Floor



Figure 13: Microbiology room (3.2)



Figure 14: Biochemistry Lab (3.5)

4.3.2.5. Fourth Floor:

The fourth floor contains the largest classrooms and the offices. There are three classrooms for 101 students, one for 93 and eleven teaching personnel offices.

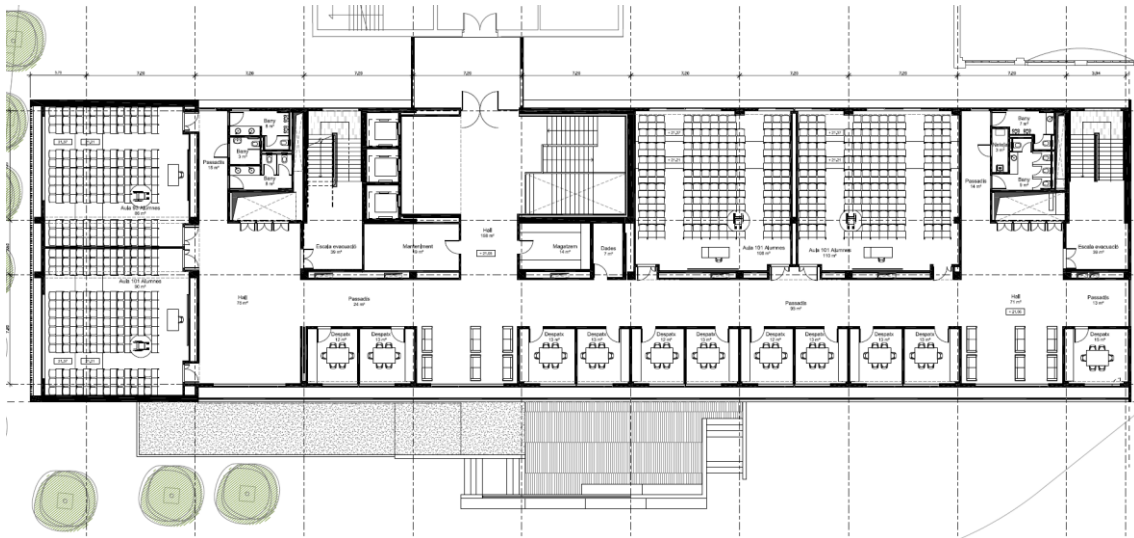


Figure 15: Fourth Floor

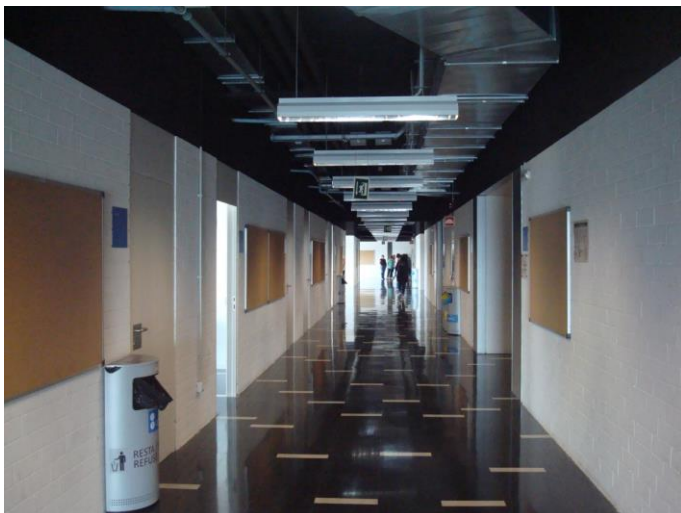


Figure 16: Corridor fourth floor

4.3.2.6. Other identifying elements and external views of the building

Representative images of other characteristic elements of the building under study are reported (Figures 17-20), along with photographs of its exterior appearance (Figures 21-25).

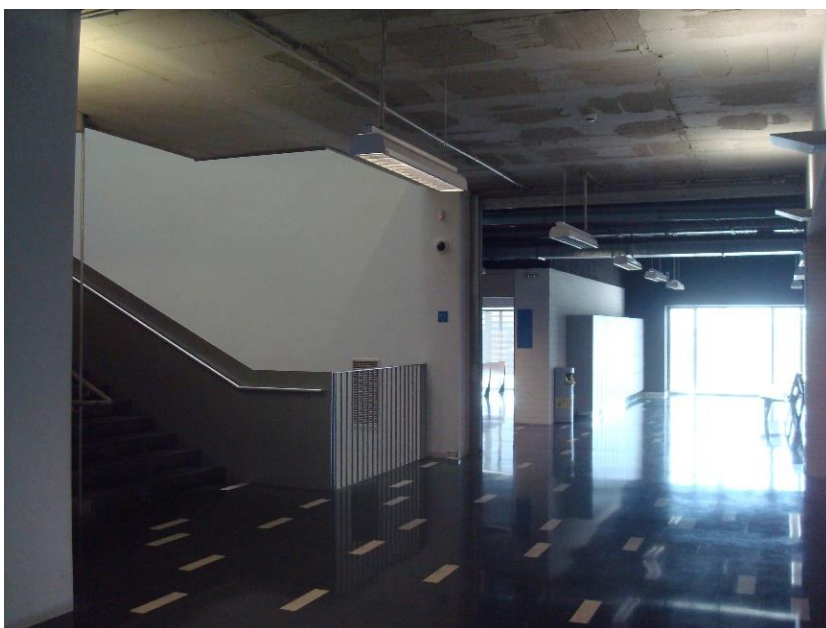


Figure 17: Landing of the main staircase on first floor



Figure 18: Connection pass with the Old Campus, repeated on the first, second, third and fourth floors

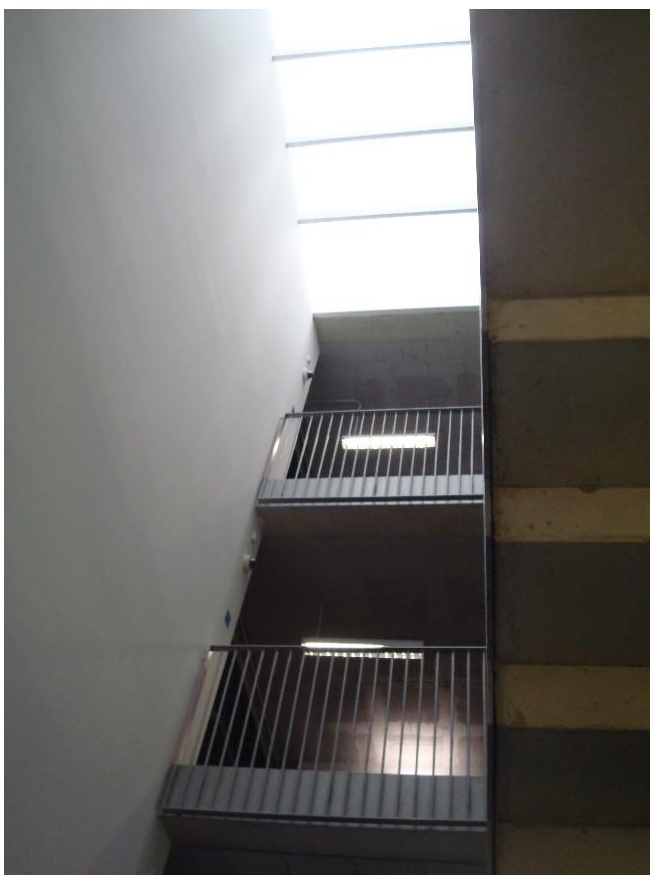


Figure 19: View of the main stairwell and the roof skylight

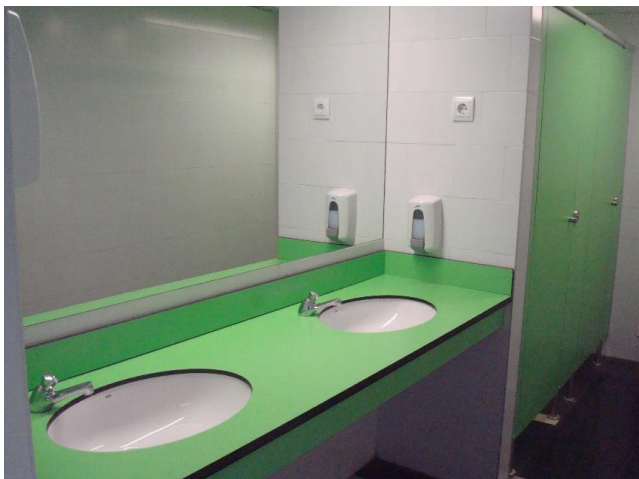


Figure 20: Women's bathroom



Figure 21: General views of the building



Figure 22: View of the south façade



Figure 23: View of the north façade



Figure 24: View of the east façade

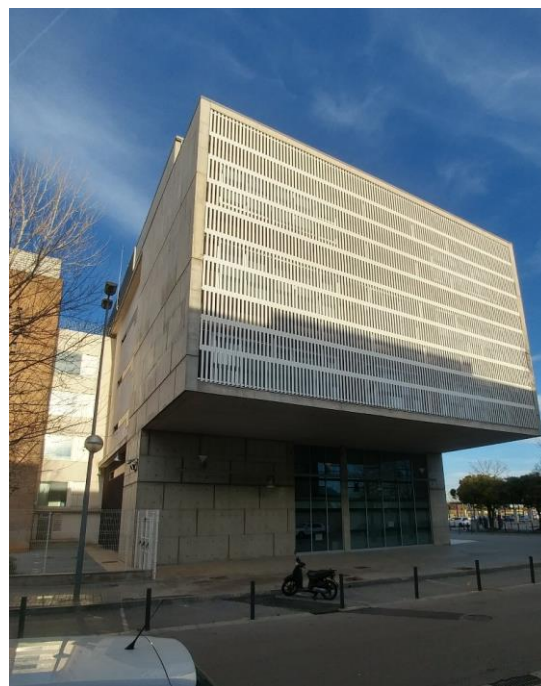


Figure 25: View of the west façade

5. MODELLING OF THE BUILDING THROUGH DESIGN BUILDER

In order to model the studied building through the Design Builder (DB) work tool (provided by the Energy Department of the Politecnico di Torino), it was necessary to plan the main steps to be followed for its elaboration.

With the purpose of explaining the modelling procedure in a simple way, the following is a chronological description of the process developed during the design of the Bellvitge Health Science Campus.

Broadly speaking, the following steps were taken:

1. Import of 2D drawing files
2. Design of each floor of the building, drawing up the individual partitions for the pertinent thermal zones.
3. Creation of Component and Template Libraries.
4. Assignment of the created activity templates to each thermal zone.
5. Linkage of the previously prepared construction templates to the involved envelopes and partitions. Additionally, incorporation of sub-surfaces.
6. Definition of windows and doors.
7. Creation of holes in ceilings and addition of ventilation elements to the corresponding sites.
8. Design of the façade shade elements "*Brise-soleils*".
9. Incorporation of component blocks.

5.1. Import of 2D drawing files

First of all it is necessary to import the plans obtained from each of the floors of the building to proceed with its implementation.

The plans have been provided by the University of Barcelona, with the permission and knowledge of the manager of the Health Science Campus under study.

The plans files (.dxf) have been imported in the Design Builder software, by selecting the needed layers to model the building, avoiding an excess of elements that make its implementation improperly difficult.

After the import has been finished, as shown in Figure 26 the modelling of each floor of the

Bellvitge Health Science Campus can start.

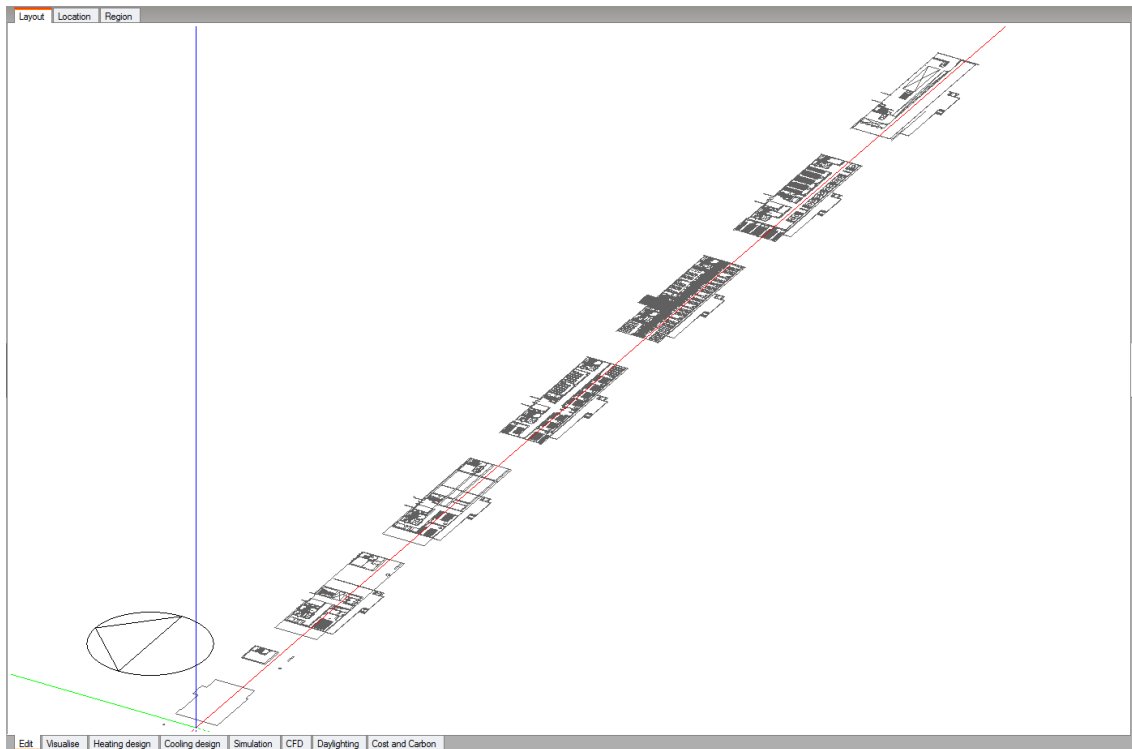


Figure 26: 2D drawing filed imported on DB

5.2. Floor design

As reported in the initial description of the Campus in point 4.3.2 ("Building uses and Functional Program"), each floor has different uses and associated functionalities.

Each of them has been above-described in broad terms in order to understand more clearly what type of activities are carried out in the building.

As it has been explained, the Campus is composed by six floors: Ground, First, Second, Third, Fourth and Fifth Floor (used for the location of the TBS). Each of them has been drawn from the imported plans by drawing the internal partitions and creating the pertinent thermal zones.

The thermal-zoning process, has been aimed to find a compromise between the level of detail to be achieved and a more simplified approach that facilitates a less loaded time-consuming simulation.

As described in point 5.4 of the present document, these thermal zones have been assigned to the different spaces to be air-conditioned (teaching areas, laboratories, computer rooms, etc).

The assignment of these thermal zones has been linked with the pertinent schedules that will define aspects like: occupancy, lighting consumption, HVAC operations, etc), the definition of which is explained in section 5.3.4 of the present document.

With regard to the thermal properties of the constructional elements associated with these thermal zones, they can be found from point 1.1.1 up to point 1.1.7 (not included) of the annex. While for windows there is a description of their composition in section 5.6 together with the thermal properties associated with the two implemented glass typologies (also there can be found on point 1.2 of the annex further information about glazing).

Parallel to these points, the use of the DB file is recommended, where it is possible to observe in a more direct and intuitive way how the different thermal zones within the building have been distributed, together with the thermal and occupancy characteristics associated with each one of them.

Finally, simplifications have been made for the areas that share the same energy demands or conditions of use. For example, the classrooms located on the first floor have not been separated by an internal partition, but have been treated as a single thermal zone (this has been done in the same way for the rest of the classrooms, laboratories, computer rooms and bathroom areas on the rest of the floors).

5.3. Creation of Component and Template Libraries

From this point on, the different elements that will later be associated with the various constructive and functional elements of the Campus are defined.

In particular, the created libraries (those associated with the technical building system will not be described yet) can be classified into the following groups:

- Constructions
- Glazing
- Local shading
- Schedules

The belonging of each building envelope component to these groups is specified below. It

has been decided to make a brief description of each component and, images of their compositions and technical characteristics can be found in the annex.

The information provided in the annex for each element are structured as follows:

- A schematic image of how the construction layers are composed together (whether is a wall, internal partition, door, window, etc.).
- Technical characteristics obtained from the calculation made by Design Builder.

5.3.1. Constructions

In order to model the building as realistic as possible, different library packages have been created and lately associated with the multiple construction elements of the building under study. Therefore, the following types of libraries have been defined:

- Floors (external)
- Floors (ground)
- Floors (internal)
- Partitions
- Roofs
- Walls
- Doors

In most of the created libraries, it can be seen that the choice of the corresponding materials has been made in Spanish. The reason why it has been done this way is due to the country election (Spain) during the creation of the file in DB, which has allowed the appearance of the used materials (defined through the Spanish Technical Building Code (Código Técnico de la Edificación CTE)) in Spanish language.

In the description section of each component, the following pattern has been used:

- Translation of the created name into English.
- Page number of the Annex where the additional information can be found (material properties, U-value, etc).
- Brief description of the concerned item.

It is in the associated page of the annex (specified in each of the different created constructive elements) where the constructive and thermal properties of these elements are specified, which are:

- Composition of the established materials as layers of each enclosure together with their thickness.
- U-Value [W/m^2K]
- Convective heat transfer coefficient [$W/m^2/K$]
- Radiative heat transfer coefficient [W/m^2K]

5.3.1.1. Floors (external)

There have been defined three different kind of external floors:

- *Aulari – Coberta P4 (external)*
- *Aulari – Coberta P4 (interior – technical building systems)*
- *Aulari – Forjat normal (pont)*

5.3.1.1.1 Aulari – Coberta P4 (external)

- Translation of the name into English: Campus – Roof 4th Floor (external).
- [Annex page number: 7 \(Point 1.1.1.1\)](#)
- Element description: It is the part of the ceiling located between the fourth and the fifth floors which is in contact with the outside air. Composed of ten layers.

5.3.1.1.2 Aulari – Coberta P4 (interior – technical building systems)

- Translation of the name into English: Campus – Roof 4th Floor (interior – technical building systems).
- [Annex page number: 7 \(Point 1.1.1.2\)](#)
- Element description: Is the other part of the slab located between the fourth and fifth floor, in which all the technical building systems of the building are situated.

5.3.1.1.3 Aulari – Forjat normal (pont)

- Translation of the name into English: Campus – Normal slab (Bridge)
- [Annex page number: 8 \(Point 1.1.1.3\)](#)

- Element description: Part of the slab located between the first and the second floor in contact with the outdoor air.

5.3.1.2. Floors (Ground)

Only one type of floor has been defined for the analysed building, labelled as “*Aulari – Solera*”

5.3.1.2.1 Aulari – Solera

- Translation of the name into English: Campus – Ground
- Annex page number: 8 (point 1.1.2.1)
- Element description: First floor (vs. Ground) of the building made up of a composition of 6 layers. Finished with an artificial stone interior surface.

5.3.1.3. Floors (internal)

There are 8 different types of interior floor slabs that separate the distinct floors of the Campus (they differ only in the first and last layers):

- *Aulari – CR01-Forjat normal-P01*
- *Aulari – CR01-Forjat normal-P02*
- *Aulari – CR02(=CR03=CR04=CR09)-Forjat normal-P01*
- *Aulari – CR04-Forjat normal-P02*
- *Aulari – CR05-Forjat normal-P01*
- *Aulari – CR06-Forjat normal-P01*
- *Aulari – CR07-Forjat normal-P01*
- *Aulari – Forjat normal*

5.3.1.3.1 Aulari – CR01-Forjat normal-P01

- Translation of the name into English: Campus – CR01-Normal Floor-P01
- Annex page number: 9 (Point 1.1.3.1)
- Element description: Slab made of a sound-absorbent plate of vegetable fibres ceiling (CR01), finished with an artificial stone terrazzo flooring (P01).

5.3.1.3.2 Aulari – CR01-Forjat normal-P02

- Translation of the name into English: Campus – CR01-Normal Floor-P02
- [Annex page number: 9 \(Point 1.1.3.2\)](#)
- Element description: Slab made of a sound-absorbent plate of vegetable fibres ceiling (CR01), finished with a 2 mm vinyl flooring (P02).

5.3.1.3.3 Aulari – CR02(=CR03=CR04=CR09)-Forjat normal-P01

- Translation of the name into English: Campus – CR02(=CR03=CR04=CR09)-Normal Floor-P01

- [Annex page number: 9 \(Point 1.1.3.3.\)](#)

- Element description:

Slab made of laminated plaster board ceiling, finished with the artificial stone terrazzo flooring P01.

In this case, a simplification has been made that affects 4 ceilings (CR02, CR03, CR04 and CR09) whose thermal properties are identical between them ("laminated plaster boards") and only differ in the applied paint on their surface.

5.3.1.3.4 Aulari – CR04-Forjat normal-P02

- Translation of the name into English: Campus – CR04-Normal Floor-P02
- [Annex page number: 10 \(Point 1.1.3.4\)](#)
- Element description: Slab composed by CR04 plaster board ceiling, finished with a 2 mm vinyl flooring (P02).

5.3.1.3.5 Aulari – CR05-Forjat normal-P01

- Translation of the name into English: Campus – CR05-Normal Floor-P01
- [Annex page number: 10 \(Point 1.1.3.5\)](#)
- Element description: Slab made up of assembled slats of masarabunda wood (defined on Design Builder as "*Froncosa pesada 750 < d < 870*", which represents a heavy hardwood), finished with the artificial stone flooring P01.

5.3.1.3.6 Aulari – CR06-Forjat normal-P01

- Translation of the name into English: Campus – CR06-Normal Floor-P01
- [Annex page number: 11 \(Point 1.1.3.6\)](#)
- Element description: Slab started with a conglomerate wood ceiling fibreboard (covered with stainless steel sheet) CR06, finished with P01.

5.3.1.3.7 Aulari – CR07-Forjat normal-P01

- Translation of the name into English: Campus – CR07-Normal Floor-P01
- [Annex page number: 11 \(Point 1.1.3.7\)](#)
- Element description: Slab started with a conglomerate wood ceiling fibreboard (covered with steel sheet) CR07, finished with P01.

5.3.1.3.8 Aulari – Forjat normal

- Translation of the name into English: Campus – Normal Floor
- [Annex page number: 12 \(Point 1.1.3.8\)](#)
- Element description: It is the central part of the floor slabs described above, without the initial and final surfaces. Composed by 6 layers.

5.3.1.4. Partitions

This part includes the set of internal partitions that constitute the divisions between the different defined thermal zones. In total, 54 have been created, which are:

- *Aulari – Int. Part. M02-CA6.5-M05-R11 (Annex page: 12, point 1.1.4.1)*
- *Aulari – Int. Part. M02-CA12-M05-R11 (Annex page: 13, point 1.1.4.2)*
- *Aulari – Int. Part. M02-R11 (Annex page: 13, point 1.1.4.3)*
- *Aulari – Int. Part. R01-M04-CA15-M05-R04 (Annex page: 14, point 1.1.4.4)*
- *Aulari – Int. Part. R01-M04-CA25-M04-R01 (Annex page: 14, point 1.1.4.5)*
- *Aulari – Int. Part. R01-M04-CA25-M05-R04 (Annex page: 15, point 1.1.4.6)*
- *Aulari – Int. Part. R01-M04-CA-M04-R15 (Annex page: 15, point 1.1.4.7)*
- *Aulari – Int. Part. R01-M04-CA-M05-R15 (Annex page: 16, point 1.1.4.8)*
- *Aulari – Int. Part. R01-M04-CA-M06-R04 (Annex page: 16, point 1.1.4.9)*
- *Aulari – Int. Part. R01-M04-R01 (Annex page: 17, point 1.1.4.10)*
- *Aulari – Int. Part. R01-M04-R05 (Annex page: 17, point 1.1.4.11)*

- *Aulari – Int. Part. R01-M04-R07 (Annex page: 18, point 1.1.4.12)*
- *Aulari – Int. Part. R01-M04-R11 (Annex page: 18, point 1.1.4.13)*
- *Aulari – Int. Part. R01-M04-R21 (Annex page: 19, point 1.1.4.14)*
- *Aulari – Int. Part. R02-M04-CA21.5-M06-R04 (Annex page: 19, 1.1.4.15)*
- *Aulari – Int. Part. R02-M04-CA25-M05-R04 (Annex page: 20, point 1.1.4.16)*
- *Aulari – Int. Part. R02-M04-CA29.5-M06-R04 (Annex page: 20, 1.1.4.17)*
- *Aulari – Int. Part. R02-M04-CA32-M02-R11 (3rd Fl.) (Annex page: 21)*
- *Aulari – Int. Part. R02-M04-CA40-M03-R05 (Annex page: 21, point 1.1.4.19)*
- *Aulari – Int. Part. R02-M04-CA-M02-R05 (Annex page: 22, point 1.1.4.20)*
- *Aulari – Int. Part. R02-M04-CA-M03-R07 (Annex page: 22, point 1.1.4.21)*
- *Aulari – Int. Part. R02-M04-CA-M03-R08 (Annex page: 23, point 1.1.4.22)*
- *Aulari – Int. Part. R02-M04-CA-M04-R07 (Annex page: 23, point 1.1.4.23)*
- *Aulari – Int. Part. R02-M04-R01 (Annex page: 24, point 1.1.4.24)*
- *Aulari – Int. Part. R02-M04-R07 (Annex page: 24, point 1.1.4.25)*
- *Aulari – Int. Part. R02-M04-R21 (Annex page: 25, point 1.1.4.26)*
- *Aulari – Int. Part. R05-M02-R05 (Annex page: 25, point 1.1.4.27)*
- *Aulari – Int. Part. R05-M04-R01 (Annex page: 26, point 1.1.4.28)*
- *Aulari – Int. Part. R06-CA10-FA40-M04-R01 (Annex page: 26, 1.1.4.29)*
- *Aulari – Int. Part. R06-CA13.5-FA40-R05 (Annex page: 27, point 1.1.4.30)*
- *Aulari – Int. Part. R06-CA13.5-FA40-R11 (Annex page: 27, point 1.1.4.31)*
- *Aulari – Int. Part. R06-CA-FA40-CA-M04-R01 (Annex page: 28, 1.1.4.32)*
- *Aulari – Int. Part. R07-M04-R27 (Annex page: 28, point 1.1.4.33)*
- *Aulari – Int. Part. R08-GRC78-R16 (Annex page: 29, point 1.1.4.34)*
- *Aulari – Int. Part. R08-M02-R08 (Annex page: 29, point 1.1.4.35)*
- *Aulari – Int. Part. R11-M03-CA-M04-R01 (Annex page: 30, point 1.1.4.36)*
- *Aulari – Int. Part. R11-M03-R05 (Annex page: 30, point 1.1.4.37)*
- *Aulari – Int. Part. R13-M04-CA19.5-M06-R04 (Annex page: 31, 1.1.4.38)*
- *Aulari – Int. Part. R13-M04-R01 (Annex page: 31, point 1.1.4.39)*
- *Aulari – Int. Part. R13-M04-R11 (Annex page: 32, point 1.1.4.40)*
- *Aulari – Int. Part. R14-M02-CA-M02-R14 (Annex page: 32, point 1.1.4.41)*
- *Aulari – Int. Part. R14-M02-R08 (Annex page: 33, point 1.1.4.42)*
- *Aulari – Int. Part. R14-M04-CA-M04-R02 (Annex page: 33, point 1.1.4.43)*
- *Aulari – Int. Part. R16-F30-R16 (Annex page: 34, point 1.1.4.44)*
- *Aulari – Int. Part. R16-FA25-R16 (Annex page: 34, point 1.1.4.45)*
- *Aulari – Int. Part. R16-FA34-R016 (R02) (Annex page: 35, point 1.1.4.46)*
- *Aulari – Int. Part. R16-FA34-R16 (Annex page: 35, point 1.1.4.47)*
- *Aulari – Int. Part. R16-FA40-R11 (Annex page: 36, point 1.1.4.48)*
- *Aulari – Int. Part. R16-FA40-R16 (Annex page: 36, point 1.1.4.49)*
- *Aulari – Int. Part. R16-FA-R15 (Annex page: 37, point 1.1.4.50)*
- *Aulari – Int. Part. R21-M03-R07 (Annex page: 37, point 1.1.4.51)*
- *Aulari – Int. Part. R21-M03-R08 (Annex page: 38, point 1.1.4.52)*
- *Aulari – Int. Part. R21-M03-R11 (Annex page: 38, point 1.1.4.53)*
- *Aulari – Int. Part. R21-M03-R12 (Annex page: 39, point 1.1.4.54)*

Given the number of internal partitions created, it has been decided for this section not to follow the structure used until now and only to specify the page where the technical specifications of each one of them can be found.

5.3.1.5. Roofs

In this section, only one roof has been created. "Aulari - Roof Floor 5" represents the upper roof above the TBS situated on the top floor.

5.3.1.5.1.1 Aulari – Roof Floor 5

- Translation of the name into English: not needed
- [Annex page number: 39, Point 1.1.5.1](#)
- Element description: Composed by 4 layers. The first and last are made of aluminium, while a 6 cm layer of extruded polystyrene XPS together with a vapour seal layer form the intermediate part.

5.3.1.6. Walls

All the external walls that constitute the envelope of the building are part of this group. There have been defined 30 different kinds of, which are:

- *Aulari – Mur de façana Est Obra vista*
- *Aulari – Mur de façana Monocapa*
- *Aulari – Mur de façana Obra vista*
- *Aulari – Mur escales evacuació*
- *Aulari – Mur.ext. FA60*
- *Aulari – Mur ext. GRC30-R07*
- *Aulari – Mur ext. GRC30-R25*
- *Aulari – Mur ext. GRC40-R07*
- *Aulari – Mur ext. GRC40-R25*
- *Aulari – Mur ext. GRC60-R07*
- *Aulari – Mur ext. GRC75-R07*
- *Aulari – Mur ext. Monocapa –FA25-R16*
- *Aulari – Mur ext. Monocapa FA30-R16*
- *Aulari – Mur ext. Monocapa FA39*
- *Aulari – Mur ext. Monocapa FA44*
- *Aulari – Mur ext. R11-M03-R07-CA12,5-M06-R04*
- *Aulari – Mur ext. R16-FA-R16*

- *Aulari – Mur Nord Monocapa – R06*
- *Aulari – Mur Nord Monocapa – R07*
- *Aulari – Mur Nord Monocapa – R09*
- *Aulari – Mur Nord Monocapa – FA60-R07*
- *Aulari – Mur Nord Monocapa-FA30-Elevators*
- *Aulari – Mur Nord Monocapa-FA40-CA10-R07*
- *Aulari – Mur Nord Monocapa-FA-Conductes*
- *Aulari – Mur Nord Monocapa-FA-R10*
- *Aulari – Mur Nord Panell alumini – R06*
- *Aulari – Mur Nord Panell alumini – R07*
- *Aulari – Mur Nord Panell alumini – R09*
- *Aulari – Mur Nord Panell alumini-FA-Conductes*
- *Aulari – Mur Nord Panell alumini-FA-R10*

5.3.1.6.1 Aulari – Mur de façana Est Obra Vista

- Translation of the name into English: Campus – East façade wall with exposed work (bricks).
- [Annex page number: 40, Point 1.1.6.1](#)
- Element description: Located on part of the east side of the building. Composed of 3 layers.

5.3.1.6.2 Aulari – Mur de façana Monocapa

- Translation of the name into English: Campus – Mono-layer façade wall
- [Annex page number: 40, Point 1.1.6.2](#)
- Element description: Made up of 5 layers. The term “Mono-layer” is referred to the outermost surface of 4 cm of cement mortar.

5.3.1.6.3 Aulari – Mur de façana Obra vista

- Translation of the name into English: Campus – Façade wall with exposed work (bricks).
- [Annex page number: 41, Point 1.1.6.3](#)
- Element description: Located on the part of the south façade that corresponds to the conference hall (the abovementioned *Sala de Graus*). Composed by 4 layers.

5.3.1.6.4 Aulari – Mur escales evacuació

- Translation of the name into English: Campus – Evacuation stairs wall
- [Annex page number: 41, Point 1.1.6.4](#)
- Element description: As its name indicates, it has been associated to the walls that conform the two emergency staircase nuclei.

5.3.1.6.5 Aulari – Mur ext. FA60

- Translation of the name into English: Campus – External wall FA60
- [Annex page number: 42, Point 1.1.6.5](#)
- Element description: External wall composed only by a 60 cm reinforced concrete layer (FA60).

5.3.1.6.6 Aulari – Mur ext. GRC30-R07

- Translation of the name into English: Campus – External wall GRC30-R07
- [Annex page number: 42, Point 1.1.6.6](#)
- Element description: External wall composed by 3 layers. Located on the north-side of the west wall below the cantilever (ground and first floors). With interior finish in laminated plaster (R07).

5.3.1.6.7 Aulari – Mur ext. GRC30-R25

- Translation of the name into English: Campus – External wall GRC30-R25
- [Annex page number: 43, Point 1.1.6.7](#)
- Element description: External wall composed by 3 layers. Located on the south-side of the west wall below the cantilever (only in the ground floor).

5.3.1.6.8 Aulari – Mur ext. GRC40-R07

- Translation of the name into English: Campus – External wall GRC40-R07
- [Annex page number: 43, Point 1.1.6.8](#)

- Element description: External wall composed by 3 layers (one of them of 40 cm of reinforced concrete (GRC40)). Situated at full height on the west side of the south and north façades (in the block formed by the cantilever).

5.3.1.6.9 Aulari – Mur ext. GRC40-R25

- Translation of the name into English: Campus – External wall GRC40-R25
- [Annex page number: 44, Point 1.1.6.9](#)
- Element description: Located only on the left side of the ground floor of the south façade (before the first windows of the conference hall).

5.3.1.6.10 Aulari – Mur ext. GRC60-R07

- Translation of the name into English: Campus – External wall GRC60-R07
- [Annex page number: 44, Point 1.1.6.10](#)
- Element description: Located on the east façade under the slab of the connection bridge on the ground and first floors.

5.3.1.6.11 Aulari – Mur ext. GRC75-R07

- Translation of the name into English: Campus – External wall GRC75-R07
- [Annex page number: 45, Point 1.1.6.11](#)
- Element description: Located in the part of the south façade (only on the ground and first floors) corresponding to the part of the Campus dedicated to low voltage switchboards and maintenance (right side of the south façade).

5.3.1.6.12 Aulari – Mur ext. Monocapa –FA25-R16

- Translation of the name into English: Campus – Mono-layer External wall FA25-R16
- [Annex page number: 45, Point 1.1.6.12](#)
- Element description: External wall formed by 25 cm of reinforced concrete (FA25), finished with a fair-faced concrete layer (R16).

5.3.1.6.13 Aulari – Mur ext. Monocapa FA30-R16

- Translation of the name into English: Campus – Mono-layer External wall FA30-R16
- [Annex page number: 46, Point 1.1.6.13](#)
- Element description: External wall formed by 30 cm of reinforced concrete (FA30), finished with a fair-faced concrete layer (R16).

5.3.1.6.14 Aulari – Mur ext. Monocapa FA39

- Translation of the name into English: Campus – Mono-layer External wall FA39
- [Annex page number: 46, Point 1.1.6.14](#)
- Element description: External wall formed by 39 cm of reinforced concrete (FA30), located on a small part of the north façade of the low voltage panel area (therefore only on the ground and first floors) next to the ventilation ducts.

5.3.1.6.15 Aulari – Mur ext. Monocapa FA44

- Translation of the name into English: Campus – Mono-layer External wall FA44
- [Annex page number: 47, Point 1.1.6.15](#)
- Element description: External wall formed by 44 cm of reinforced concrete (FA44). Situated along the second, third and fourth floors of the right-hand side of the east façade.

5.3.1.6.16 Aulari – Mur ext. R11-M03-R07-CA12,5-M06-R04

- Translation of the name into English: Campus – External wall R11-M03-R07-CA12,5-M06-R04
- [Annex page number: 47, Point 1.1.6.16](#)
- Element description: Small exterior wall located in the corner of the junction between the left-most part of the south façade and the beginning of the wall formed by the second skin of brise-soleils. It therefore covers the second, third and fourth floors.

5.3.1.6.17 Aulari – Mur ext. R16-FA-R16

- Translation of the name into English: Campus – External wall R16-FA-R16
- [Annex page number: 48, Point 1.1.6.17](#)

- Element description: Exterior wall located in the reception area of the building (ground and first floors).

5.3.1.6.18 Aulari – Mur Nord Monocapa – R06

- Translation of the name into English: Campus – North Mono-layer wall – R06
- [Annex page number: 48. Point 1.1.6.18](#)
- Element description: Small exterior wall placed in the part of the north façade corresponding to the emergency staircase nucleus (from the ground floor to the fourth one).

5.3.1.6.19 Aulari – Mur Nord Monocapa – R07

- Translation of the name into English: Campus – North Mono-layer wall – R07
- [Annex page number: 49, Point 1.1.6.19](#)
- Element description: Small exterior wall placed in the part of the north façade corresponding to the corridor of the left bathroom area (from the ground floor to the fourth one).

5.3.1.6.20 Aulari – Mur Nord Monocapa – R09

- Translation of the name into English: Campus – North Mono-layer wall – R09
- [Annex page number: 49. Point 1.1.6.20](#)
- Element description: Small exterior wall placed in the part of the north façade of all the bathroom areas (from the ground floor to the fourth one).

5.3.1.6.21 Aulari – Mur Nord Monocapa – FA60-R07

- Translation of the name into English: Campus – North Mono-layer wall – FA60-R07
- [Annex page number: 50, Point 1.1.6.21](#)
- Element description: Placed in the part of the north façade (ground and first floors) that corresponds to the central staircase nucleus.

5.3.1.6.22 Aulari – Mur Nord Monocapa-FA30-Elevators

- Translation of the name into English: Campus – North Mono-layer wall – FA30-Elevators
- [Annex page number: 50, Point 1.1.6.22](#)
- Element description: As its name indicates, part of the north façade associated with the exterior wall of the elevators (runs along all floors).

5.3.1.6.23 Aulari – Mur Nord Monocapa-FA40-CA10-R07

- Translation of the name into English: Campus – North Mono-layer wall – FA40-CA10-R07
- [Annex page number: 51, Point 1.1.6.23](#)
- Element description: It is the prolongation of the previously defined exterior wall *Aulari – Mur Nord Monocapa – FA60-R07*, starting from the second floor until the fourth one.

5.3.1.6.24 Aulari – Mur Nord Monocapa-FA-Conductes

- Translation of the name into English: Campus – North Mono-layer wall – FA-Ducts
- [Annex page number: 51, Point 1.1.6.24](#)
- Element description: Small part of the outer wall of the north façade corresponding to the sanitation duct area. Covers all floors.

5.3.1.6.25 Aulari – Mur Nord Monocapa-FA-R10

- Translation of the name into English: Campus – North Mono-layer wall – FA-R10
- [Annex page number: 52, Point 1.1.6.25](#)
- Element description: it is another part of the exterior wall located inside the bathrooms (north façade).

5.3.1.6.26 Aulari – Mur Nord Panell alumini – R06

- Translation of the name into English: Campus – North wall aluminium panel – R06
- [Annex page number: 52, Point 1.1.6.26](#)

- Element description: has the same composition as the wall *Aulari – Mur Nord Monocapa – R06* described in point 5.3.1.6.18, but with aluminium panel exterior finish.

5.3.1.6.27 Aulari – Mur Nord Panell alumini – R07

- Translation of the name into English: Campus – North wall aluminium panel – R07
- [Annex page number: 53, Point 1.1.6.27](#)
- Element description: has the same composition as the wall *Aulari – Mur Nord Monocapa – R07* described in point 5.3.1.6.19, but with aluminium panel exterior finish.

5.3.1.6.28 Aulari – Mur Nord Panell alumini – R09

- Translation of the name into English: Campus – North wall aluminium panel – R09
- [Annex page number: 53, Point 1.1.6.28](#)
- Element description: as in the two previous enclosures, it has the same internal layers as *Aulari – Mur Nord Monocapa – R09* described in point 5.3.1.6.20, but again with aluminium panel exterior finish.

5.3.1.6.29 Aulari – Mur Nord Panell alumini-FA-Conductes

- Translation of the name into English: Campus – North wall aluminium panel – FA - Ducts
- [Annex page number: 54, Point 1.1.6.29](#)
- Element description: has the same internal layers as *Aulari – Mur Nord Monocapa – FA - Conductes* defined in point 5.3.1.6.24, with aluminium panel exterior finish.

5.3.1.6.30 Aulari – Mur Nord Panell alumini-FA-R10

- Translation of the name into English: Campus – North wall aluminium panel – FA – R10
- [Annex page number: 54, Point 1.1.6.30](#)
- Element description: it has the same internal layers as *Aulari – Mur Nord Monocapa – FA – R10* explained at point 5.3.1.6.25, with aluminium panel exterior finish.

5.3.1.7. Doors

Two groups of doors have been defined, which are:

- *Aulari - Doors B.El. - a1-a2-a3*
- *Aulari - Doors B.F. - a1-a2-a3-a4-a5*

5.3.1.7.1 Aulari – Doors B.El. – a1-a2-a3

- Translation of the name into English: Campus – Firefighting doors – a1-a2-a3
- [Annex page number: 55, Point 1.1.7.1](#)
- Element description: composed by 4 layers that provide resistance against fire.

5.3.1.7.2 Aulari – Doors B.F. - a1-a2-a3-a4-a5

- Translation of the name into English: Campus – Common doors – a1-a2-a3-a4-a5
- [Annex page number: 55, Point 1.1.7.2](#)
- Element description: formed by 3 layers, wood-finished and without fire resistance.

5.3.2. Glazing

Two kind of glazing have been created for the definition of the windows of the Campus:

- *Aulari - M.C.-a1_a6 + F.AL.V.-a1_a2*
- *Aulari - C.B.F.AL.V.-a1_a10 + F.B.AL.V.-a1_a3 + E.AL.V.-a1*

5.3.2.1. Aulari - M.C.-a1_a6 + F.AL.V.-a1_a2

- Translation of the name into English: not needed
- [Annex page number: 56, Point 1.2.1](#)
- Element description: glazing placed in the large windows of the ground and first floors. Compared to the next type of installed windows, they are 4 cm thicker (on both inside and outside glass layers) to provide greater security.

5.3.2.2. Aulari - C.B.F.AL.V.-a1_a10 + F.B.AL.V.-a1_a3 + E.AL.V.-a1

- Translation of the name into English: not needed
- Annex page number: 56, Point 1.2.2
- Element description: include the windows that are not contained in the previous type of glass, in other words, all the windows of the building except the large ones of ground and first floors.

5.3.3. Local shading

As explained in detail in section 5.8 of the present document, it was decided to create a new library for modelling the sun protection elements contained in the Campus, also known as "*brise-soleils*".

Only one type of element from the local shading folder of Design Builder was used, the *Louvres*. The created *louvre* is as follows:

5.3.3.1. Aulari – BriseSoleils Sala Inst. C.LA.AL.- a1 + C.B.LA.AL.- a1_F

- Translation of the name into English: Campus – BriseSoleils Tech. Build. Syst. C.LA.AL.- a1 + C.B.LA.AL.- a1_F
- Annex page number: Not included in the annex, check point 5.8 of the present document.
- Element description: As it can be seen on point 5.8, it was initially thought to be the final solution for modelling the *brise-soleils*, but given the reasons explained on the mentioned point of the present document, it was decided to implement another system.

5.3.4. Schedules

As explained in more detail in the following point 5.4 of the present document, 5 types of schedules have been created for each activity template (also specified with more information in the following section).

In order to design these schedules, the Nursing Degree calendar has been adopted as a reference.

The classes of schedules that have been generated for each activity template are:

5.3.4.1. Heating (Heat)

It specifies the operation availability of the heating system on an hourly-base, for a typical day of the considered year.

This schedule and the Cooling (Cool) one only delimit the switching on and off of the technical building system (TBS), allowing its operation to full load (1 in the schedule) from 7am to 9pm (turned off as a 0 in the schedule for the rest of hours, as shown in the following chart Figure 27, corresponding to the schedule *Aulari – D1_Edu_CellOff_Heat*).

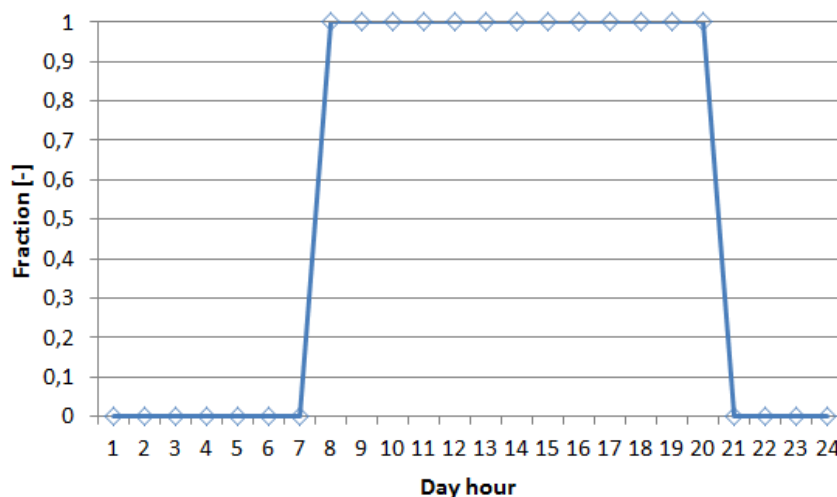


Figure 27: Established schedule for the heating system of the Computer rooms

5.3.4.2. Cooling (Cool)

Same functionality as the Heating schedule, but for the cooling system.

5.3.4.3. Occupancy (Occ)

Determines the occupancy fraction in each thermal zone for the different time slots of the day. These fraction will then be used in the simulations to define the occupancy internal heat gains of each space of the Campus.

For the definition of these percentages, the approximate occupation of the different areas of the building was observed during a morning and an afternoon of two different days.

Being aware of the lack of representation of this taken sample with respect to the user's behaviour of the building during an entire year, the logic has been used to complete the elaboration of such percentages (completed with the author's experience with respect to the number of students who usually attend lessons during the different periods of the year).

The chart reported in Figure 28 shows the daily occupancy pattern for a typical day associated to the teaching areas (schedule called: *Aulari – D1_Edu_ClassRm_Occ*):

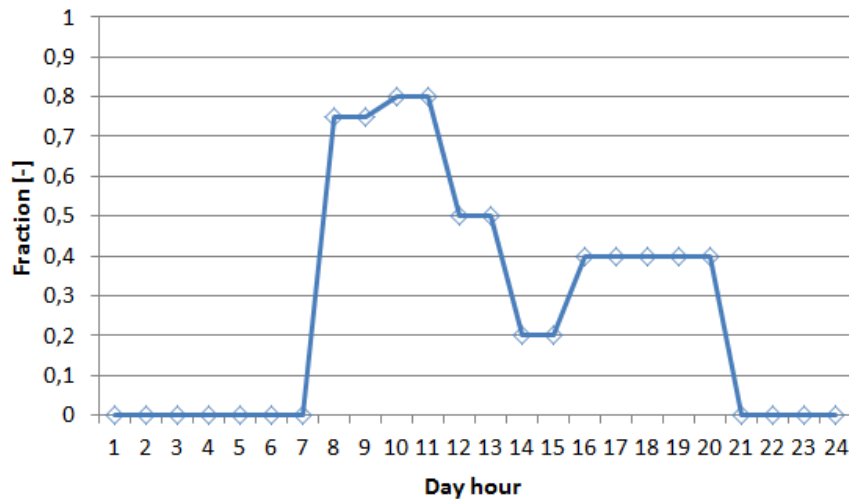


Figure 28: Established schedule for the teaching areas occupancy (winter period)

5.3.4.4. Equipment (Equip)

This schedule has the function of defining the internal heat gains from the electronic equipment present in the thermal zone.

For example, as regard the schedule defined for the computer rooms, **Error! No s'ha trobat l'origen de la referència.** show the usage rates of the present equipment. It has been decided to limit the use of PC's in the aforementioned rooms based on the facts seen in the two visits made to the Campus. The computers are initially turned off (8am), and as the students arrive at the different classrooms, the number of running computers rises until midday in which the usage of pc's drops again, there is another increase during the afternoon and finally decreases until 8pm, at which time the maintenance staff is in charge of turning off the few pc's that are still switched on.

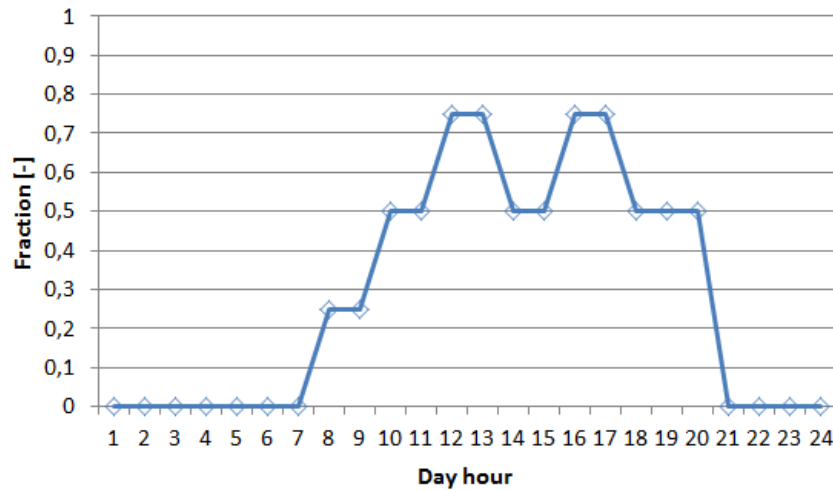


Figure 29: Established schedule for the equipment of the Computer Labs

5.3.4.5. Lighting (Light)

In the same way as the other programmes, a schedule has been defined for the lighting operation of the building.

To do so, it has been made a programming using the same criteria as in the Equipment schedule for limiting the lighting operation, stipulating the different lighting rates from 7am to 9pm.

The following chart (Figure 30) shows the daily lighting pattern for a typical day of the winter period in the laboratories (schedule: *Aulari - D1_Edu_Lab_Light*).

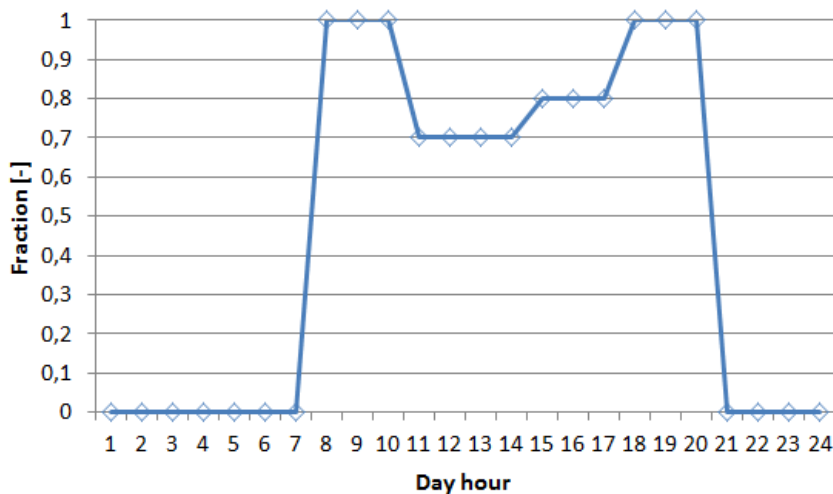


Figure 30: Established schedule for the lighting pattern of the laboratories

5.4. Assignment of the activity templates to each thermal zones

Once the separations between the thermal zones have been established and they have been tagged with their corresponding names, each one of them is associated with the created activity templates.

Eight activity templates have been defined that cover the different types of functionalities developed in the studied building, which are:

- Teaching Area
- Circulation Area (corridors and stairways)
- Computer Lab
- Laboratory
- Office and consulting areas
- Store room
- Toilet
- Reception

Design Builder (DB) has predefined activity templates that have been useful for its implementation. Templates from the "Education (Non-residential)" folder have been used as a reference, where the functionalities that best fit the type of the analysed building are located. Despite this, most of its inputs have been modified, adapting them more accurately to reality.

Each activity template to be defined requires the introduction of the following characteristics:

- Occupancy
- Other gains
- DHW
- Environmental control

The following is a brief description of the changes made to the "Education (Non-residential)" reference in order to adapt them to the real functions and uses of the Campus.

Unanimously for all created activity templates, the DHW option has been dropped as the concerned building is not equipped with domestic hot water plant.

As can be seen in the DB file, it has been modified the work schedules or Workday profile, and the heating and cooling temperatures defined in the section of Environmental control, adapting them to each space depending on its use.

Also noteworthy is the activation of the Office Equipment option in the case of the computer labs, which were disabled in the Educational non-residential reference cited above.

Simultaneously, as aforementioned at point 5.3.4, it has been decided to create programmed schedules associated with each thermal zone. Five schedules have been created for each type of activity: Heating (Heat), Cooling (Cool), Occupancy (Occ), Equipment (Equip) and Lighting (Light).

In the case of unconditioned areas (bathrooms, store rooms, circulation areas, etc.), the linked schedules with heating and cooling have not been set.

The programming of each one of them has been carried out according to the time of the considered year. For this purpose, the calendar of the Nursing Degree (taught in the Campus) has been adopted as a reference to determine in which periods of the year classes are given, in which weeks examinations are carried out and in which dates there are vacations.

Once the corresponding dates have been entered for the different types of schedules, a working schedule has been programmed for each one of them in which different operating percentages have been defined.

For example, in the case of the schedule associated with the occupation of the circulation areas (schedule: *Aulari - D1_Edu_Circulation_Occ*), the following schedule has been carried out (see Figure 31).

For the rest of the created schedules, the Design Builder file can be consulted):

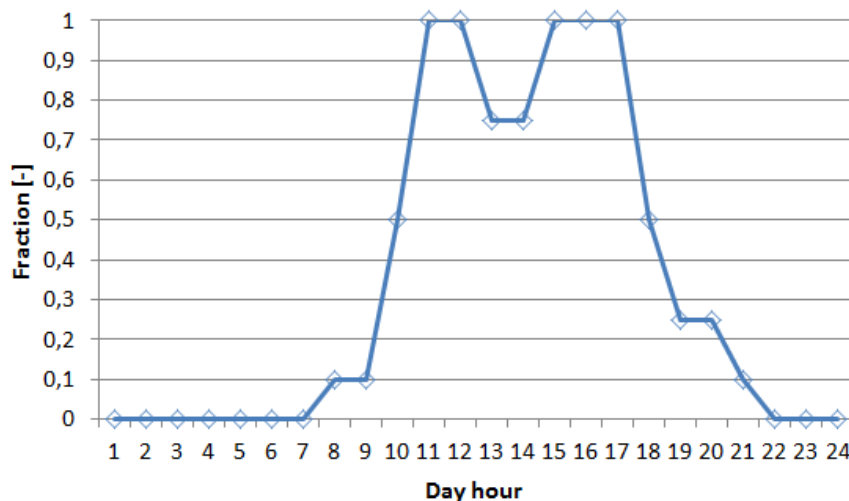


Figure 31: Created schedule for occupancy of the circulation areas

For the remaining parameters, in terms of latent fractions and metabolic factors, the reference numbers previously established by DB have been maintained.

The following images show the different floors once they have been associated with the pertinent activity templates. Beneath them there is in greyish colour the initially imported drawing of the ground floor. This fact is due to the way in which the Campus has been drawn up.

As it can be seen in the figures, the floors were modelled separately one next to each other. Once they were individually finished, they were incorporated/assembled (starting with the movement of the first floor) one on top of the other until they constituted the whole of the building.

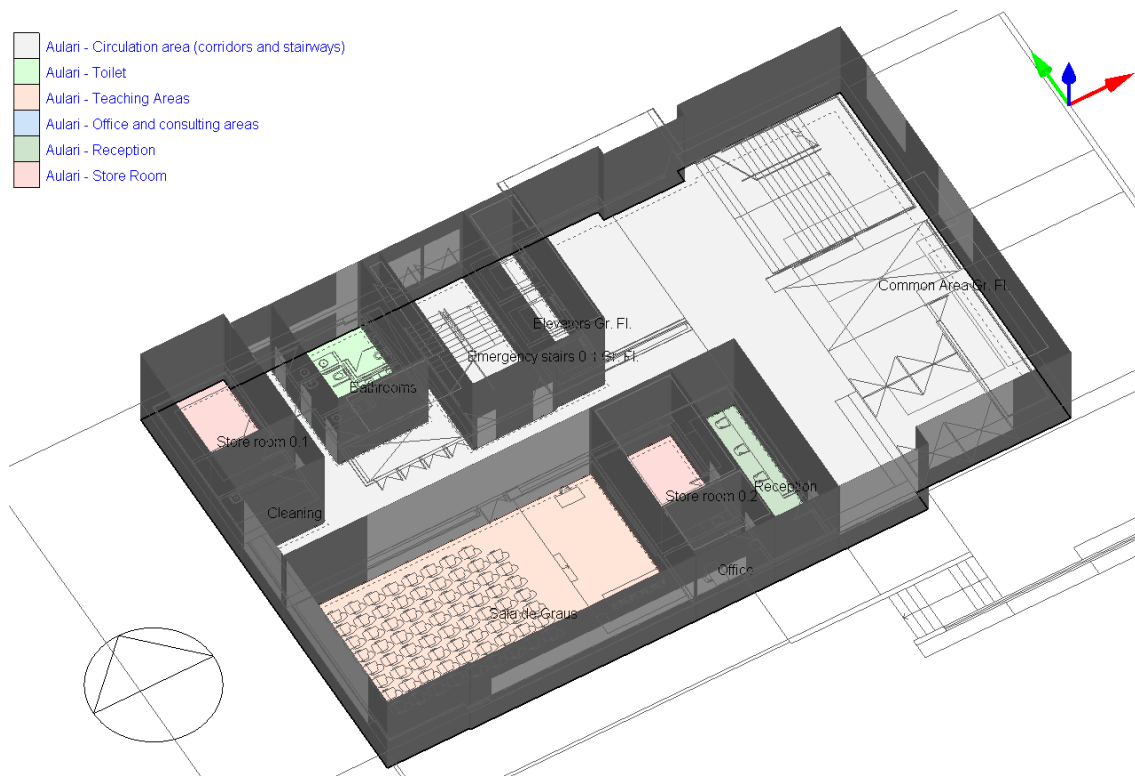


Figure 32: Ground floor

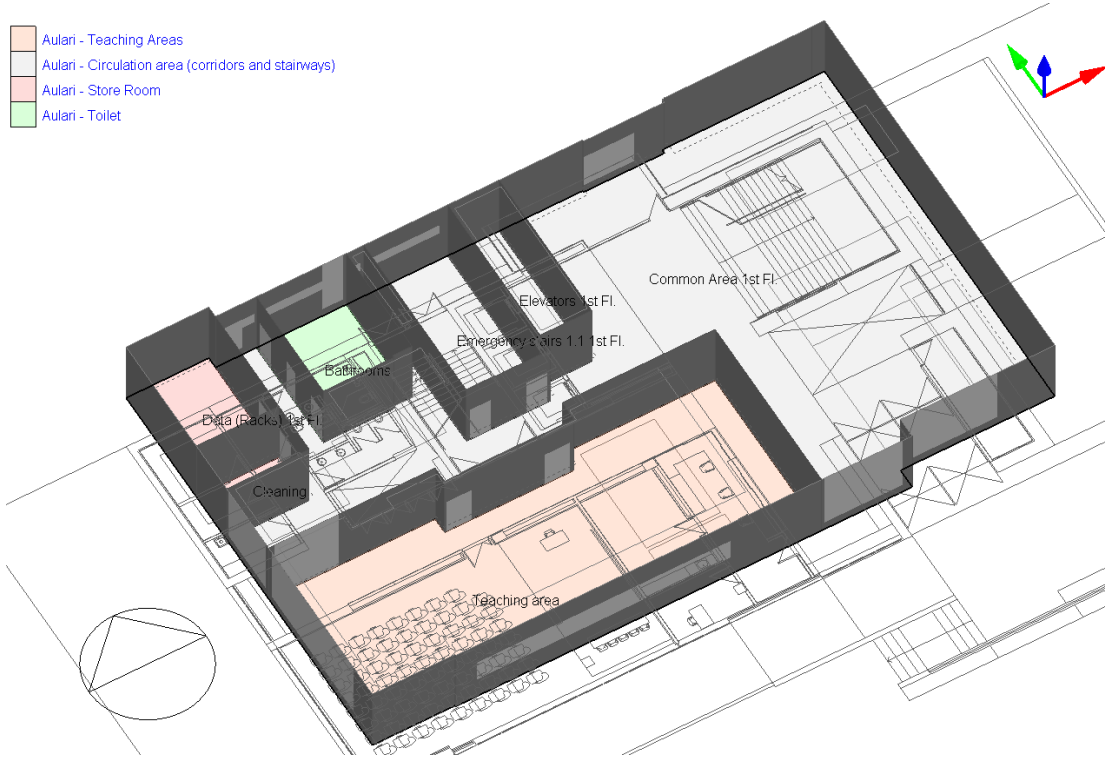


Figure 33: First floor

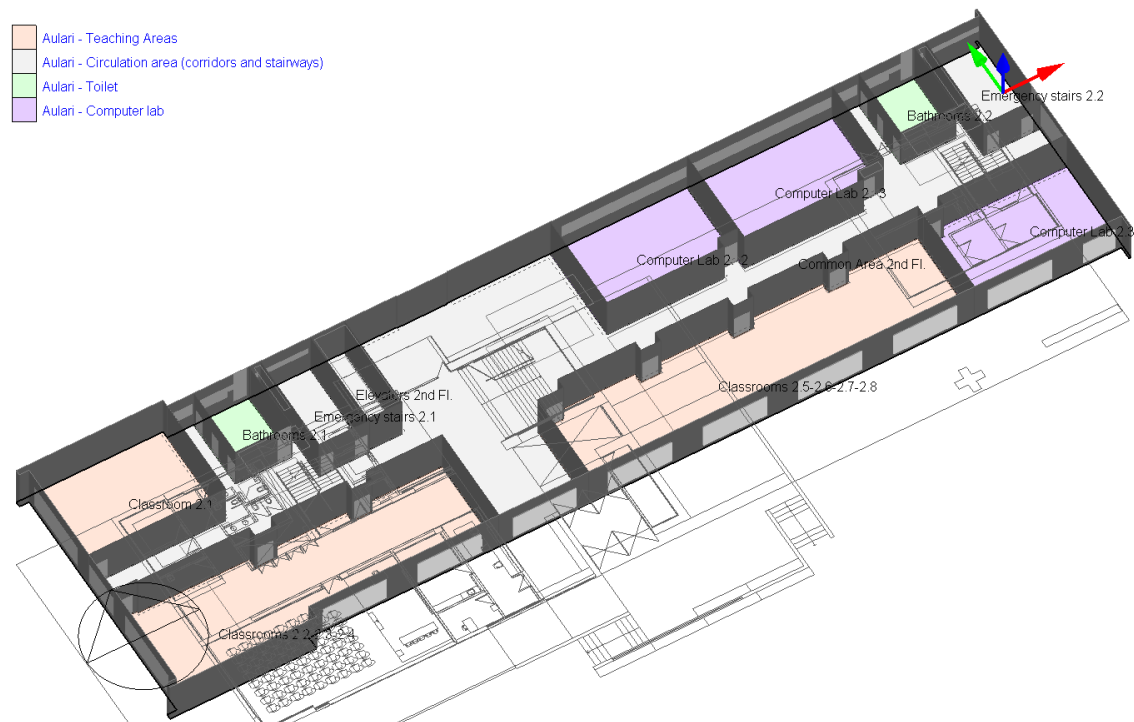


Figure 34: Second floor

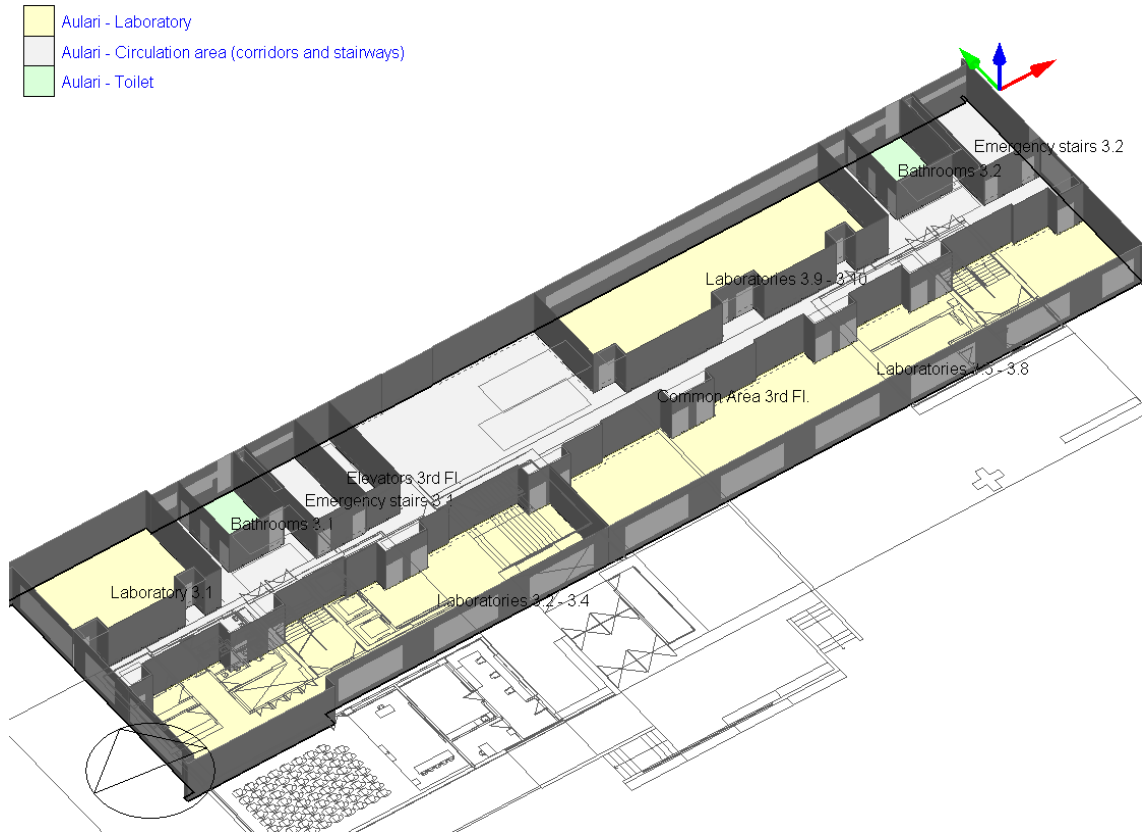


Figure 35: Third floor

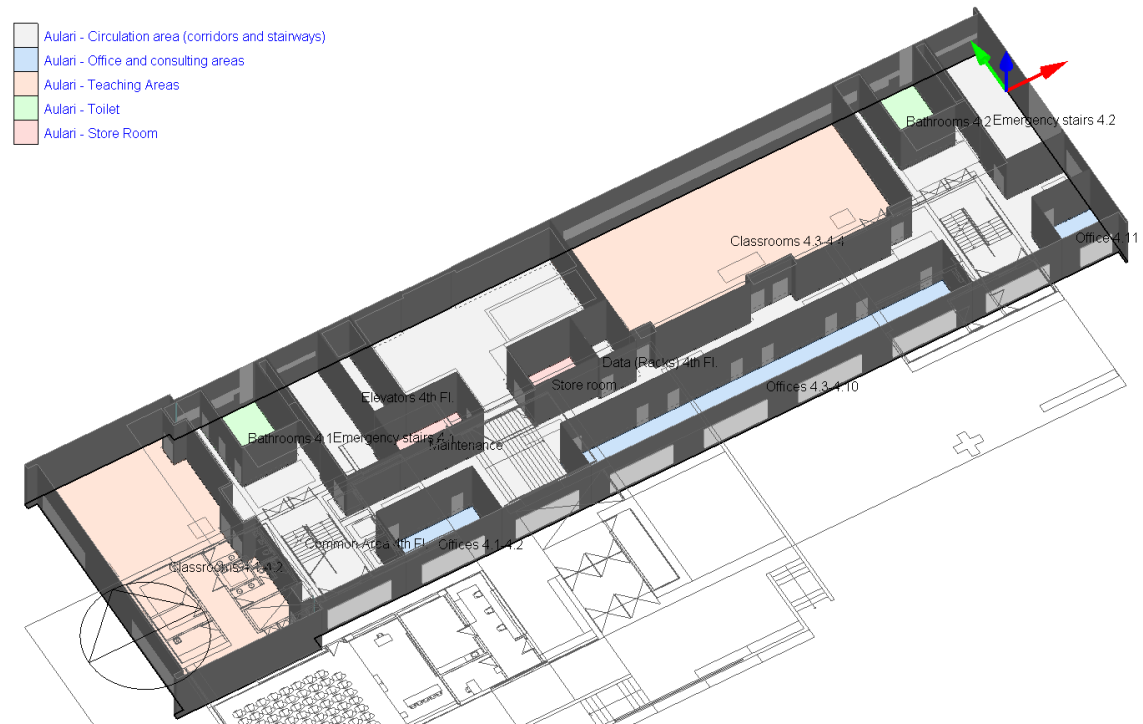


Figure 36: Fourth floor

5.5. Linkage of envelopes and internal partitions with construction templates

Once each of the floors has been modelled with its relevant walls and internal partitions, each of them is then linked to the previously created construction templates (all of them specified in section 5.3.1.4 of the present document).

In order to reduce the required time for this task, it has been decided to follow a global criteria that consists on determining for each wall or partition which is the predominant composition that defines it.

Once this information is known, the element is associated with the pertinent library, and it is checked if the wall or internal partition is made up of other surfaces with different construction layers. If so, a sub-surface should be created at the site concerned and linked with the corresponding composition.

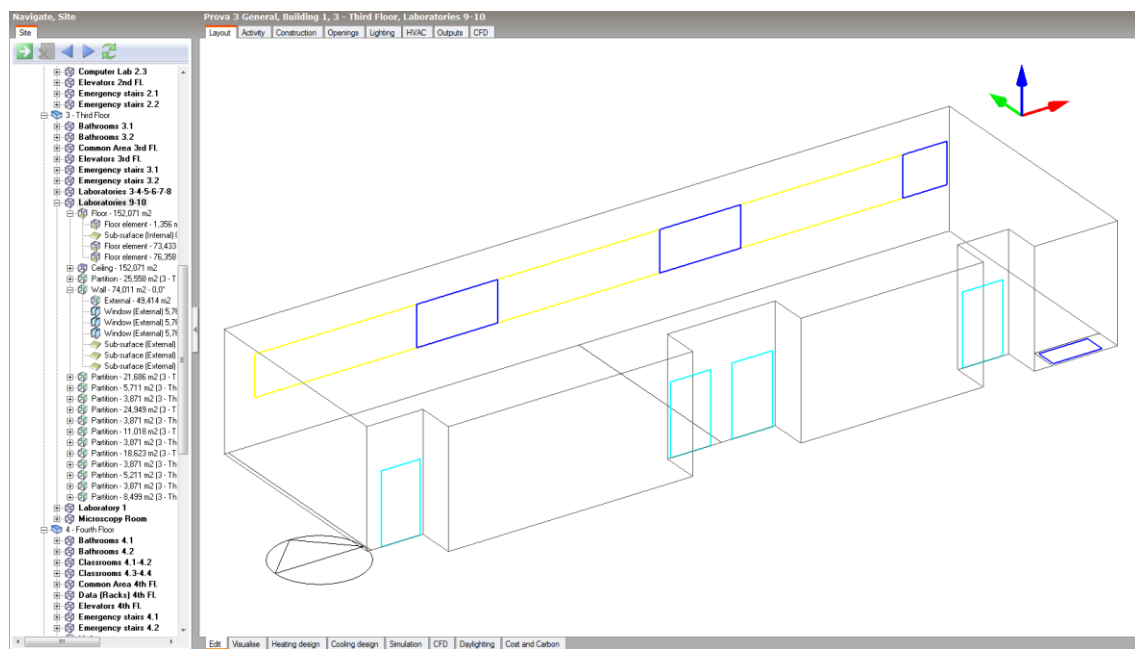


Figure 37: Laboratories 3.9-3.10

As shown in Figure 37 (corresponding to the thermal zone associated with laboratories 3.9-3.10 on the third floor) after the different construction compositions have been matched, three sub-surfaces can be distinguished in dark blue (in the rear internal partition) that have served to specify three aluminium panels located in the corridor of the aforementioned floor.

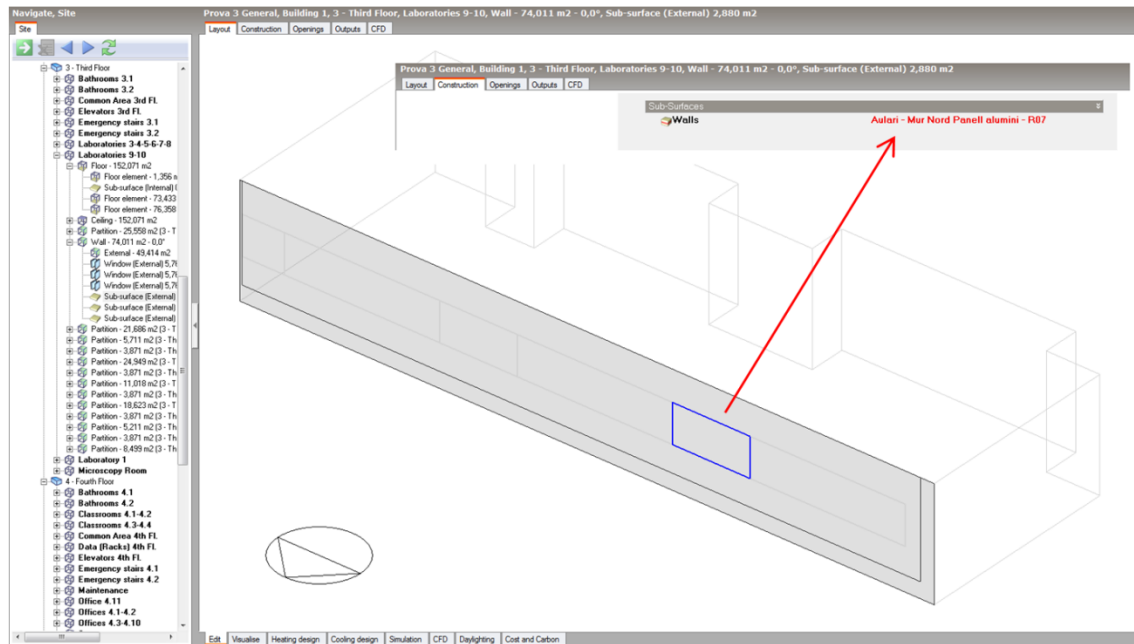


Figure 38: Sub-surface application

The image also serves to illustrate the usefulness of such elements as in the case of the small sub-surface located in the upper-right corner of Figure 38 which is a part of the slab finished with a different type of finish than the rest of the laboratory.

On the other hand, the elements in cyan blue and yellow are doors and windows respectively that will be treated in the next section.

5.6. Definition of windows and doors

From this point on, doors and windows are created in the different locations of the Campus. As explained in sections 5.3.1.7 (doors) and 5.3.2 (glazing) these have been previously defined within the "Doors" folder located inside the "Constructions" library and inside the "Double" folder contained in the "Glazing" library respectively.

As specified in the aforementioned section 5.3.1.7 of libraries (check which layers has been chosen for their composition on point 1.1.7 of the Annex), in the case of doors, two types have been created:

- *Aulari - Doors B.El. - a1-a2-a3*: made up of 4 layers that provide resistance against fire.
- *Aulari - Doors B.F. - a1-a2-a3-a4-a5*: formed by 3 layers, wood-finished and without fire resistance.

While in the matter of windows, two other types have been created (see composition on point 1.2 of the Annex):

- *Aulari - C.B.F.AL.V.-a1_a10 + F.B.AL.V.-a1_a3 + E.AL.V.-a1*: composed by 3 layers:
 - Outermost pane: Saint Gobain Glass SGG PLANILUX 6 mm
 - Air gap of 12 mm
 - Innermost pane: Saint Gobain Glass SGG PLANILUX 8 mm

Calculated values:

- Total solar transmission [SHGC]: 0,741
 - Direct solar transmission: 0,661
 - Light transmission: 0,793
 - U-Value [W/m²K]: 2,679
- *Aulari - M.C.-a1_a6 + F.AL.V.-a1_a2*: consisting of 3 layers:
 - Outermost pane: Saint Gobain Glass SGG PLANILUX 10 mm
 - Air gap of 12 mm
 - Innermost pane: Saint Gobain Glass SGG PLANILUX 12 mm

Calculated values:

- Total solar transmission [SHGC]: 0,682
- Direct solar transmission: 0,566
- Light transmission: 0,761
- U-Value [W/m²K]: 2,621

The reason why the glass panels were placed with the above-mentioned layout (the thinnest glass panel on the outside of the building and the thickest after the air gap) is due to thermal and optical insulation reasons.

As shown in Figure 37, the doors are marked in blue cyan, while windows in yellow.

5.7. Creation of holes in slabs and addition of ventilation elements to the corresponding sites

After this point, the corresponding holes are created in the floor ceilings and the ventilation elements are added.

These last ones are located in the different floors of the emergency staircases (in charge of ensuring the adequate air renewal and smoke evacuation in case of fire) and the ventilation system of the fifth floor (where the TBS (Technical Building System) is located) is modelled using this same technique. The technical area is directly ventilated to the outside by means of perforated aluminium sheet panels (see Figure 39).



Figure 39: Roof in the fifth floor and TBS area

As for the emergency staircases (shown in Figure 40), the ventilation grilles are made with perforated mesh deployee panels of two sizes (2.4m x 0.575m and 2.4m x 0.675m) with a thickness of galvanised sheet metal of 1 mm.

As shown in Figure 40, once the ventilation grille has been installed in the respective position of the emergency staircase, Design Builder illustrates it in fuchsia.

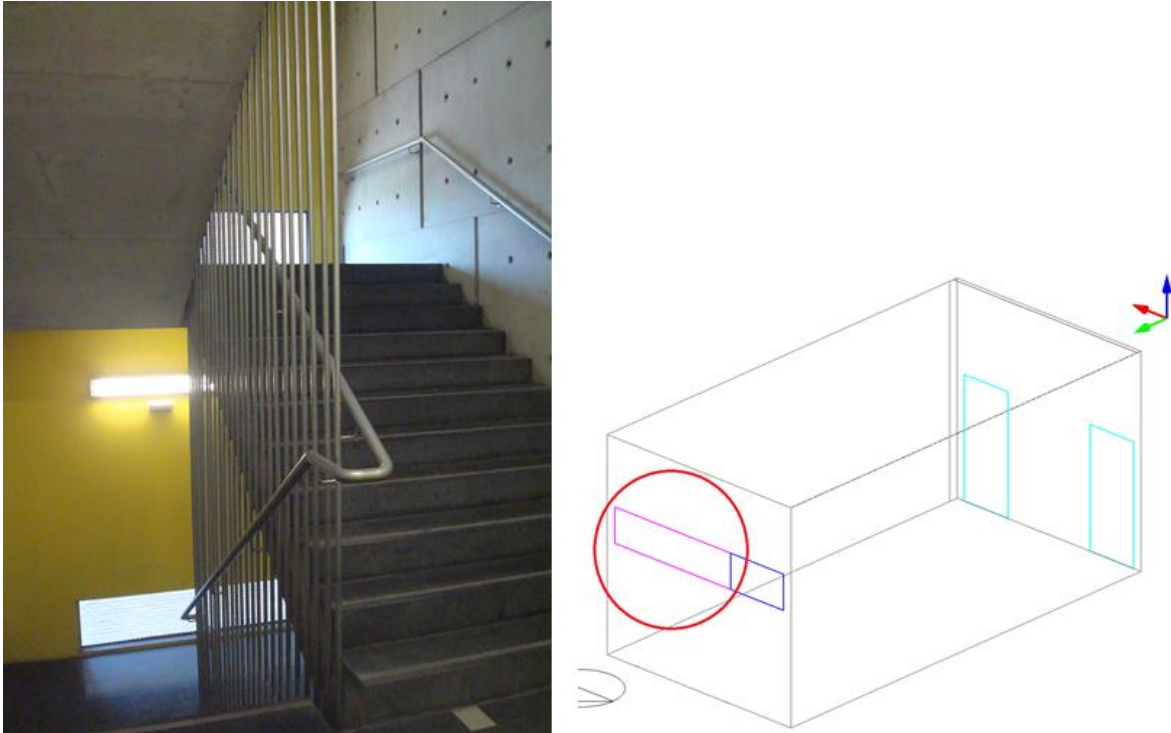


Figure 40: Emergency staircase and application of ventilation grille

With regard to the creation of holes, they permit the modelling of the following elements:

- Staircase cores (both service and emergency)
- Elevators
- Creation of spaces between floors (for example, the absence of ceiling slab at the entrance of the building between the ground and first floors).
- Addition of air extraction ducts.

One space that illustrates the modelling of three of the mentioned elements (in this case the elevators are not shown because they have been defined as another thermal zone) is the Common Area of the first floor.

Starting on the left side of the image in Figure 41, there is an example of an elongated rectangular shape (green Holes Num. 1) of an area for air extraction ducts. On the other hand, Hole Num. 2 shows the space of the main staircase, while holes No. 3 concern the above-mentioned connection between the ground and first floors.

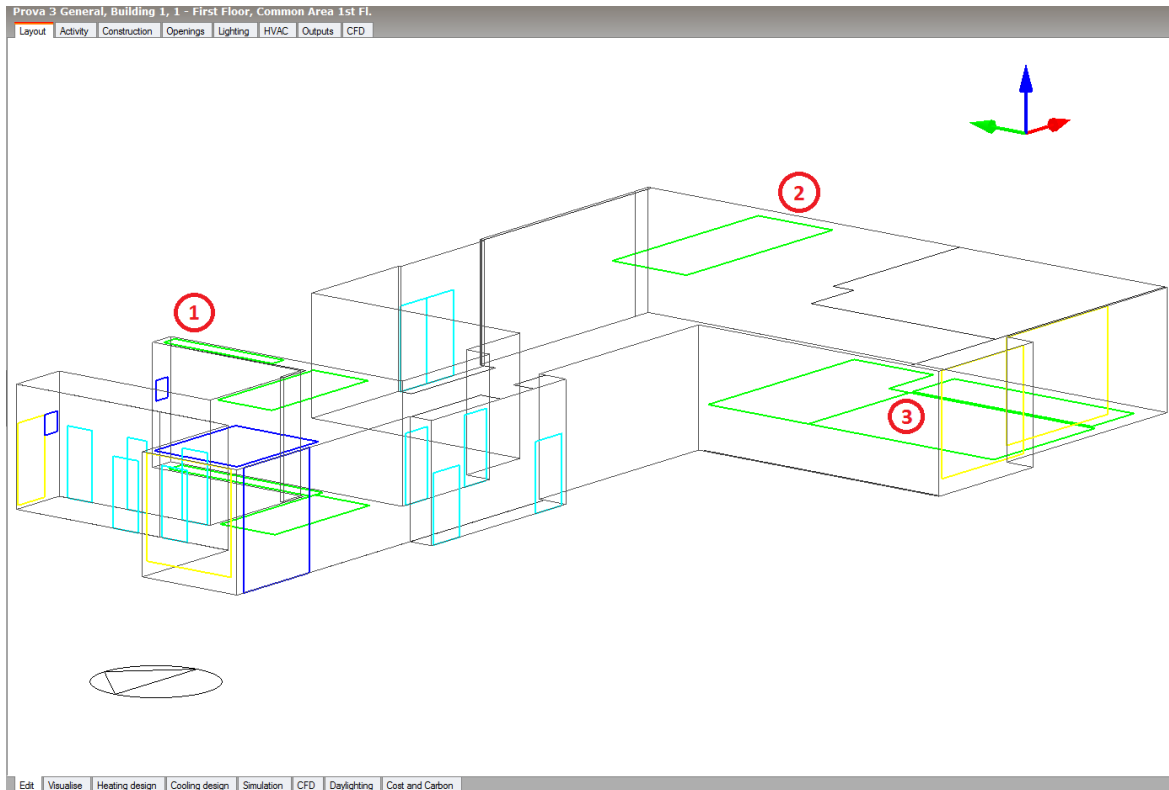


Figure 41: Modelling of the different types of holes

5.8. Design of the façade shade elements *Brise-soleils*

As described in section 4.3 of the present study (Building description), the façade of the Campus is characterised by a second skin that allows a better sun protection inside the building, both on the south and west façades.

On the other hand, its implementation also allows the creation of an additional space between the end of the building's "constructive façade" and the protective skin, although it is only accessible to authorized maintenance personnel.

The elements that characterise this second façade, also known as *brise-soleils*, are a set of Agrob-Buchal porcelain ceramic slats with two different formats for the two mentioned faces of the Campus:

- South Façade (check Figure 42):
 - Horizontally placed.
 - Dimensions: 1,4m x 0,06m x 8,75mm (width x height x thickness).

- West Façade (check Figure 42):
 - Vertically positioned.
 - Dimensions: 0,06m x 1,22m x 8,75mm (width x height x thickness).



Figure 42: Brise-soleils on west and south-oriented façades

In order to model these sun protection elements, it was initially decided to replicate reality as faithfully as possible.

For this purpose, component blocks were used only specifying the material they were made of (ceramic type) as their function is to reproduce the shadows produced inside the Campus.

Initially, an attempt was made to model each of the pieces in real size in groups of 20 ceramic slats and then copying them one next to the other in a chain (view Figure 43) However, incorporating a large number of component blocks in the program meant a considerable increase of the simulation running times (especially in the calculation of shadows produced in the different periods of the year).

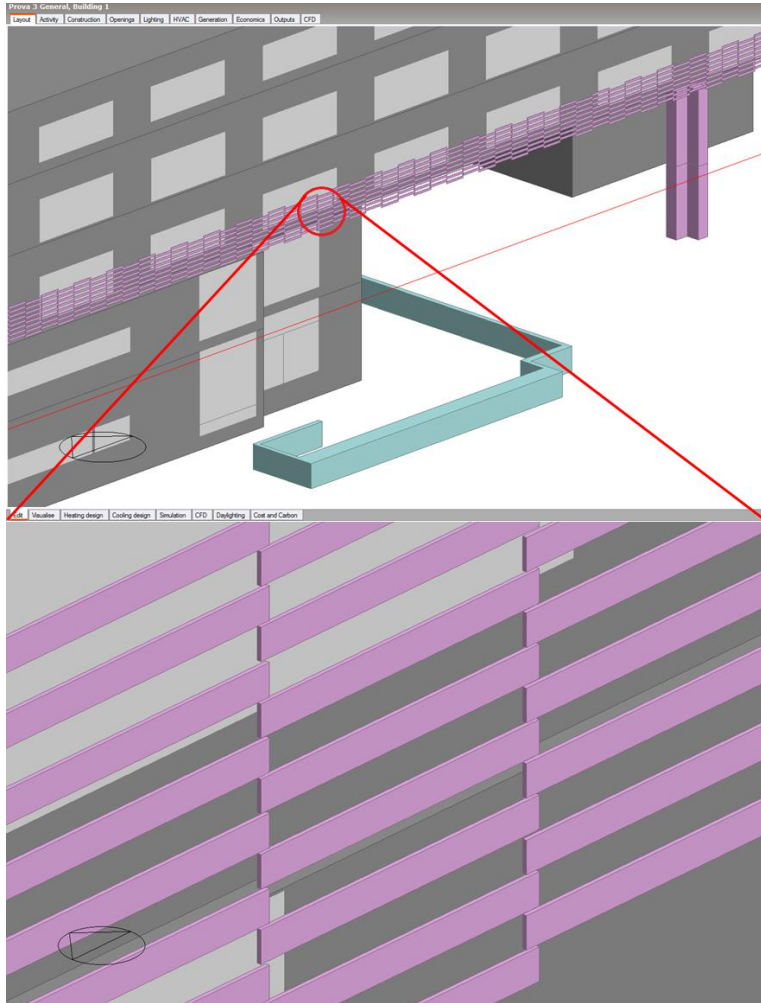


Figure 43: First modelling of the brise-soleils on south façade

For this reason it was decided to simplify the size of the *brise-soleils* by increasing them three times its actual size. With this simplification, on one hand the number of created blocks was reduced and on the other hand the light/shade ratio entering into the building was preserved.

Despite the application of this simplification, the simulation times (the simulation parameters used at that time are shown in more detail below) were increased at values of nearly 4 hours and 30 minutes without having applied the TBS (Technical Building System) inside the building yet, for which reason the definition of the *brise-soleils* had to be simplified even further.

After this point, it was decided to implement the second skin of the south façade (formed by a larger number of sun protection elements compared to the west façade) through the *Louvres* component libraries located inside the “Local shading” folder (provided by Design Builder).

From this option, a *Louvre* was set with the intention to reproduce the result obtained through the *brise-soleils* in the most similar way. The *Louvre* to be applied was therefore defined as shown in Figure 44 (with a blade thickness of 0,012 m):

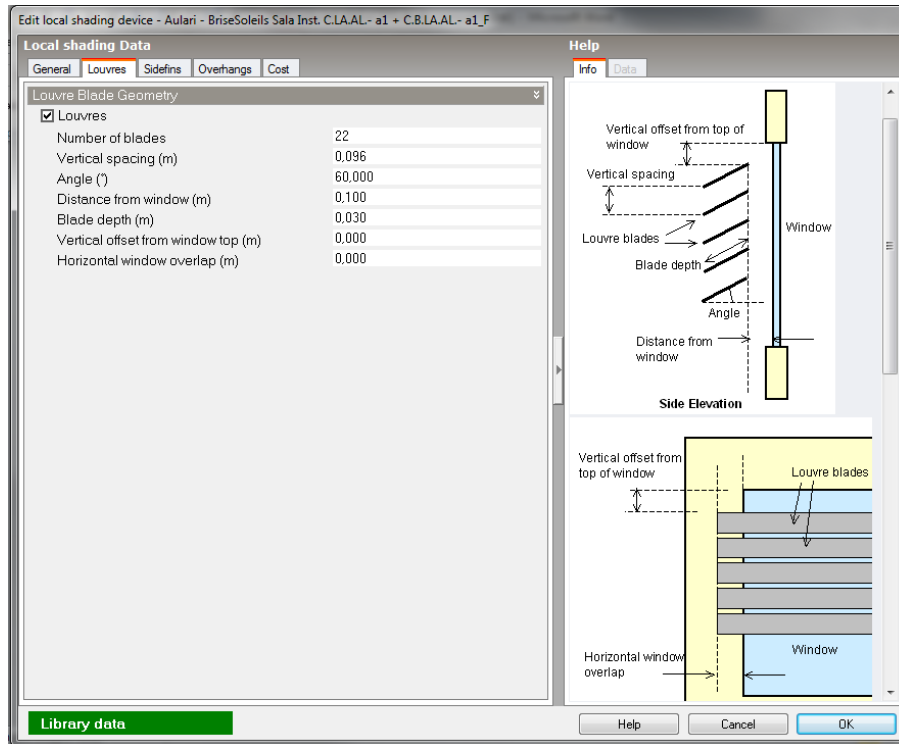


Figure 44: Creation of the local shading device Louvre

Once the parameters for defining the *louvre* had been introduced, they were implemented in the windows of the south façade.

One of the main drawbacks in the introduction of its parameters was the angle of inclination of the horizontal slats. The ideal situation would have been to be able to set a value that would allow them to be tilted parallel to the plane of the south-oriented façade, but DB allows a maximum value of 60° , reason why this inclination was chosen as it was the one that was closest to reality.

The obtained result with the application of the louvres in windows can be observed in the renderings of the following Figure 45. The left pair of images corresponds to the rendered views from 15th of July at 10 am, while the right pair is from 15th of January at the same hour.

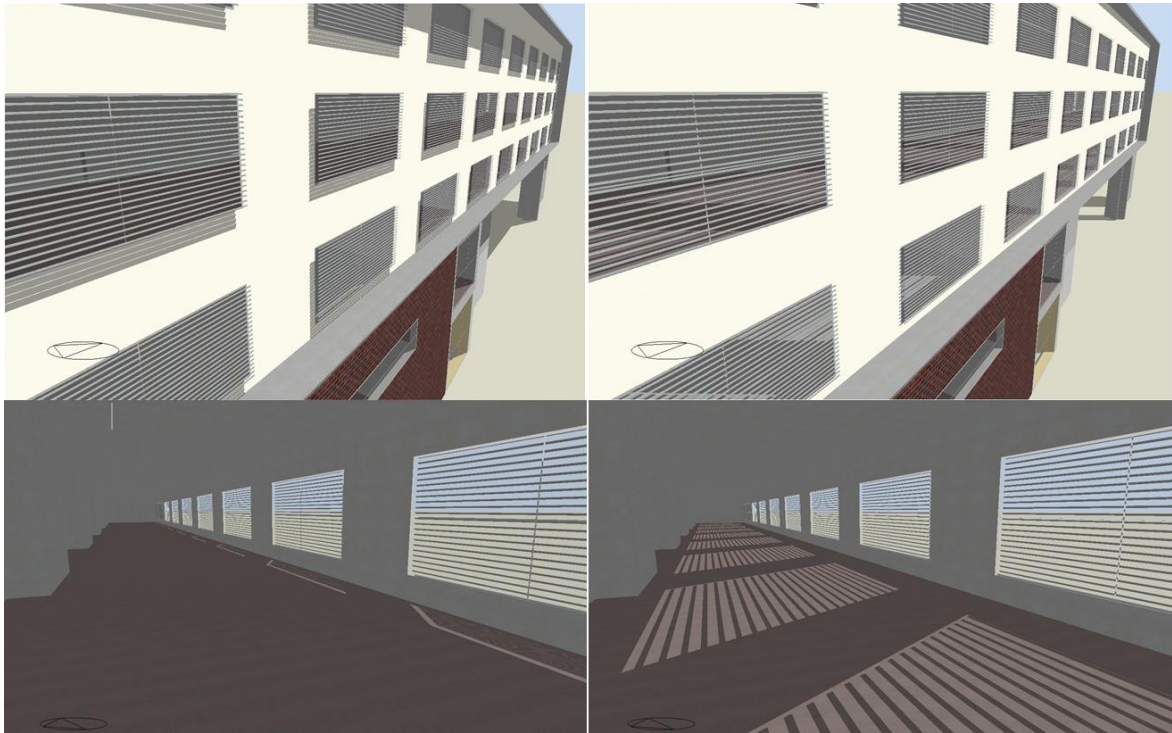


Figure 45: On left side 15th July and in the right 15th January

Both couples of images show the effect produced by the shading devices both outside and inside of the building, with special emphasis on the 15th of January, when the solar trajectory produces a greater incidence.

The following Table 1 details the different options created for the implementation of the *brise-soleils* with the respective resulting times obtained from simulations of one year (all of them without having implemented the technical building systems yet).

They were all run with a time steps per hour of 4 and a shadowing interval of 40 days.

	1	2	3	4
Options to be implemented	With drawn <i>brise-soleils</i> in both façades	Without any <i>brise-soleil</i> or <i>louvre</i>	<i>Brise-soleils</i> in West Façade and <i>louvres</i> on South Façade	<i>Louvres</i> on both façades
Simulation time	4h 19 min	1h 30 min	2h 14 min	1h 48 min

Table 1: *Brise-soleil* modelled options simulation times

From the obtained times shown in Table 1, it was decided to initially discard options 1 and 2:

- 1) Option 1: Too long in time. Almost four and a half hours to carry out a simulation of a year without having introduced the TBS would imply excessive time afterwards.
- 2) Option 2: Offered interesting simulation times, but not placing any solar protection element (nor in the windows) would keep the thermal behaviour of the building too far from the reality.

Therefore, given the difference of 26 minutes between the last two proposals, it was decided to proceed jointly with both proposals.

Both options share the fact that they are composed of *louvers* in the windows of the south-oriented façade, which has allowed the simulation times to be reduced by 2h and 5 min (Option 3) and 2h 31 min (Option 4) compared to Option 1 respectively.

On one side, Option 3, being made up of drawn *brise-soleils* on the west façade, provides greater fidelity to the reality of the building (with an increase of 26 minutes over option 4). While the fourth proposal offers a more uniform solution, with a shorter time frame and the possibility (once TBS is implemented) of obtaining results not far away from the third option.

Finally, two rendered images of how Option 3 are added (Figure 46 taken at 10 am on 15th of June, and Figure 47 taken at 5 pm on the same day). In both figures it can be seen that on the south façade only the *louvres* have been placed in the corresponding windows, and on the west side of the Campus, a network of component blocks has been implemented with the intention of recreating the second skin.

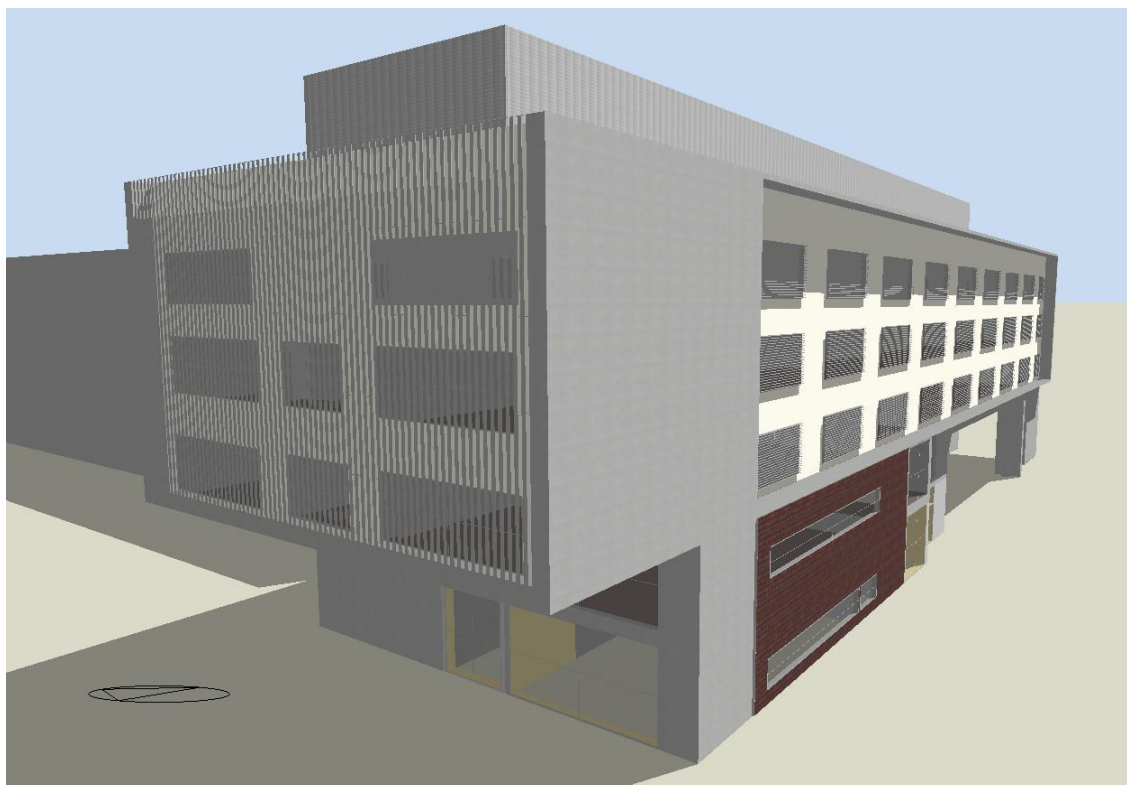


Figure 46: 15th of June at 10am



Figure 47: 15th of June at 5pm

However, the implementation of this solution through *louvres*, although reducing simulation times, as it does not provide the desired thermal effect on the south and west walls (the *louvre* only allows the windows to be protected from solar radiation, leaving the rest of the façade at maximum exposure), it was decided to elaborate a third model of the *brise-soleils*.

This has been constituted by the use of a component block layer "with semi-transparency properties" (with the relevant thickness of the *brise-soleils*) for each of the two façades.

These two component block layers have been configured with a maximum solar transmittance of 1 (transparent) and have been associated with programmed schedules, which function allows to set a percentage value of transmitted solar radiation to each component block of each façade. This value is modified through the schedule code depending on the period of the year and the hour of the day.

In order to draw up this programme, several simulations of the two façades (studying it through one floor of the Campus to speed up the simulating process) were carried out in a parallel DB file during two periods of the year, orienting it with the same graduation as the corresponding west and south façades of the studied building.

As can be seen in the attached Figure 48, in each of them, two different situations were located:

- Zone 1: Protected with the solar elements designed in the first modelling of the *brise-soleils*.
- Zone 2: without the aforementioned solar protection elements.

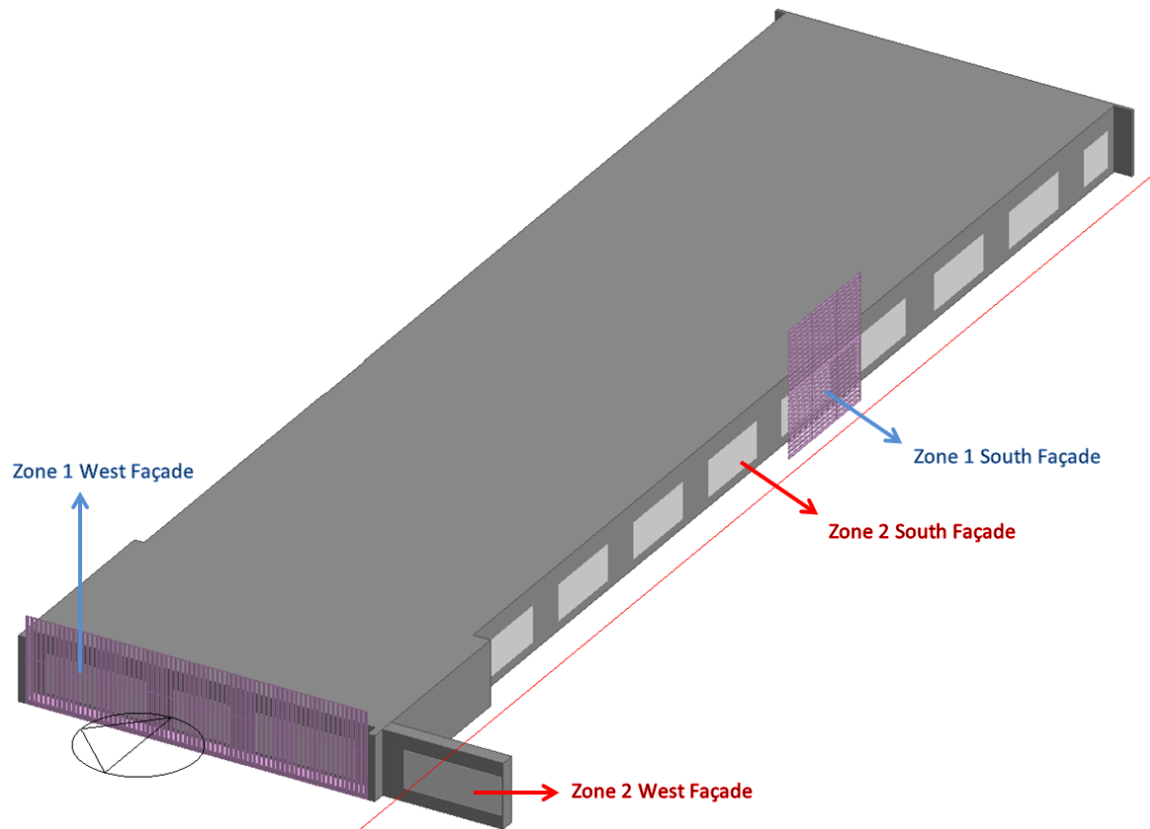


Figure 48: Third brise-soleils modelling process

From the simulations carried out at two times of the year (January 27 for typical winter radiation values and June 22 for summer ones), it was possible to observe the effect produced by the presence of the *brise-soleils*.

With the compilation of the numbers of transmitted and received solar radiation, the transmitted rate in the wall located behind the solar protection elements was calculated and an average of the different values obtained in the simulations was made, which were simulated every 15 minutes.

A graphical example of the obtained results during the winter period of solar incident radiation and transmitted radiation on the South-oriented Façade for each of the mentioned areas is reported below (first graph without *brise-soleils* and the second one with them).

Winter period in South Façade:

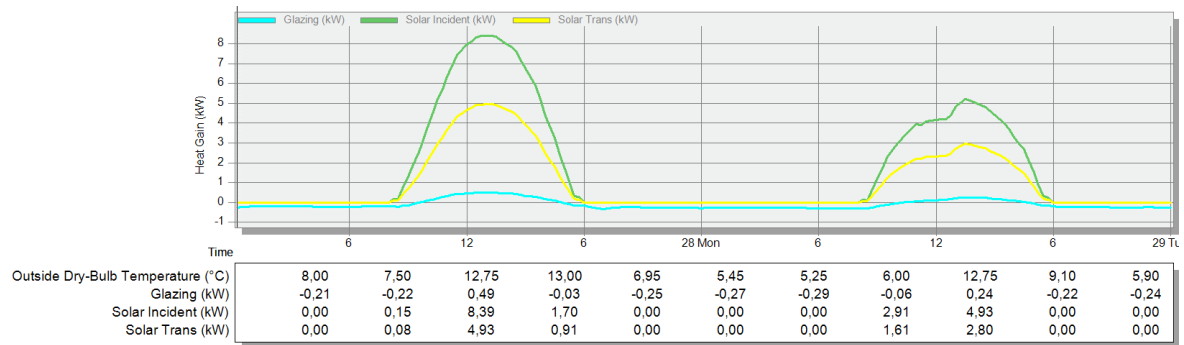


Figure 49: Obtained results in South-oriented Façade Zone 2 (Winter period)

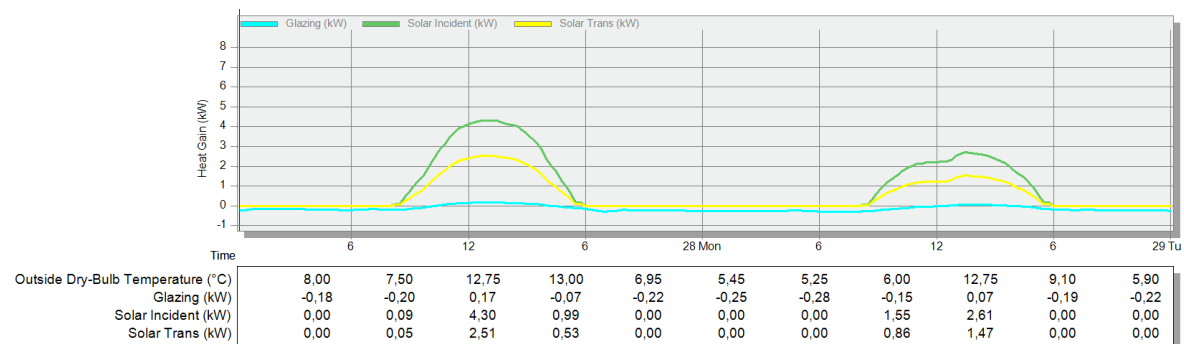


Figure 50: Obtained results in South-oriented Façade Zone 1 (Winter period)

Based on the obtained results, in order to apply them to the component blocks of each façade, it was decided to divide the year into three periods or sections:

- 1st period: 1/01 - 20/03 applying winter results.
- 2nd period: 21/03 - 22/09 applying summer results.
- 3rd period: 23/09 - 31/12 applying winter results.

The election of these dates was based on the number of solar hours in Barcelona along with the respective beginnings and ends of the seasons. In the attached graph (Figure 51) it can be seen how the year is clearly divided into the three mentioned sections with respect to the annual solar hours.

Finally, the applied results to the South-oriented façade during winter and summer periods are the following (the corresponding to the west can be found in the DB file inside the schedules folder):

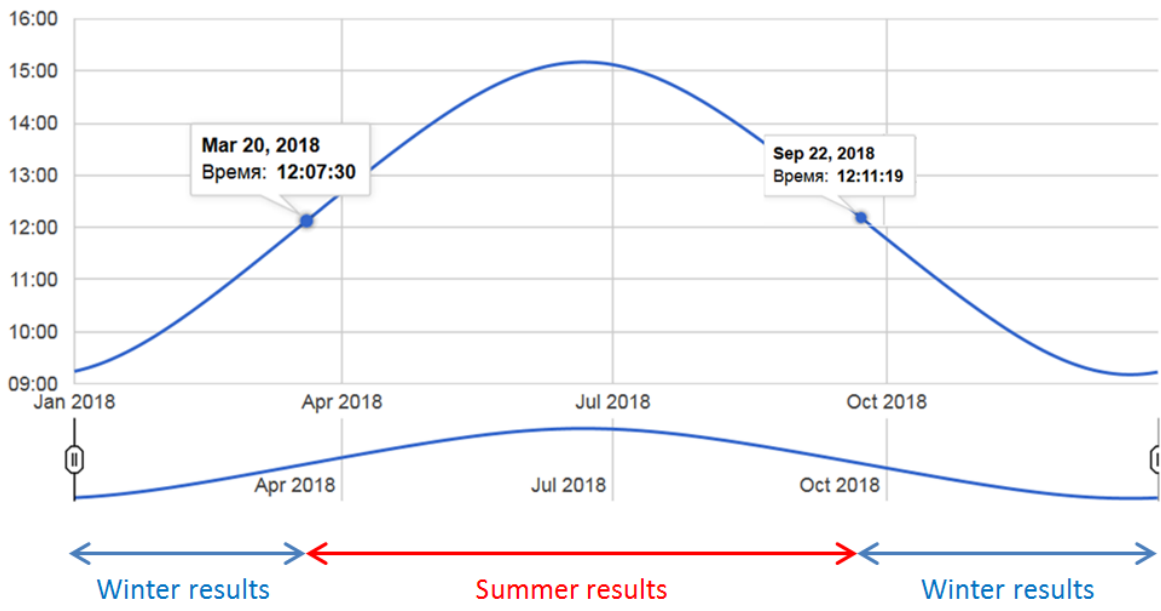


Figure 51: Solar hour's diagram of Barcelona

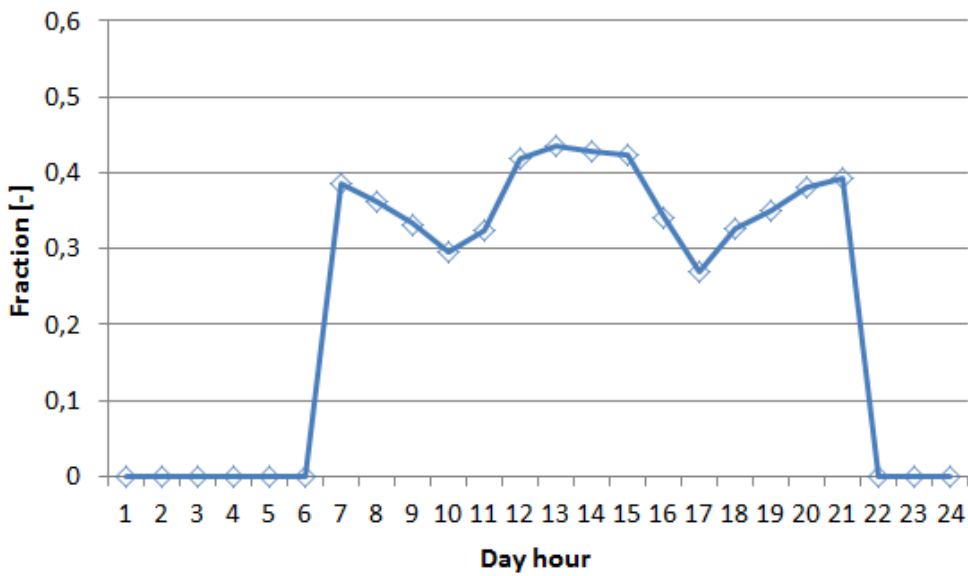


Figure 52: Applied results for summer period on South façade

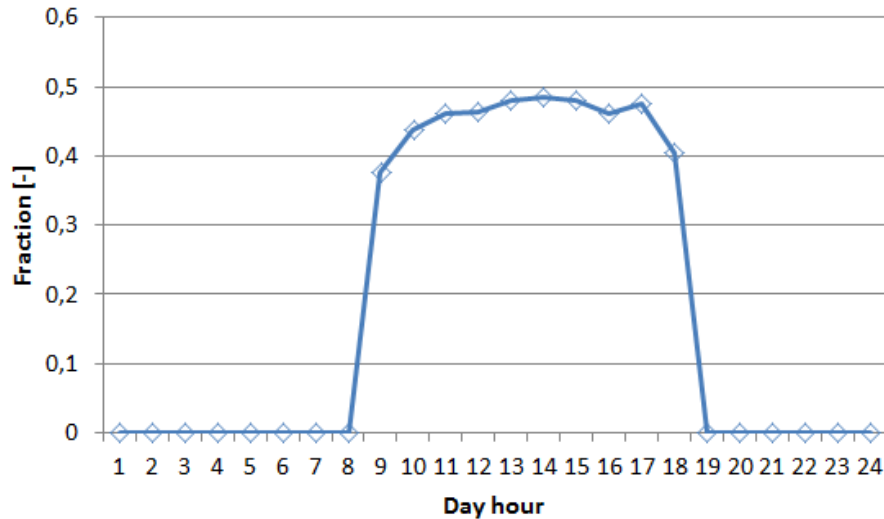


Figure 53: Applied results for winter period on South façade

On the following point 5.9, the final appearance of the building can be seen once the two "sheets" have been added on the south and west-oriented façades with the described solar and thermal properties, together with the incorporation of the remaining component blocks, the function of which is detailed below.

5.9. Incorporation of component blocks

Once the sun protection elements have been implemented in both façades, the rest of the complementary parts of the building are introduced.

Component blocks are a flexible way to apply shading to any part of the building. It is through them that the following aspects not described yet are introduced:

- Buildings adjacent to the studied Campus
- Pillars and structural elements of support
- Auxiliary construction elements

The following shows how the whole looks like once the component blocks mentioned above have been inserted (Figure 54)

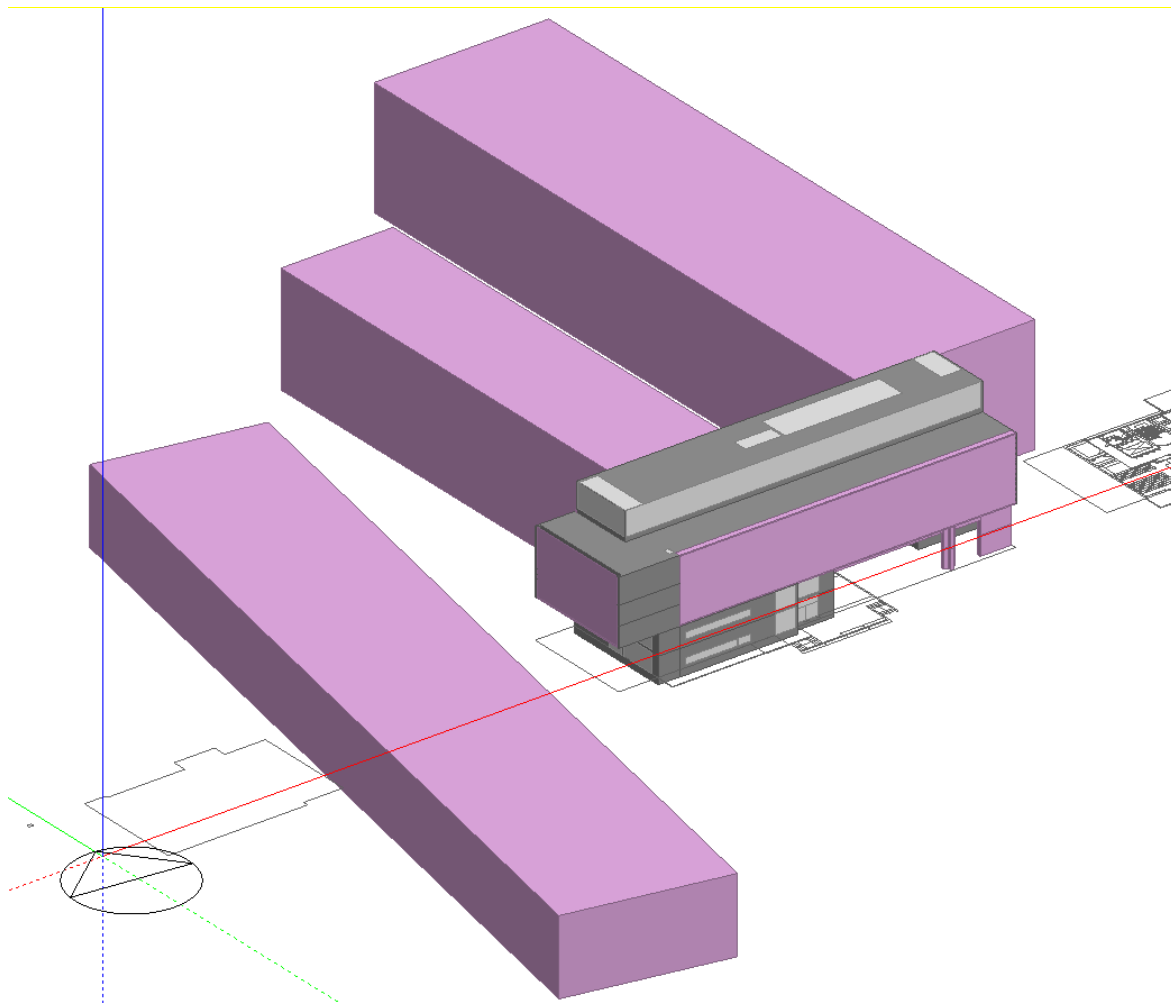


Figure 54: Final modelled building

6. CURRENT TECHNICAL BUILDING SYSTEM

6.1. General description of the current technical building system

6.1.1. Primary circuit

The building is equipped with a heating and cooling system, composed of three water plants, condensed by air (with electric drive), two of them with cycle inversion (Air to Water Heat Pumps BC1 and BC2) and the third one only for cooling with heat recovery (Air-cooled Chiller with Heat Recovery RF-HR).

As it can be seen in the general primary circuit scheme on page 76 of the present document, the primary circuit elements (RF-HR, BC1 and BC2) are responsible for supplying water at the required temperature and pressure to the Air Handling Units (AHU's), the Fan-coils and the post-heating batteries, depending on the desired conditions in each of the building's rooms.

The heat pumps BC1 and BC2 are able of feeding both heating and cooling coils depending on the current thermal needs of the building.

The heating and cooling data and the power of the three plants are specified in the following Table 2:

Ref.	Description	Cooling Power	Heating power	Electric power	COP (Heating Mode)	EER (Cooling Mode)
		[kW]	[kW]	[kW]	[kW/kW]	
RF - HR	Air-cooled Chiller with Heat Recovery	421,3	-	147	-	2,2
BC 1	Air to Water Heat pump	334	366,2	144	2,85	2,65
BC 2	Air to Water Heat pump	334	366,2	144	2,85	2,65
Total installed power		1089,3	732,4	435		
Total demand		877,82	599,27			

Table 2: Technical data of the main units

The total cooling installed power on the building is 1089,3 kW and 732,4 kW for the heating power. Technical data of the primary circuit equipment can be found on points 2.1 and 2.2 of the Annex document.



Figure 55: Main units distribution on fifth floor



Figure 56: Primary and secondary circuit pumps distribution

The “Fifth Floor Distribution Plan” (page 78) shows the functioning of B1 and B4 primary pumps. On one side B1 is in charge of the return in air-cooled mode of the RF-HR cooling

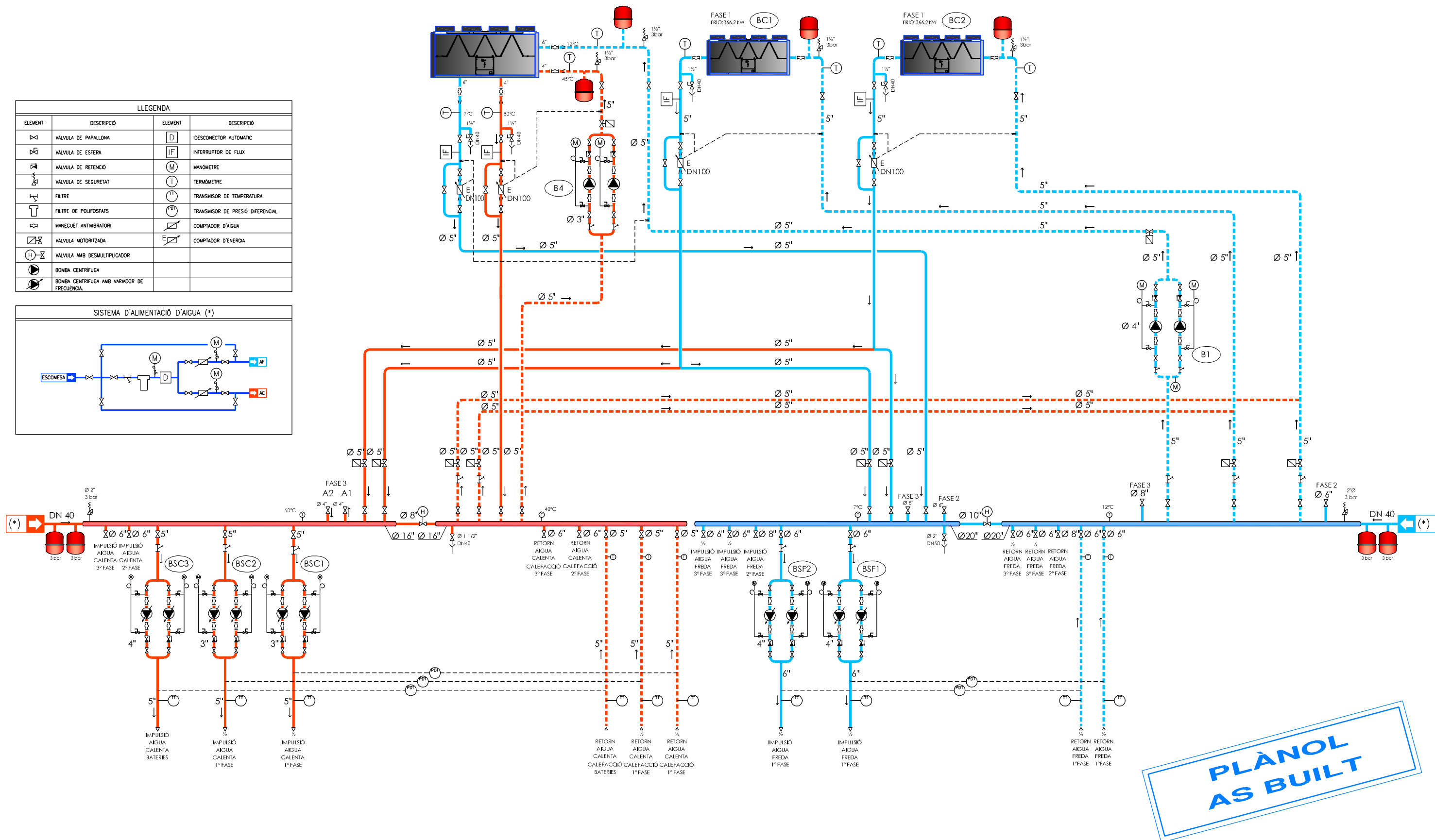
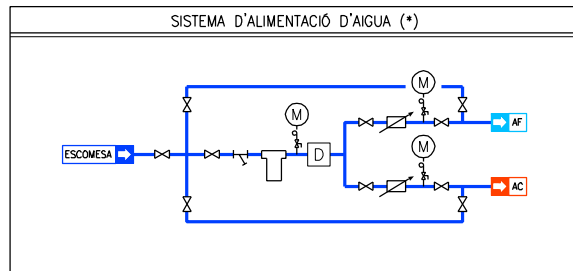
tower, while B4 is responsible for pumping the return water for the heat recovery mode of this same RF-HR unit.

The primary pumps B2 and B3 (not indicated in the mentioned floor drawing) carry out the return for the air-to-water heat pumps BC1 and BC2 respectively.

Just after the mentioned general scheme of the primary circuit, the following diagrams of the secondary circuit are attached (the description of which can be found in point 6.1.2 of the present document):

- Fifth Floor Distribution Scheme
- Hot Water Circuit
- Cold Water Circuit

LLEGENDA			
ELEMENT	DESCRIPCO	ELEMENT	DESCRIPCO
	VÀLVULA DE PAPALLONA		IDESCONNECTOR AUTOMÀTIC
	VÀLVULA DE ESFERA		INTERRUPTOR DE FLUX
	VÀLVULA DE RETENCIÓ		MANOMETRE
	VÀLVULA DE SEURETAT		TERMOMETRE
	FILTRE		TRANSMISOR DE TEMPERATURA
	FILTRE DE POLIFOSFATS		TRANSMISOR DE PRESSIÓ DIFERENCIAL
	MANEGUET ANTIVIBRATORI		COMPTADOR D'AIGUA
	VÀLVULA MOTORIZADA		COMPTADOR D'ENERGIA
	VÀLVULA AMB DESMULTIPLICADOR		
	BOMBA CENTRÍFUGA		
	BOMBA CENTRÍFUGA AMB VARIADOR DE FRECÜÈNCIA		



PLÀNOL
AS BUILT

Client:

IMPULSA **ORTIZ**
CONSTRUCTORA CONSTRUCCIONES

agefred **U.T.E. AULARI BELLVITGE**

Assumpte:
AMPLIACIÓ DE L'AULARI DEL CAMPUS DE BELLVITGE

Denominació:
esquema de principi CIRCUITS HIDRÀULICS DE CLIMATIZACIÓ

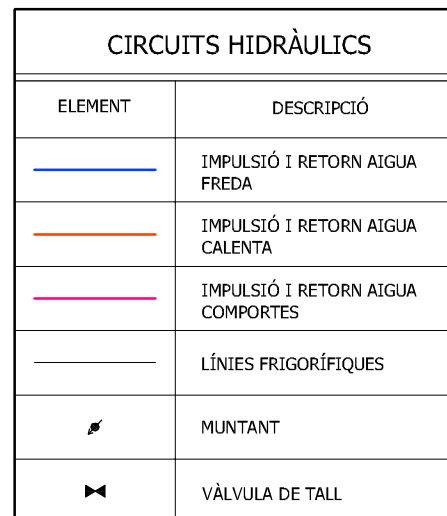
Projectat:	E.FERNÁNDEZ
Dibuixat:	C.VERDUGO
Revisat:	E.FERNÁNDEZ
Data:	29-10-2013

Nom arxiu:	W102892-TU070-ESQ-05_DO-06.05.13A.DWG
Pàg.	1 de 1
Ctb.	AGF-PIID-00.ctb

Codi plànol:
TU070
DO 06.05.13A.3

S/E

Ruta: S:\Delimitacion OBRES EN PROCESO\LIB. AULARIO BELLEVITGE\2015-16\PLANS ANOS\WU0292-TU060-PL-5-6-DO-06-05-12A.dwg



Fase	Ref.	Zona	fundó	marca	mod	Tipo	BATERIA DE FIO			BATERIA DE CALOR			Ventiladors		VENTILADORES		FILTROS	RECUPERADOR	ANCHO	LARGO	ALTO	peso						
							Pot. total (kW)	Temp. aigua (°C)	Caudal aigua (l/h)	Pot. total (kW)	Temp. aigua (°C)	Caudal aigua (l/h)	IDA	Caudal imp. (m³/h)	pressió disp. (mm cda)	Tipo							Caudal ret. (m³/h)	pressió disp. (mm cda)	Alternativa	Tipo		
I	CL1	aules	P0/P1	climatització + ventilació	Wolf	KG Top 210	1	140	8°C - 13°C	24.040	98	45°C - 40°C	17.040			12.490	25	Plug Fan	12.490	20	TERMOVEN / SABIANA / TROX	Plug Fan	F7+F9+F7	Rotativo entalpico	2237	4915	2644	2148
I	CL2	aules	P2	climatització + ventilació	Wolf	KG Top 170	1	127	8°C - 13°C	21.810	85	45°C - 40°C	17.780			10.400	25	Plug Fan	10.400	20	TERMOVEN / SABIANA / TROX	Plug Fan	F7+F9+F7	Rotativo entalpico	1932	4875	2644	1837
I	CL3	laboratoris	P3	climatització + ventilació	Wolf	KG Top 130	1	100	8°C - 13°C	17.170	72	45°C - 40°C	12.520			8.700	25	Plug Fan	8.700	20	TERMOVEN / SABIANA / TROX	Plug Fan	F7+F9+F7	Rotativo entalpico	1932	4570	2034	1482
I	CL4	aules	P4	climatització + ventilació	Wolf	KG Top 130	1	94	8°C - 13°C	16.140	64	45°C - 40°C	11.130			8.200	25	Plug Fan	8.200	20	TERMOVEN / SABIANA / TROX	Plug Fan	F7+F9+F7	Rotativo entalpico	1932	4570	2034	1479
I	CL5	aules	P2	climatització + ventilació	Wolf	KG Top 170	1	132	8°C - 13°C	22.670	82	45°C - 40°C	14.260			11.400	25	Plug Fan	11.400	20	TERMOVEN / SABIANA / TROX	Plug Fan	F7+F9+F7	Rotativo entalpico	1932	4875	2644	1861
I	CL6	laboratoris	P3	climatització + ventilació	Wolf	KG Top 210	1	143	8°C - 13°C	24.550	103	45°C - 40°C	17.910			12.300	25	Plug Fan	12.300	20	TERMOVEN / SABIANA / TROX	Plug Fan	F7+F9+F7	Rotativo entalpico	2237	4915	2644	2154
I	CL7	aules	P4	climatització + ventilació	Wolf	KG Top 170	1	113	8°C - 13°C	19.400	74	45°C - 40°C	12.870			9.100	25	Plug Fan	9.100	20	TERMOVEN / SABIANA / TROX	Plug Fan	F7+F9+F7	Rotativo entalpico	1932	4875	2644	1810
I	CL8	despatxos	P4	ventilació	Wolf	KG Top 64	2	29	8°C - 13°C	4.980	24	45°C - 40°C	4.170			3.250	25	Plug Fan	3.250	20	TERMOVEN / SABIANA / TROX	Plug Fan	F7+F9+F7	Flujos cruzados	1017	4677	1424	805
I	CL VEST	vestibul	P0	climatització	Wolf	KG Top 96	3	20	8°C - 13°C	3.430	18	45°C - 40°C	3.130			5.900	15	Plug Fan	X	X	TERMOVEN / SABIANA / TROX	X	F7+F9	X	1017	4170	1017	587

PLÀNOL AS BUILT

No.	Data	Descripció	Creació	Revisat
00	17-09-2012	CREACIÓ	C.PÉREZ	E.FERNÁNDEZ
01	-	-	-	-
02	11-12-2012	REPLANTEIG TÈCNIC	C.PÉREZ	MLARGO
03	14-12-2012	REPLANTEIG GENERAL	C.PÉREZ	E.FERNÁNDEZ
04	16-12-2012	REPLANTEIG GENERAL	C.PÉREZ	E.FERNÁNDEZ
05	15-03-2013	REPLANTEIG GENERAL	C.VERDUGO	MLARGO
06	15-10-2013	AS BUILT	C.VERDUGO	MLARGO

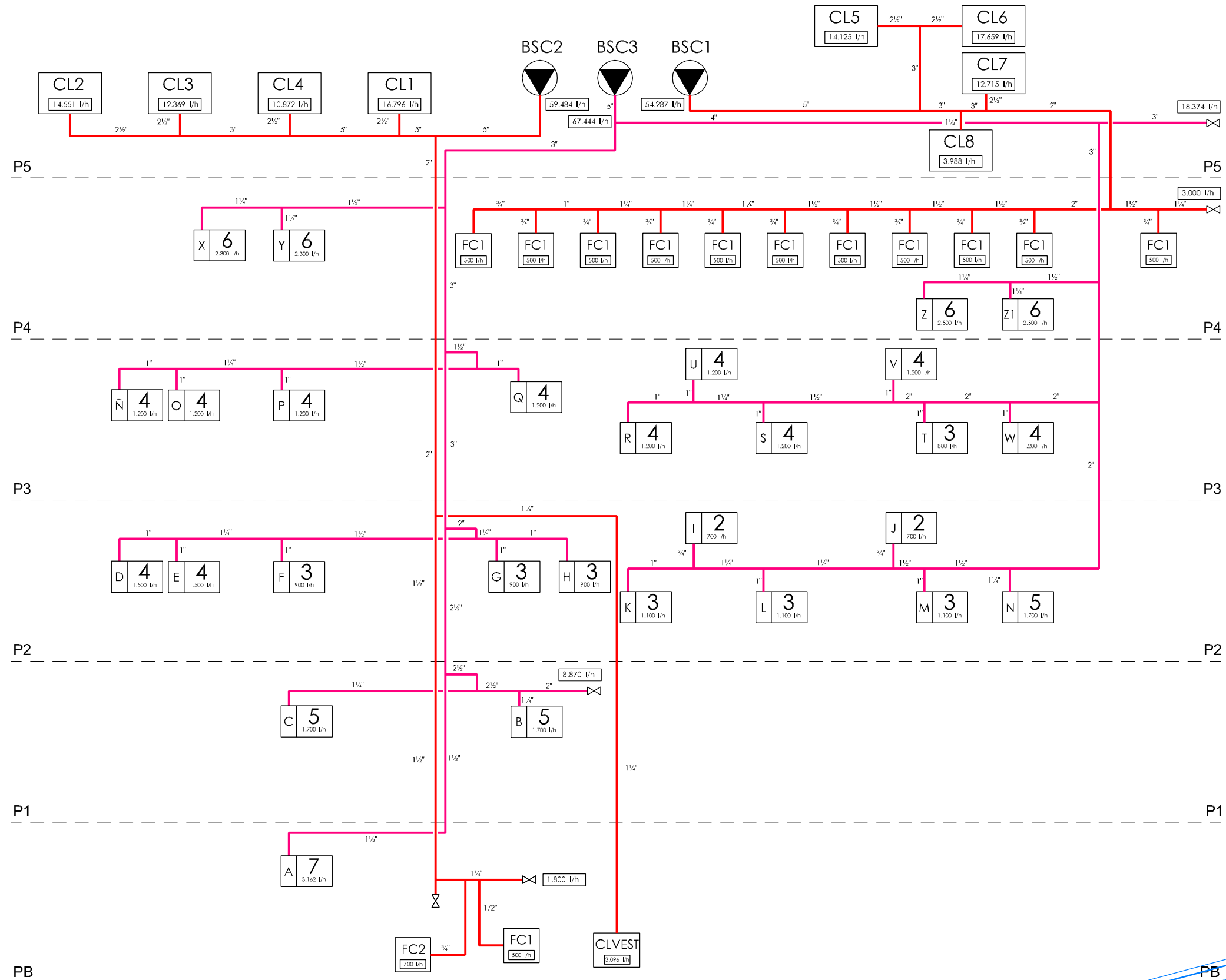
Cliant: UNIVERSITAT DE BARCELONA

IMPULSA **ORTIZ**

Assumpte: AMPLIACIÓ DE L'AULARI DEL CAMPUS DE BELLEVITGE

Denominació: planta cinquena CLIMATIZACIÓ, DISTRIBUCIÓ DE CANONADES
 Codi plànol: TU060 DO-06.05.03A.2

Nom arxíu: WU0292-TU060-PL-5-06_DO-06.05.12A.DWG
 Cib: AGF-BASE-01.ctb
 A1 A3 1/100 1/200
 Pàg. 1 de 2



CIRCUITS D'AIGUA CALENTA

PLÀNOL
AS BUILT

Client:

IMPULSA CONSTRUCTORA
ORTIZ CONSTRUCCIONES
agefred U.T.E. AULARIO BELLVITGE

Assumpte:
AMPLIACIÓ DE L'AULARI DEL CAMPUS DE BELLVITGE

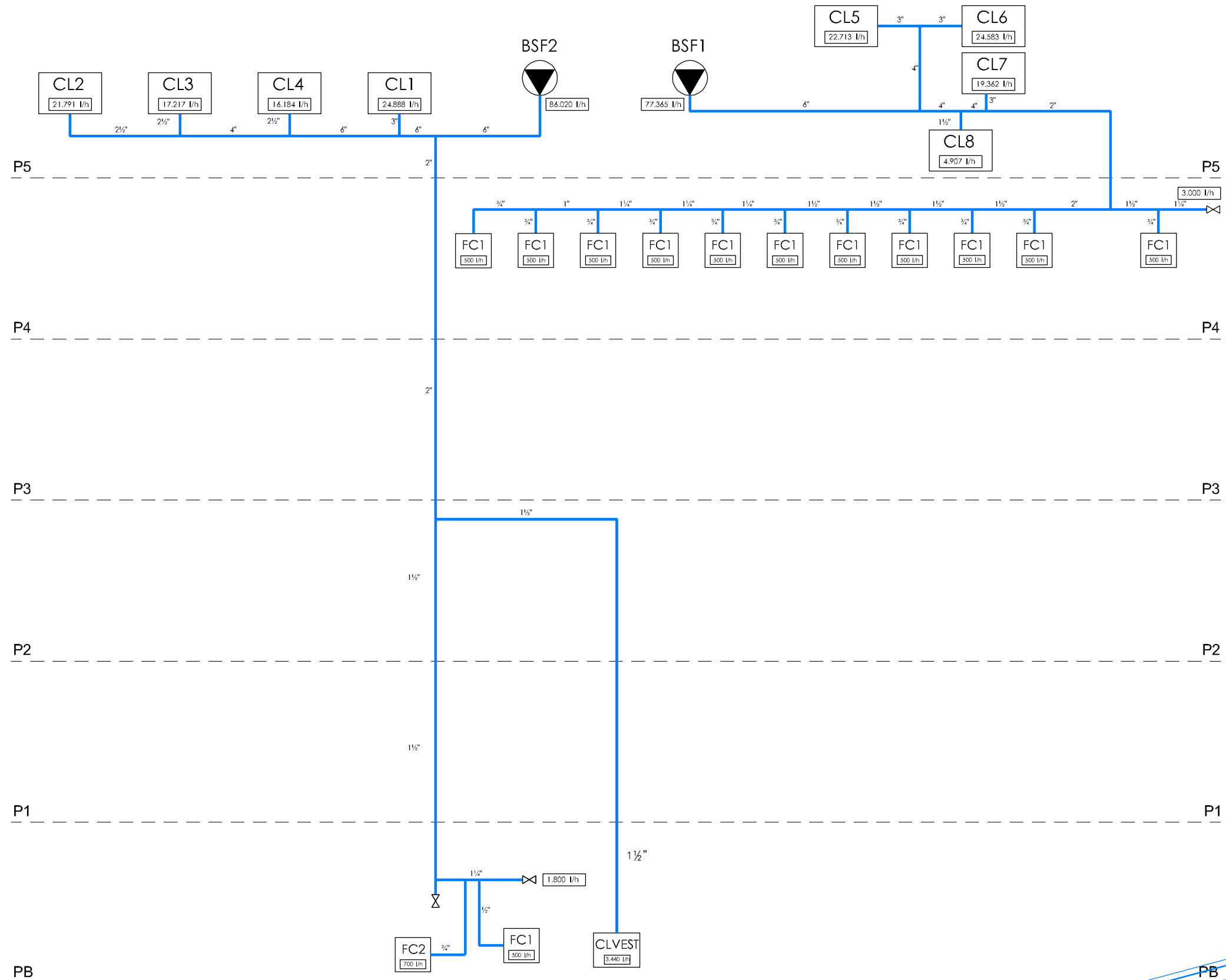
Denominació:
esquema de principi vertical CIRCUIT D'AGUA CALENTA

Projectat:	E.FERNÁNDEZ
Dibuixat:	C.VERDUGO
Revisat:	E.FERNÁNDEZ
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Nom arxiu:	W102892-TU080-ESQ-02_DO-06.05.15A.DWG
Pàg.	1 de 1
Ctb.	AGF-PIID-00.ctb

Codi plànol:
TU080
DO 06.05.15A
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CIRCUITS D'AIGUA FREDA

**PLÀNOL
AS BUILT**

Client:

IMPULSA CONSTRUCTORA
ORTIZ CONSTRUCCIONES
agefred
U.T.E. AULARI BELLVITGE

Assumpte:
AMPLIACIÓ DE L'AULARI DEL CAMPUS DE BELLVITGE

Denominació:
esquema de principi vertical
CIRCUIT D'AIGUA FREDA

Projectat:	E.FERNÁNDEZ
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Revisat:	E.FERNÁNDEZ
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Nom arxiu:	W102892-TU090-ESQ-00_DO-06.05.16A.DWG
Pàg.	1 de 1
Ctb.	AGF-PID-00.ctb

Codi plànol:	TU090 DO 06.05.16A
	S/E

6.1.2. Secondary circuit

As can be seen in the distribution scheme of the Fifth Floor of the page 80, the secondary circuit is composed by the following elements:

- Air Handling Units (AHU's)
- Fan-coils (in charge of the air conditioning of the offices of 4th Floor)
- Post-heating batteries (VAV boxes)

6.1.2.1. Secondary circuit pumps

With regard to the secondary pumps BSC1, BSC2, BSC3, BSF1 and BSF2, they have the following functions (observe in particular the “Hot Water Circuit” scheme on page 81 for the BSC's and “Cold Water Circuit” on page 82 for the BSF's):



Figure 57: Secondary circuit pumps together with heat pump BC1

- Secondary hot water pumps (BSC's):
 - BSC1: In charge of supplying hot water to air handling units CL5, CL6, CL7 and CL8 and also to the fan-coil units of the offices of the 4th floor.

- BSC2: Pumps hot water to air handling units CL1, CL2, CL3, CL4 and CL_Hall (called CLVEST in the scheme), and additionally to two fan-coil units of the ground floor (FC1 responsible of the climate control and air-renew of an office and FC1 in charge of the reception).
- BSC3: Responsible of pumping hot water to all the post-heating coils located on the different floors of the Campus.
- Secondary cold water pumps (BSF's):
 - BSF1: Supplies cold water to CL5, CL6, CL7 and CL8, and to the fourth floor fan-coil units.
 - BSF2: in charge of pumping cold water to the AHU's CL1, CL2, CL3, CL4 and CL_Hall air handling units and to the two above-mentioned fan-coil units of the ground floor.

The distribution of the hot and cold water piping circuits is shown below:



Figure 58: Distribution of hot and cold water through pipe circuit

Pipe Number	Description
1	Supply of Cold water to Air Handling Units CL5-6-7-8
2	Return of Cold water from Air Handling Units CL5-6-7-8
3	Supply of Hot water to Air Handling Units CL5-6-7-8
4	Return of Hot water from Air Handling Units CL5-6-7-8
5	Return of Hot water from Post-Heating Batteries (associated with CL5-6-7 zones)
6	Supply of Hot water to Post-Heating Batteries (to all thermal zones)
7	Return Hot water Post-Heating Batteries (associated with CL1-2-3-4 zones)
8	Supply of Hot water to Air Handling Units CL1-2-3-4
9	Return of Hot water from Air Handling Units CL1-2-3-4
10	Supply of Cold water to Air Handling Units CL1-2-3-4
11	Return of Cold water from Air Handling Units CL1-2-3-4

Table 3: Glossary of Figure 53

6.1.2.2. Air distribution circuit

Most of the thermal zones (teaching areas, computer labs, laboratories and the Conference Hall or *Sala de Graus*) are heated and cooled through the air handling units CL's, with heat recovery of the ventilation air. Additionally, the air conditioning system is equipped with dampers for regulating the airflow depending on the air quality and the external enthalpy (see point 6.4.2.2 of the present document).

The offices of the 4th floor are air-conditioned by means of four tubes fan-coil units with treated air supply and extraction through the air handling unit CL8.

As regard the control system, each classroom, computer room and laboratory, are equipped with a climatic control system, performed by flow control units (VAV boxes) equipped with post-heating coils through the heat recovery of the Air-cooled Scroll Chiller RF-HR. These post-heating batteries are used in the cooling-period of the year only.

With these coils the performance of the AHU's is improved, as they can supply air at a lower temperature. On the other hand, the fact that these coils contained in the VAV boxes (located in each of the entrances of the different air-conditioned thermal zones of the Campus) are fed through the heat recovery cycle of the RF-HR cooling tower, further increases the efficiency of the installed system.

Each flow control unit has a servo-engine, the function of which consists on regulating the air contribution depending on the occupancy of each thermal zone. If the zone is not occupied, the ventilation is switched off, leaving a minimum flow ventilation rate of the 10% of the total air flow.

For the two server and computer rack room (located on the 1st and 4th floors), the installation of a separate split unit was planned.

All circuits have variable flow rates depending on the differential pressure. The terminal units have two-way valves for temperature control except for a few units that are equipped with a three-way valve to ensure a minimum circulation of 20% of the circulating air flow.



Figure 59: General extraction grille located on a corridor

The air is blown through diffuser elements and anodised aluminium grilles. The return air is sucked in through fixed fin grilles placed on the ceiling of the offices, while in the classrooms, computer rooms and laboratories the air is inhaled in through the wall facing the corridor and from the corridor to a general grille located on the side of the column air ducts (see Figure 59).

With this system, the corridor is air-conditioned with the residual heat/cold of the classrooms (depending on whether heating or cooling mode is used).

6.1.2.3. Water distribution circuit

Both the air handling units and the distribution lines of each floor are equipped with flow control and differential pressure stabilising valves.

The pipelines are made of drawn steel, seamless black DIN 2440, properly insulated following the Spanish legislation RITE (Regulation of thermal technical building systems in buildings), and protected with aluminium in the external zones.

All pipes and fittings, as well as equipment, apparatus and tanks that make up the TBS were properly isolated.

6.2. Management and control systems of the technical building system

The entire system is controlled by a centralized management system, which manages several facilities in addition to the air conditioning.

Each office has a control system that allows the adjustment of the cooling/heating operation according to the desired room temperature. For the other thermal zones, the temperature control is done through the central management system.

In addition, the control system measures and records the electrical energy consumption of the air-conditioning systems and the chilling plant.

6.2.1. System architecture

The management system design is based on reliability and flexibility criteria.

High reliability must be associated with all the elements of the management system. A reliable system must prevent the failure of one of its parts from causing the collapse of the rest of the system.

In order to meet these objectives, a hierarchical architecture was created with the following levels:

6.2.1.1. Level 1:

Made up of the elements located in the technical building systems (sensors and actuators), from which the measurements and digital inputs are collected and sent to the second level. From this first level, the elements of the technical building system are acted upon directly according to the orders received from the higher level.

6.2.1.2. Level 2:

This level is made up of freely programmable type Xenta distributed control processors with the assigned functions of regulation, command and control corresponding to the production of cold and heat, air conditioning and electrical control.

It can work autonomously with respect to the rest of the controllers that join the same communications bus and with respect to the central station, at the same time as they receive and send information to the Control Centre of the system through the bus.

These controllers manage the production and energy distribution to the air conditioning, as well as the air treatment carried out in the air conditioning units. They are also in charge of sending information to the Control Centre about:

- Temperature of the rooms
- Current set point values
- Variations with respect to the set values
- Heating and cooling demands
- Energy consumption

6.2.1.3. Level 3:

This last level is formed by the Control Centre of the building which is in charge of coordinating and supervising the technical building system acting on the elements of the lower levels.

The Control Centre is equipped by an user interface focused on simplifying the control of the technical building systems in an independent way from the rest of the levels. All users of the system will be able to connect with different codes and categories of access to it.

From this general Control Centre it is possible to manage the different elements of the technical building system in such a way that (automatically or manually) activation or deactivation orders can be given, and the operating parameters of the installations can be modified (set point temperatures of the different units, lighting schedules, etc).

The functionalities provided to the system are:

- State monitoring of all the elements, through the display of synoptic diagrams of each supervised installation, using a colour code associated with the current status of each one of them.
- Reception of any occurred or raised alarms.
- Automation of:
 - Start and stop equipment.
 - Graphic and numerical recorders to follow the historical evolution of the installation signals. The recorders are configurable in number of signals and scales of the coordinate axes.
 - Chronological recording of alarm events of the various installations and of the user commands, noting in this case the name of the user who requested the command.
 - Control of access to the System, through a system of keys configurable by the user. This determines for each user the level of access that it grants them for each facility.

6.3. Production – Heating / Cooling

6.3.1. Performance

The production of Cold/Heat is started automatically according to the demand or in manual mode (24h), the operating mode is selected by the user from the Management system.

The user also has the possibility to set the following options:

- Operating mode of the Heat Pumps BC1 and BC2: Cold or Heat
- Individual operating mode of each device: Manual / 0 / Automatic
- If the automatic mode is selected, the heat pumps are alternating (equalizing the number of working hours), and by means of a collector flow temperature range, if necessary, they would start working in parallel.
With this option, even if one of the two heat pumps goes into alarm, the other one starts working automatically.
- Changing Heat/Cold Mode:
 - Automatic mode: by outdoor temperature
 - Manual mode

If the Automatic Mode is chosen, the winter-summer change of the heat pumps BC1 and BC2 is carried out automatically through the building automation and control system depending on the external temperature (T_{ext}), following the next Table 4 and the following criteria:

Ext. Temp. [°C]	BC 1 (mode)	BC 2 (mode)	Secondary heat circuit pumps	Secondary cold circuit pumps
$T_{\text{ext}} < 15$	Heating	Heating	On	Off
$30 < T_{\text{ext}}$	Cooling	Cooling	Off	On

Table 4: Operation of BC1 and BC2 as a function of external temperature

6.3.2. Boot sequence:

If there is an authorized operating order or a manual command is given from the keypad, the devices are started up using the following range working procedure:

6.3.2.1. Heating Mode:

- Range 1: BC1 has priority 1 in front of heat pump BC2.
 - Lower Limit: 0 W
 - Upper Limit: 219720 W (60% of the heating capacity of BC1)
- Range 2: BC1 still has priority in front of BC2, but BC2 will be started up working in parallel with the first one on the same set point.
 - Lower Limit: 219720 W
 - Upper Limit: 1000000 W (is the introduced number in the DB file, but it could have been a ∞).

6.3.2.2. Cooling Mode:

- Range 1: RF-HR has priority for cooling in front of BC1 and BC2, until it reaches the 60% of its cooling capacity.
 - Lower Limit: 0 W

- Upper Limit: 252780 W
- Range 2: RF-HR still has priority n° 1, BC1 can be started up for contributing in the cooling performance, until BC1 reaches its own 60%.
 - Lower Limit: 252780 W
 - Upper Limit: 472500 W
- Range 3: BC2 will be started up with priority n° 3. RF-HR still has priority n° 1.
 - Lower Limit: 472500 W
 - Upper Limit: 1000000 W



Figure 60: Detail of the distribution of hot and cold water pipes

6.4. Air Handling Units (AHU's)

An initial summary screen is available to configure the operation of the Air handling units of the TBS. The display shows the following characteristic parameters for each one of them:



Figure 61: Air Handling Units control display

As shown in Figure 61, a list of the AHU's that constitute the technical building system is provided for their management. For each of them the following parameters are displayed:

- Inlet and outlet air temperatures [°C]; ("Temperaturas: Impulsión/Retorno")
- Air humidity [%]; ("Humedad")
- Air pressure [Pa]; ("Presión")
- CO concentration [ppm]; ("CO")

In yellow ("Consignas: Impulsión/Presión") the user-configurable instructions are set, which are the flow air temperature and the corresponding pressure.

In the second-last panel ("Paro/Marcha") the operating mode of each AHU can be selected: Stop (0), Manual Mode (Man) and Automatic Mode (Auto). The last of the panels ("Horario") allows setting the running time independently for each unit.

The following are the technical characteristics of each of the AHU's, which can be grouped into three types/groups depending on their operating sequence:

- **Type 1: CL8**
- **Type 2: CL1, CL2, CL3, CL4, CL5, CL6, CL7**
- **Type 3: CL-Hall**

The specific technical data of each air handling unit can be found on point 2.3 of the Annex document.

6.4.1. Type 1: CL8 (Offices):

The AHU CL8 only takes care of the air renewal of the offices located on the fourth floor. The air-conditioning of these rooms is carried out individually for each of them by means of fan-coil units.

6.4.1.1. Performance:

The climate control system is started up according to the time schedule or in manual mode (24 Hrs), the operating mode is selectable by the user from the Management system.

The user has the following instructions at his disposal:

- Air conditioner time schedule (Manual (M) / 0 / Automatic (A)).
- Supply air temperature set-point.



Figure 62: Detail of the RF-HR cooling tower, and AHU's CL7 and CL8

6.4.1.2. Sequence of operation:

If there is an authorized operating order or a manual command is given from the keypad, the devices are started up using the following procedure:

- 1) A running order is given to the driving fan.
- 2) Once the status of the drive fan has been confirmed, another running order is given through a start command to the return fan.
- 3) Once the fan running state is checked, the PID Control Loop is unlocked by actuating on the Heat and Cold valve to maintain the flow temperature according to the set point.

6.4.2. Type 2: CL1, CL2, CL3, CL4, CL5, CL6, CL7

This group of seven AHU's is in charge of the heating, cooling and air renewal of the main part of thermal zones that compose the Campus, as can be seen on point 2.3 of the Annex, they have under their "responsibility" the classrooms, computer rooms, the laboratories and the Conference Hall (*Sala de Graus*).

6.4.2.1. Performance:

As in the CL8 climate control unit (Type 1), Type 2 air handling units are switched on according to the time schedule or in manual mode (24 Hrs), the operating mode can be selected by the user from the Management system.

The user has the following commands at his disposal:

- Air conditioner time schedule (M / 0 / A)
- Supply air temperature set-point (M / A)
- CO set-point
- Humidity set-point (for dehumidification)
- Flow pressure set-point



Figure 63: Zone located on the right side of the TBS zone where the AHU's CL5, 6, 7 and 8 are located



Figure 64: Zone located on the left side of the TBS zone where the AHU's CL1, 2, 3 and 4 are located

6.4.2.2. Sequence of operation:

If there is an authorized operating order or a manual command is given from the keypad, the devices are started up using the following procedure:

- 1) A running order is given to the driving fan.

- 2) Once the status of the drive fan is confirmed the fan frequency will be calculated to ensure the flow pressure.
- 3) With the confirmation of the status of the driving fan, a running order is given to the return fan with a 20% lower working frequency to ensure overpressure.
- 4) Once the running state of the drive fan has been recognised, the PID Control Loop is unlocked, actuating on the Heat and Cold valve to maintain a temperature in the flow according to the set point.

There are two ways to calculate the flow command:

- Manual: The user chooses a fixed drive set-point.
- Automatic: The flow command is determined according to the needs of the classrooms.

Three control functions are available for the control of these Type 2 Air Handling Units and its dampers/gates:

Control function	External Dampers	By-pass Dampers	AHU Heat Recovery	Result
Favourable external conditions. Independent of the CO (Carbon Monoxide).	Opened	Closed	Switched off	100% outdoor air
Unfavourable external conditions. Correct CO.	Closed (to the minimum percentage, 20%)	Opened (80%)	Turned off	80% of recirculated air and 20% of external air
Unfavourable external conditions. High amount of CO.	Opened	Closed	Turned on	100% of outdoor air but recovering energy with the indoor environment

Table 5: Sequence of operation for Type 2 Air Handling Units

With regard to whether the external conditions are favourable or not, the installed control device analyses the external conditions of temperature and humidity, to determine if they are within the adequate margins that allow to use the external air or not.

Normally the carbon dioxide concentration is analysed, but in this case, the TBS installation team decided to analyse the accumulated amount of carbon monoxide. The reason why this decision was made is unknown.

There is a minimum opening percentage of the dampers to ensure a minimum supply of outside air.

Type 2 Air Handling Units are equipped with a dehumidification function, so that if the humidity in the return duct exceeds the established humidity setting (set at a maximum of a 70%), the cooling valve will open at 100% to ensure the dehumidification of the air.

6.4.3. Type 3: CL-Hall

The AHU CL_Hall is in charge of the air conditioning (not the air renewal) of the common area located on the ground floor or entrance hall (Common Area Gr. Fl.).

6.4.3.1. Performance:

The climate control system is started up according to the time schedule or in manual mode (24 Hrs), the operating mode is selectable by the user from the Management system.

The user has the following commands at his disposal:

- Air conditioner time schedule (M / 0 / A).
- Return temperature set-point.
- Maximum flow temperature set-point.
- Minimum flow temperature set-point.

6.4.3.2. Sequence of operation:

If there is an authorized operating order or a manual command is given from the keypad, the devices are started up using the following procedure:

- 1) A running order is given to the driving fan.
- 2) Once the fan running state has been confirmed, the PID regulation loop will be unlocked by acting on the Heat and Cold valve to maintain a temperature on the return line according to the set point.
- 3) The temperature at the impulsion is limited by maximum and minimum values to ensure comfort in air-conditioned spaces.

6.5. VAV BOXES (With Post-Heating Batteries)

They are in charge of supplying, with variable flow, the conditioned air coming from the corresponding AHU's to the thermal zones.

They are equipped with the aforementioned post-heating batteries (whose operation is produced thanks to the hot water supplied through the heat recovery of the condensing cycle of the RF-HR cooling tower), the function of which is to finish the conditioning of the air to be supplied into the thermal zone, allowing the AHU's to work at lower temperatures and consequently, improving their performance.

6.5.1.1. Overall performance:

Grouped by floor, the VAVs are activated according to the hourly schedule (one schedule per floor) or in manual mode (24 Hrs). In the same way as in the AHU's, the operating mode is selectable by the user from the Management system.

The following general values are available to the user (per floor):

- VAV group timetable (M / 0 / A).
- General VAV set-point per plant.

Specific technical data of the VAV boxes equipment can be found on points 2.7 and 2.8 of the Annex document.

6.5.1.2. Individual operation:

The switching on of each individual VAV is conditioned by the timetable of the superior hierarchical level (grouping by floor).

The user has individually for each VAV the following values:

- Selector 0 / A: The automatic option depends on the plant time schedule.
- Individual temperature set-point: This option allows the user to individually change the temperature set-point for each VAV, but if the upper level set-point is modified (per floor), all the individual set-point of the VAVs will be affected.
This option is beneficial when the general set-point change per floor is made (for example, when the summer season begins), and when we want to set another individual set-point for an office.

- Depending on the outdoor temperature and the set-point selected by the user (set-point of the management system), the system will act on the dampers and the heat valve, according to the needs.
- The dampers/gates will have a minimum opening to ensure the air renovation flow of the classrooms.

6.5.1.3. Control displays:

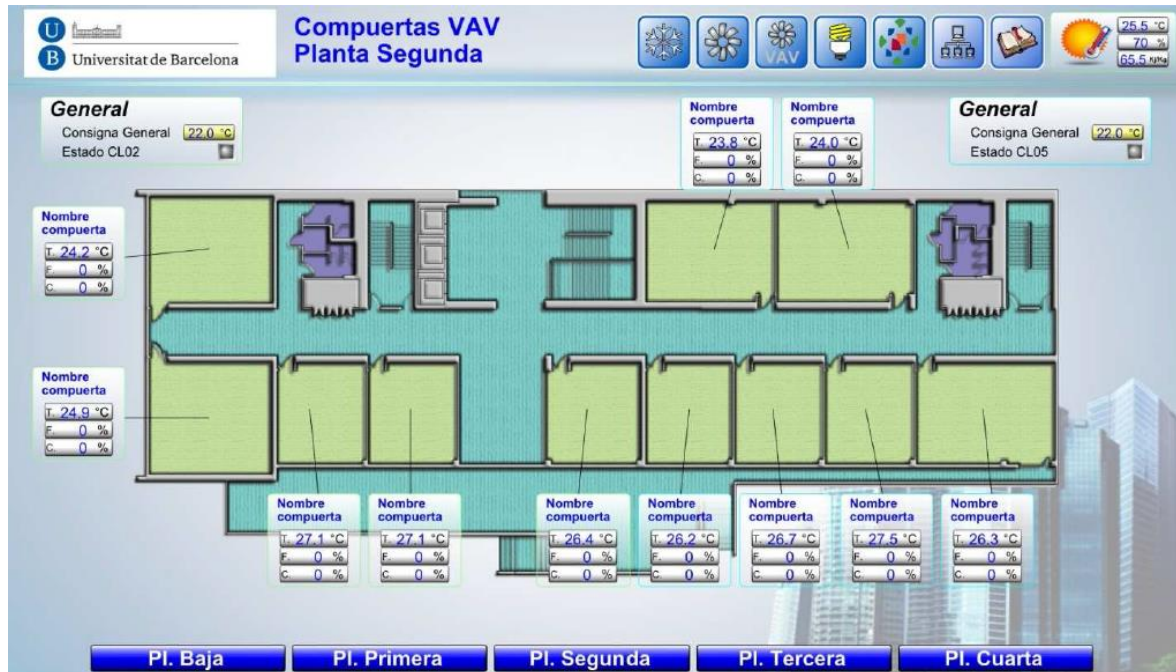


Figure 65: VAV general control display

Figure 65 shows the main control panel of the VAV gates of the Second Floor (“*Planta Segunda*”). In this case, the air conditioning of the floor is carried out by the air handling units CL2 and CL5 (as it can be seen in the upper left and right corners of the screen written in Spanish with the titles “*General*” and “*Consigna General*”, with the corresponding general temperature set points fixed at 22°C).

As described above, the management system allows the user to individually modify the temperature settings for each space of the floor. The three parameters that characterize the current state of each of them are the following (with the individual titles of “*Nombre compuerta*”):

- Current temperature [°C]; (T)
- Cooling calculation [%]; (F)
- Heat valve opening percentage [%]; (C)

Finally, in the lower part of the described panel, there is a selection menu to access to the management of the different floors of the building (“*Pl. Baja, Pl. Primera, Pl. Segunda, Pl. Tercera, Pl. Cuarta*”).

7. Modelling of the Technical Building System

7.1. Design Criteria

Once the modelling of the building has been completed and it has been understood how the Technical Building System that compose it works, it is proceeded to model through Design Builder the system described in the last section.

It has been decided to separate its modelling into two independent systems, on one side the part of the TBS dedicated to the heating of the Campus, and on the other, the system in charge of cooling.

This measure aims to simplify the modelling process, allowing quicker identification of which are the elements to be corrected, thus creating a set with sufficient robustness to obtain a system as reliable as possible to reality.

Initially the TBS modelling was carried out entirely with heating and cooling on the same HVAC scheme (see Figure 66) but given the lack of practice of the author with this type of DB modelling and the complexity of the system, the identification of the more influencing factors on the obtained results has been considerably difficult.

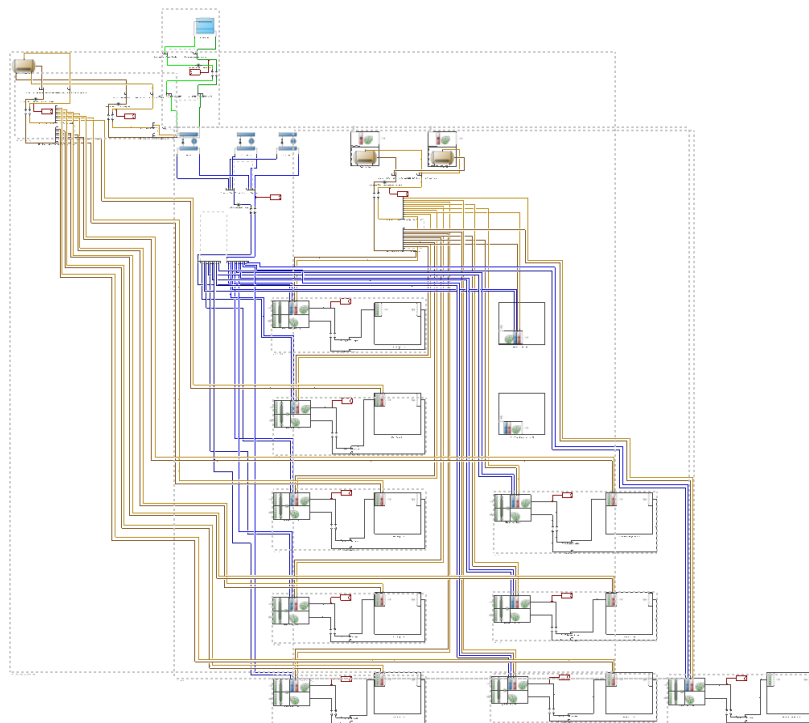


Figure 66: Initial HVAC modelling

It is for this reason that it was preferred to opt for this separating solution which allowed to obtain identically acceptable results, with the difference that, in each of the two systems, the author has focused on the months in which each system will be working.

For example, in the case of the modelling of the heating system, the relevant results are located in the months in which such HVAC scheme is required to obtain an indoor temperature of 20°C, while it has been disregarded the fact that during the summer months, temperatures of around 30°C are obtained in different thermal zones of the Campus, given that in this scheme, the cooling elements have not been introduced.

7.2. External calculation conditions

As general design criteria, the following conditions were taken into account:

- Maximum summer temperature: 31°C
- Minimum winter temperature: 0°C
- Daily temperature variation: 8,4°C
- Mean relative humidity in summer: 68%

7.2.1. Thermal quality of the environment, indoor conditions

The operating temperature and relative humidity values shall be within the following limits:

	Summer	Winter
Temperature	25°C ± 1°C	20°C ± 1°C
Humidity	55% (Relative)	50% (Relative)

Table 6: Operating temperature and humidity limits

7.2.2. Indoor air quality - Occupation and ventilation

The building has a TBS that must ensure the maintenance of adequate indoor air quality, eliminating contaminants that occur regularly during the use of the different thermal zones of the Campus by the users. To this end, sufficient external air must be provided and an adequate extraction and expulsion of the vitiated air must be guaranteed.

The ventilation airflow that have been considered to obtain such results have been taken from the established values in the Spanish RITE legislation. In it, different categories of indoor air quality (called IDA) are set, each of which has a specific ventilation flow associated with them.

The selected indoor quality air categories have been IDA2 for teaching areas, computer rooms and offices, while IDA1 category has been chosen for laboratories. From the indirect method of outdoor airflow per person proposed by the RITE legislation, the following airflow rates are obtained:

- Teaching areas, Computer rooms and Offices: $0,0125 \text{ m}^3/(\text{s} \cdot \text{person})$
- Laboratories: $0,02 \text{ m}^3/(\text{s} \cdot \text{person})$

With regard to the calculation of ventilation airflows, the value required to guarantee the correct air renewal of the thermal zones, the RITE legislation sets an external air flow per surface unit of $0.83 \text{ l}/(\text{s} \cdot \text{m}^2)$ for category IDA2, leaving the value of IDA1 (not applicable) unspecified.

If the flow calculations are carried out with the provided value of the surface criteria, the results are much lower than those obtained through the proposed ranges of the IDA categories.

From this fact, it has been decided to size the design air flow rates of each thermal zone based on the maximum number of people that may be inside it, multiplying the occupancy by the aforementioned flows of $0,0125$ and $0,02 \text{ m}^3/(\text{s} \cdot \text{person})$ of the IDA categories.

7.3. Heating system

The heating system consists of the following elements:

- Air to Water Heat Pumps BC1 and BC2
- Air Handling Units AHU's (CL's)
- Zone Groups with the thermal zones associated to the corresponding AHU's.

7.3.1. Introduced simplifications and encountered limitations

7.3.1.1. BC1 and BC2 Heat Pumps (Heating Mode)

The first difficulty encountered in this system was how to model heat pumps BC1 and BC2. As previously analysed, these two are air to water heat pumps that can generate both hot and cold water.

Design Builder only provides a default template of ASHP (Air Source Heat Pump) capable of generating hot water, not cold. Therefore with this type of HVAC element only heating can be supplied, however, this fact does not create major problems since as described above, heating and cooling have been modelled separately.

However, this situation (as detailed in the next point 7.4.1 of the present document) will lead to an important limitation when it comes to designing the part of BC1 and BC2 in charge of supplying cold water to the AHU's cooling coils.

On the other hand, another limiting aspect of the concerned ASHP template is that it is equipped with an accumulation tank where the generated hot water is collected and then supplied to the relevant collectors. This tank does not exist in the studied TBS of the Campus.

In order to see the effect produced by the presence of the accumulation tank, different simulations were carried out modifying the value of its volume. On one side with the "Autosize" DB option and on the other with 0 m³ volume. As both options achieved the same results both at temperature and humidity levels within the heated thermal zones, as well as the consumption of the different AHU's, it was decided to proceed with the accumulation tank at volume 0 m³. Therefore, the hot water is supplied to the coils instantaneously (as it actually happens).

7.3.1.2. Air Handling Units and Zone Groups

Regarding the AHU's, there have been no such limitations. The used software allows to model them with amplitude of factors, the great majority of which have been introduced, avoiding this way the use of the provided DB tool of "autosize" or "autocalculate" to dimension the different elements that conform the HVAC system.

As can be seen in the delivered DB Heating file ("Master Thesis Lambert Aulari – Heating System.dsb") as it is the scheme corresponding to the heating system, the cold water coils of the AHU's have been removed.

Additionally, a final simplification has been made with regard to the HVAC zone element for introducing air into the different zone groups to be heated. In contrast to the cooling system, no post-heating coils have been placed at this stage, given that they are only used during the months in which cooling is necessary. The air system has consequently been made through the VAV no reheat model, whereas in the cooling system as will be seen below, VAV reheat has been used.

7.3.1.3. Fan-coil units offices 4th Floor

An additional difficulty encountered was the modelling of the fan-coil units in charge of heating the offices on the 4th floor.

As explained in section 6.4.1, on one side the air handling unit CL8 is in charge of the air renewal of the offices, while the fan-coils allow an individualized air conditioning of each one of them.

In order to be able to model this operation, the fact that DB does not allow conjugating an AHU that does not heat and at the same time this AHU is connected to fan-coil units that do so, prevented its incorporation into the system.

Moreover, using only the fan-coil units without modelling the AHU CL8, gave problems of execution in the simulations. These were linked to the functioning of the heat coil incorporated in such units. To be able to solve it, it was necessary to leave most of the parameters that define them in "Autosize" mode, thus losing precision with respect to their real operation.

It is for this set of arguments that it has been decided to design the functioning of the air conditioning of the offices of the 4th floor as in the rest of thermal zones. The AHU CL8 is responsible for both air renewal and heating. This fact allows to model the CL8 and to define both the technical parameters of operation and the air renewal flow rates of the offices through the zone groups without having to use the resource "Autosize".

A problem that could lead such decision was the difference in consumption by not actually defining the fan-coil units, however their consumption has been taken into account in the AHU CL8 with the heat capacity of its coil.

7.3.1.4. Secondary BSC's Pumps

Finally it is also important to highlight another constraint produced by the used software, which does not allow introducing water pumps in certain points of the HVAC scheme. This fact implies that the secondary BSC's pumps (previously described at point 6.1.2.1 of the present document), which are in charge of supplying hot water from BC1 and BC2 heat pumps to the AHU's heating coils, could not be added to the model.

In order to define the impact of this constrain, their associated consumptions were incorporated "inside" the primary pumps. However, this caused incompatibilities at calculation level in the DB simulations between the factors that determine pump performance (consumption, pressure, performance curves and efficiency), which prevented

the simulation from being executed.

These incompatibilities combined with the low energy consumption linked to the pumping equipment (as will be seen later in the results point 7.3.4) led to definitively omit the introduction of the secondary pumps both in the heating and cooling models.

7.3.2. Modelled system

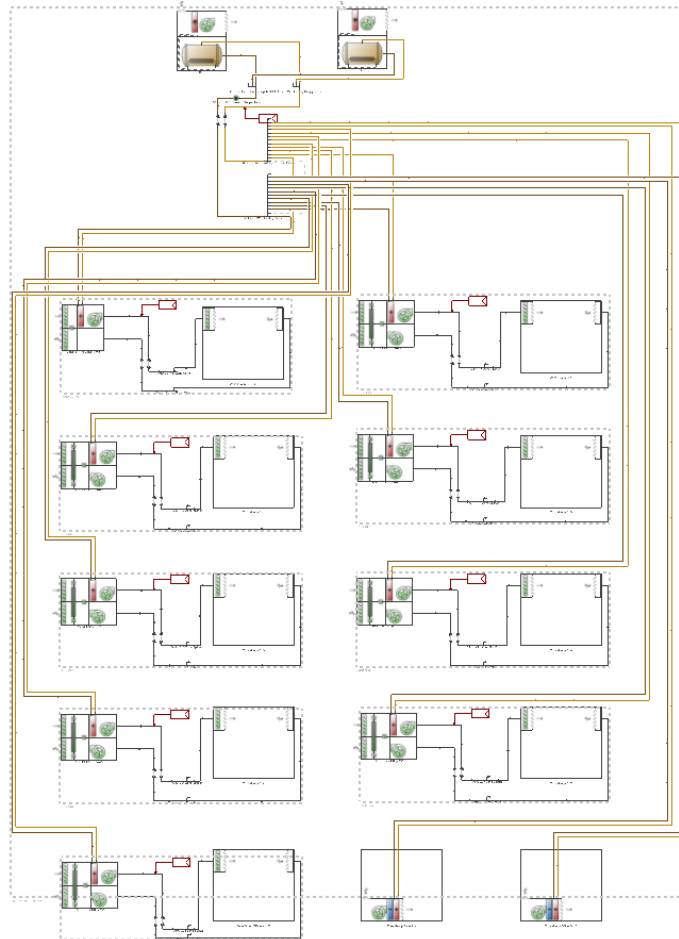


Figure 67: Final modelling of the heating system

7.3.2.1. Air to Water Heat Pumps BC1 and BC2 (Heating Mode)

The first element to be modelled in the heating system is the two heat pumps BC1 and BC2.

In order to be able to reproduce their operation as realistically as possible, the following performance curves have been created through *Energy Plus Curve Fit Tool*:

- HeatingCAP: Heating Capacity as a function of Temperature curve (Biquadratic)

$$\text{CAPFT} = -0,64518 + 0,10348x - 0,00139x^2 - 0,00253y - 0,00052y^2 + 0,00151xy$$

- HeatingCOP: Heating COP as a function of Temperature curve (Biquadratic)

$$\text{EIRFT} = -0,172346 + 0,036359x - 0,000241x^2 - 0,024867y - 0,000045y^2 - 0,000244xy$$

In order to obtain these curves, the tool requires the entry of the following parameters:

- DX Coil type: Cooling or Heating
- Independent variable: Flow or Temperature
- Curve type: Biquadratic, Quadratic or Cubic
- Units: IP or SI

After entering this information, different operating points of the heat pump are needed, which are determined by the next variables:

- Supply air volume flow rate
- Gross total cooling capacity
- Compressor plus outdoor coil fan power

The rest of the parameters belonging to the functioning of the heat pumps BC1 and BC2 were introduced from the technical specifications of such model (see point 2.1 in the attached Annex).

With regard to the primary pumps responsible for pumping the water from the AHU's return to BC1 and BC2, a simplification has been made with respect to B2 and B3 pumps (in charge of the return of BC1 and BC2 respectively) which consists of combining their operation in a single pump. This action is conditioned by the fact that Design Builder only allows to introduce a single pump into the return of the TBS system.

Therefore, B2 and B3 are modelled with the following specifications:

- Rated power consumption: 6 kW (3 kW consumption each)
- Rated pump head: 245.159,5 Pa (12,5 mwc each)
- Engine efficiency: 0,86

Finally, the performance curve that had been established by default in the DB file (it was simply a linear graph of slope 1) has been modified by the following Cubic curve (in which y represents the rated head [m] and x the water flow rate [m^3/h]):

$$y = 0,25 + 0,0045x - 0,00045x^2 + 0,0000078x^3$$

7.3.2.2. Air Handling Units

The AHU's have been defined through three aspects:

- Performance design parameters:

Factors such as inlet air flow rate, calculated design flow rate, outlet air temperature and humidity values are defined. The schedules created by the author are also associated to properly set to the academic calendar the functioning of the AHU.

- Recirculation:

The minimum and maximum outdoor air flow rates [m^3/s] associated with recirculation must be determined, and the same schedule established in the general AHU parameters is applied.

- Heat recovery:

It has been defined for each AHU the nominal electric power consumed during the HR process, the nominal supply air flow rate (the same as the design outdoor air flow rate), and the effectiveness values in sensible and latent mode have been determined.

7.3.2.3. Zone Groups

As mentioned above, the zone groups for the heating system have been defined as VAV no reheat given the non-use of the post-heating coils during the months in which heating is required.

For this purpose, the necessary design air renewal flow has been calculated for the thermal zones to be heated, and it has been determined together with minimum and maximum levels of operation.

In the case of the maximum flow, it has been established from the design flow taking into account the maximum air renewal capacity that the AHU can give to the set of associated thermal zones.

In addition, temperature and humidity conditions of the outgoing air have been defined, which must be in accordance with the values established in the corresponding AHU.

7.3.3. Previous considerations (also for the cooling results analysis)

As explained in the following section, one of the aspects that will be taken into account to assess the robustness and validity of the two created models (both heating and cooling) are the number of unsatisfied hours of thermal comfort during periods of time in which the thermal zone is occupied by users.

These unsatisfied hours are calculated by DB from model ASHRAE 55, which uses the PMV/PPD method to determine whether or not there is thermal comfort in the analysed space.

The following graph (Figure 68) illustrates the way the abovementioned method works:

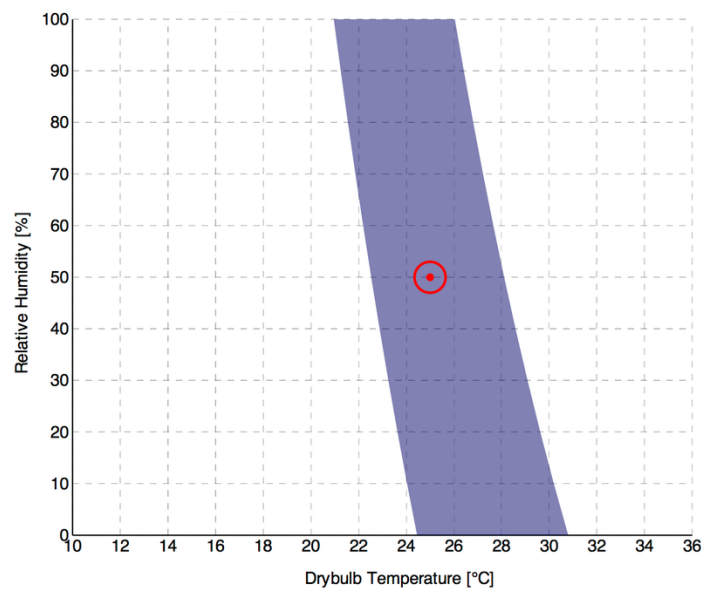


Figure 68: Comfort model ASHRAE 55

Depending on the relative humidity and drybulb temperature of the room, if the operating point enters within the blue region, Design Builder will consider that moment in that room as a satisfied time, if such conditions do not occur (e.g. 23°C but with a relative humidity of 25%), DB will mark this time as unsatisfied.

With this explanation prior to the analysis of the results, the intention was to show how one of the factors taken into account in the evaluation of the HVAC models created works. The ASHRAE 55 model of comfort has been useful to have a reference during the calibration process of both models, although it has not been wanted to give a major importance with respect to the rest of parameters that will be cited below.

7.3.4. Obtained Results

Once the HVAC system in charge of heating has been modelled, the calibration process is carried out by adjusting different parameters until the results that most closely resemble the real annual consumption (which will be shown later) are obtained.

The set of obtained results from the hourly annual simulation can be viewed through the EnergyPlus results viewer in the attached file (Results Aulari - Heating System.drs).

For its analysis, the following aspects have been taken into account:

- Energy consumed by each of the elements that make up the part of the TBS in charge of heating.
- Temperature and humidity conditions obtained in the heated thermal zones.
- Achieved air renewals in the studied thermal zones.
- Unsatisfied heating hours during occupancy according to the ASHRAE 55 comfort model.

In addition, the consumption obtained as a result of lighting and internal equipment has been analysed. This has been compared with the actual consumption of the Campus to evaluate the created model.

Time Setpoint Not Met					End Uses	
	During Heating [hr]	During Cooling [hr]	During Occupied Heating [hr]	During Occupied Cooling [hr]		Electricity [kWh]
0GROUND FLOOR:COMMON AREA GR.FL.	2837.50	1650.00	432.25	278.25	Heating	0.00
0GROUND FLOOR:SALA DE GRAUS	938.75	2267.00	26.50	415.00	Cooling	0.00
0GROUND FLOOR:OFFICE GR.FL.	535.75	3650.50	2.75	1465.25	Interior Lighting	238233.72
0GROUND FLOOR:RECEPTION	1161.50	2799.00	8.00	1057.50	Exterior Lighting	0.00
1FIRST FLOOR:CLASSROOMS1.11.2	776.00	3265.00	8.50	736.00	Interior Equipment	21072.29
2SECOND FLOOR:CLASSROOM2.1	2087.25	2754.75	37.50	701.00	Exterior Equipment	0.00
2SECOND FLOOR:COMPUTER LABS2.12.2	1513.50	3079.00	52.25	737.00	Fans	85635.75
2SECOND FLOOR:CLASSROOMS2.22.32.4	882.75	3753.50	5.00	1045.50	Pumps	3511.65
2SECOND FLOOR:CLASSROOM2.5	564.00	4015.75	9.00	1079.75	Heat Rejection	0.00
2SECOND FLOOR:CLASSROOMS2.62.72.8	762.25	3667.00	14.50	944.50	Humidification	0.00
2SECOND FLOOR:COMPUTER LAB2.3	1108.50	3677.75	27.75	912.00	Heat Recovery	20462.90
3THIRD FLOOR:LABORATORY3.1	1061.75	3860.75	23.25	958.75	Water Systems	14993.21
3THIRD FLOOR:LABORATORIES3.93.10	800.75	3690.00	26.75	805.75	Refrigeration	0.00
3THIRD FLOOR:LABORATORIES3.23.4	777.50	4202.25	13.50	1088.00	Generators	0.00
3THIRD FLOOR:LABORATORIES3.53.8	715.00	4202.25	14.50	1059.75		
4FOURTH FLOOR:OFFICES4.14.2	1335.50	4226.25	54.00	1188.25	Total End Uses	383909.52
4FOURTH FLOOR:OFFICES4.34.10	1340.50	4179.75	41.50	1197.25		
4FOURTH FLOOR:OFFICE4.11	1871.50	3956.75	137.00	1111.75		
4FOURTH FLOOR:CLASSROOMS4.14.2	1275.50	3667.25	16.00	944.50		
4FOURTH FLOOR:CLASSROOMS4.34.4	659.75	4141.50	13.50	1081.50		

Figure 69: Unsatisfied heating hours during occupancy (red zone) and final electric consumptions of the heating system

These are the achieved results of unsatisfied hours during periods in which there were users in the thermal zone to be heated, and at the right of this table, the total annual consumption of the building for each energy service.

With regard to the table of consumptions (End Uses), it should be noted that the Heating section gives zero consumption due to the fact that the DB template used to model the BC1 and BC2 air-water pumps is not considered as an element of this category, but belongs to equipment intended to supply domestic hot water.

Analysing the End Uses table, we obtain the total consumption associated with the equipment in charge of heating, which will be the sum of the consumption of fans (belonging to the AHU's and the two incorporated in each of the two heat pumps BC1 and BC2), pumps (in this case there is only one, whose modelling has been specified in section 7.3.2.1), heat recovery (belonging to the AHU's) and water systems (associated with BC1 and BC2 due to the fact that they are classified as DHW suppliers).

This results in a total heating consumption of **124.603,51 kWh per year**.

This obtained consumption together with those achieved from interior lighting and interior equipment will be analysed together in comparison with the real consumptions in section 7.5 of the present document.

As regard the indoor thermal comfort, the comfort table, specifically in the red frame, shows the unsatisfied occupation hours of each thermal zone.

It is noteworthy the high number obtained in the Common Area of the ground floor with 432,25h (associated with the CL_Hall air conditioner), the 137 unsatisfied hours of the office 4.11 (together with the other two group zones of offices on the fourth floor), and a certain discomfort at specific moments in computer rooms 2.1 and 2.2 with 52.25 unsatisfied hours.

To show more graphically and comprehensively this information, the results obtained in two representative hours of the 4th of March are shown below.

As can be seen in the first image (Figure 70), corresponding to 8 o'clock in the morning, the AHU's are already working (with the exception of CL5) since one hour in order to reach the desired winter temperature of 20°C at 9 o'clock (the time when the students start to arrive).

In the second image (9am, Figure 71) the temperature of 20°C has been widely reached with the exemptions of the Common area of the ground floor and the Office 4.11 (the same situation is found for the rest of the offices of the 4th floor), which are respectively at 16,92°C and 18.87°C.

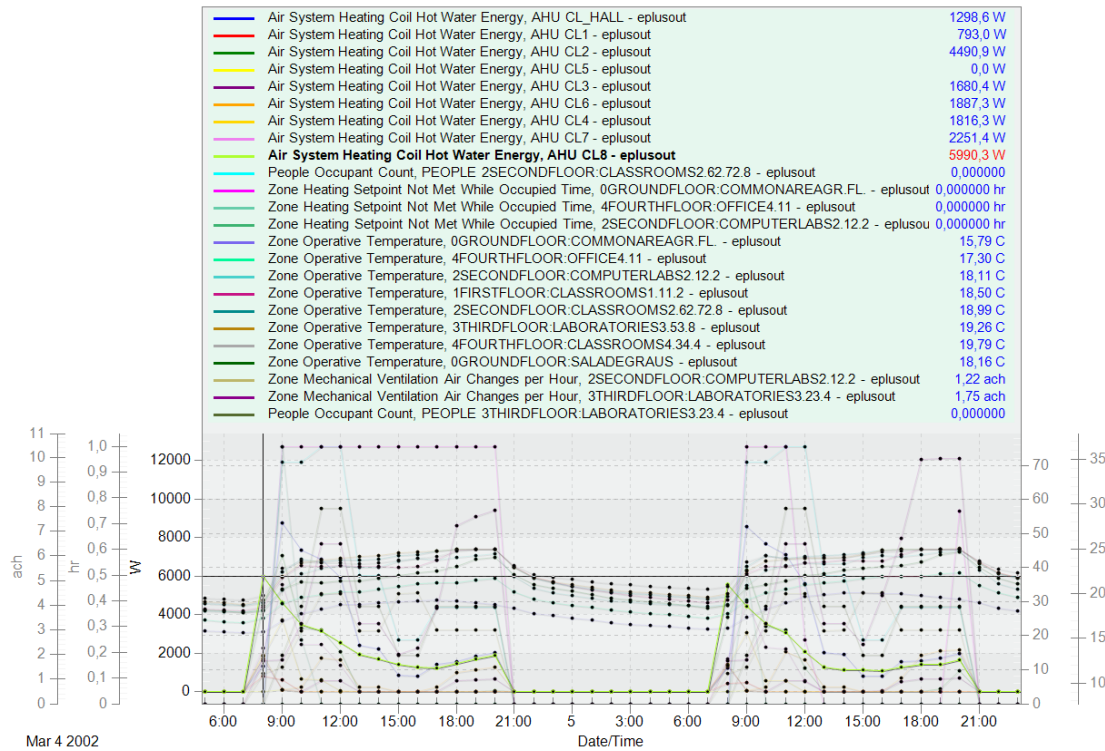


Figure 70: Obtained results on 4th March at 8 am

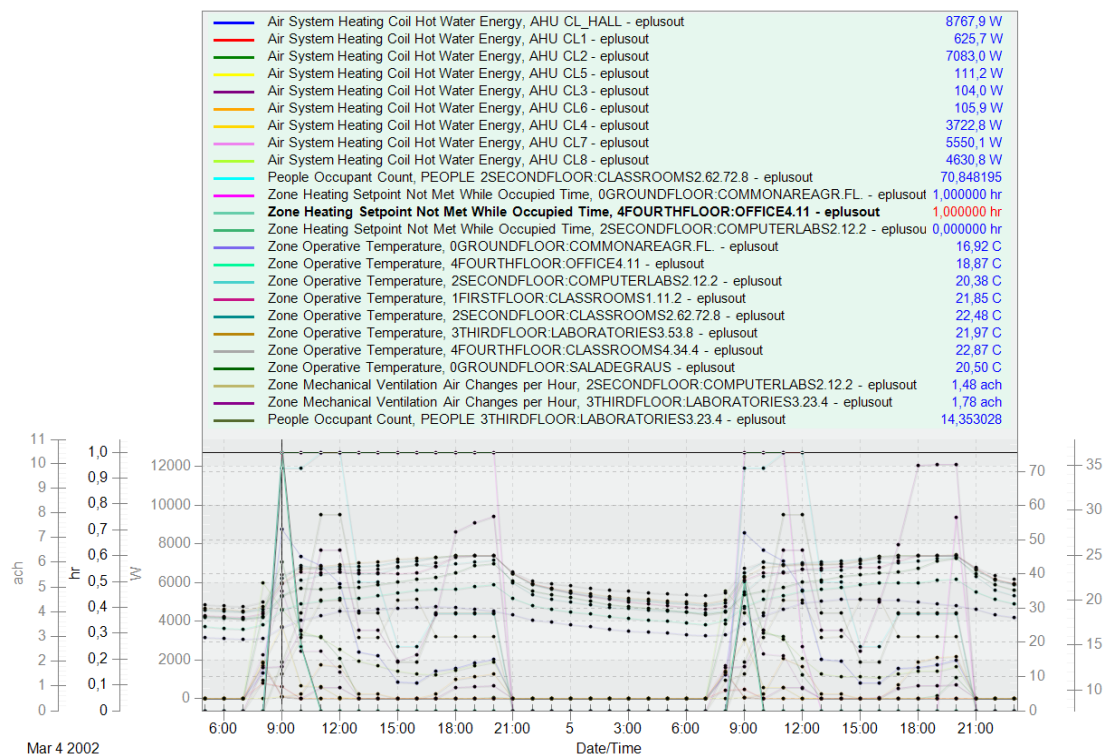


Figure 71: Obtained results on 4th March at 9 am

In the attached Annex, additional images of the following hours can be observed for this same day (point 3.1.1 of the Annex). In them, it is seen how it is not until the 12h of midday the required 20°C have not been reached in the offices, while the Common area remains below that temperature.

The rest of the air handling units in the following hours have been switched off (with the exception of CL_Hall, CL3 and CL6) since the desired comfort in their respective thermal zones has already been reached.

Analysing the images corresponding to December 16th, it can be seen how the same situation occurs in the first two hours previously mentioned (8h and 9h in the morning) in which the desired temperatures are reached in the great set of thermal zones excepting the same ones of March 4th.

Despite this, this situation can be considered not problematic especially in the case of the Common area of the ground floor. This is an area of transit in which no teaching activity is carried out and which therefore does not require the same thermal demands as the rest of zones. Furthermore, being in contact with the main entrance of the building, it is normal (and consistent with the reality of the Campus) that such temperatures are lower in those months.

Considering the scenario produced in the offices of the 4th floor, it is true that the desired level of comfort is not obtained in the early hours of the morning, a fact that may differ from reality. However, these are areas intended for the consulting of doubts between teachers and students, the use of which is more typical of midday hours and the afternoon when classes have already ended, periods in which the temperature of 20 ° C has already been reached.

The same fact can be seen in the last day attached at point 3.1.3 of the Annex document corresponding to the 17th of January.

Additionally, if the results are consulted through the EnergyPlus visualization tool (file to be consulted: *Results Aulari – Heating System.drs*), it can be observed the number of air changes per hour [ach] for each thermal zone by activating the option “Zone mechanical ventilation air changes per hour” to the zone that wants to be consulted.

In the results file mentioned above, the display of the air renovations in computer rooms 2.1 and 2.2, and of the set of laboratories 3.2, 3.3 and 3.4 have been activated. It can be seen how the value of air changes per hour fluctuates depending on the temperature and humidity conditions of the zone, also taking into account the occupation of that room.

7.4. Cooling system

The cooling system consists of the following elements:

- Air-Cooled Scroll Chiller with Heat Recovery RF-HR
- Air to Water Heat Pumps BC1 and BC2
- Heat Recovery Loop
- Air Handling Units AHU's (CL's)
- Zone Groups with the thermal zones associated to the corresponding AHU's.

7.4.1. Introduced simplifications and encountered limitations

7.4.1.1. BC1 and BC2 Heat Pumps (Cooling mode)

As mentioned in the previous point 7.3.1.1, the first encountered limitation in designing the cooling system was the fact that the air to water heat pumps available in DB do not have the option of supplying cold water to the collectors in charge of cooling.

It is for this reason that the first simplification that has had to be undertaken has been to reformulate the cooling part of BC1 and BC2 heat pumps as air-cooled chillers, since otherwise it would not have been possible to model them.

7.4.1.2. Air-cooled Chiller or Water-cooled Chiller RF-HR

Another important simplification that had to be carried out was regarding the RF-HR cooling tower. As widely described, it is an air-cooled scroll chiller with heat recovery and it is responsible for providing cold water to the cooling collectors and supplying hot water to the post-heating batteries (through the heat recovery).

However, DB does not offer the possibility to model the heat recovery part for an air-cooled chiller, but only for water-cooled chillers. From this point on, it has been decided to model RF-HR as a water-cooled chiller, otherwise it would have not been possible to design the heat recovery in conjunction with the VAV boxes.

The modelling of the cooling tower as a water-cooled type implies the incorporation of three other auxiliary elements that DB provides. These are: a condensation tower for the water-

cooled chiller, a hot water accumulation tank for the hot water generated through the heat recovery of RF-HR and finally a connection element between the chiller and the tank (called “HR connection loop” in the DB cooling file).

The simplification by changing not only the operation of the chiller but also the fact of incorporating three auxiliary elements, could produce important differences in the modelling with respect to reality.

For this purpose, simulations were carried out with the ground and first floors of the building with two models: on the one hand the cooling system equipped only with an air-cooled chiller, and on the other hand the finally chosen water-cooled chiller system with other auxiliary elements. Both of them associated to the AHU's CL_Hall and CL1.

As it can be seen on Figure 73 and Figure 74, BC1 and BC2 heat pumps have not been included in either system as the associated consumption of only these two AHUs did not exceed 60% of the RF-HR cooling capacity.

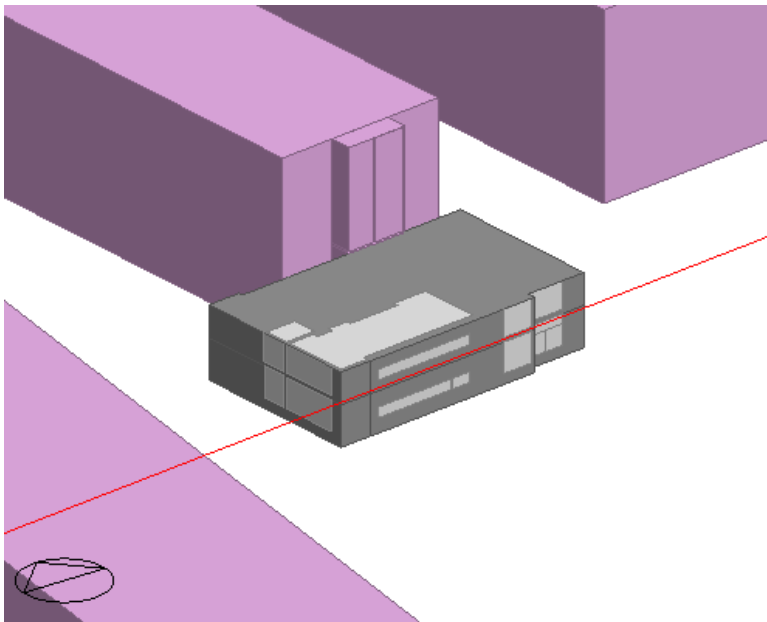


Figure 72: Used parts of the Campus for the study that was carried out

The aim of this study was to compare the conditioning of the air-conditioned thermal zones and the associated consumptions of the two sets of equipment.

In the case of the air-cooled chiller model, temperatures above the intended 25°C were obtained, while in the water-cooled chiller, despite the fact that certain time slots were produced with unsatisfied comfort (ASHRAE reference), the desired temperature and humidity values were achieved.

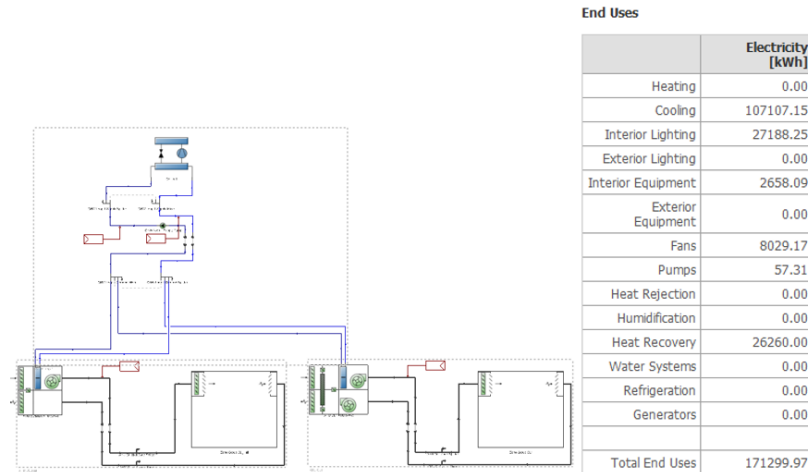


Figure 73: Air-cooled chiller model

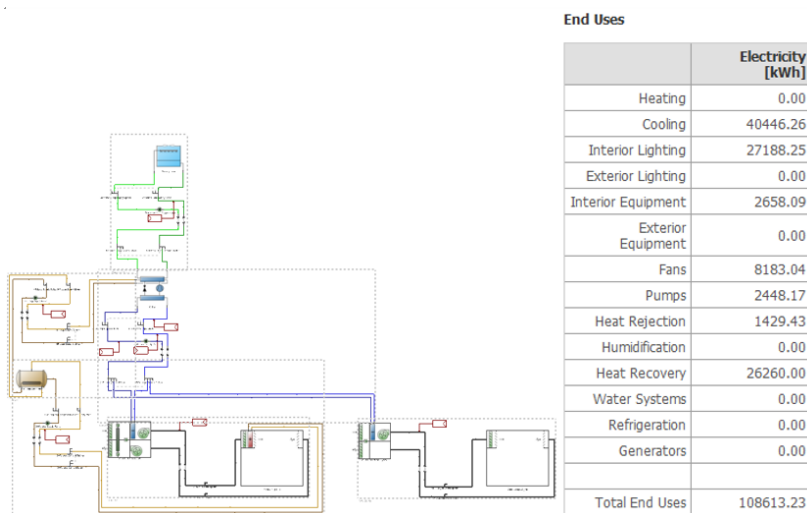


Figure 74: Water-cooled chiller model

On the other hand, the consumption associated with the air-cooled chiller was much higher than the one obtained only with the ground and 1st floors (107.110 kWh in front of the 40.450 kWh obtained in the water-cooled system). While the energy consumed by the auxiliary elements of the water-cooled did not produce a significant increase in cooling energy (just a rise of the pump consumption respect the air-cooled system of 2,40 kWh, the fans consumption was very similar).

It was for these reasons that it was decided to continue with the water-cooled chiller model.

7.4.1.3. Fan-coil units offices 4th Floor

It is produced the same problem occurred in the heating system with the incompatibility generated by DB to model the joint operation of the AHU CL8 and the fan-coils units.

In order to solve it, the same decision has been taken to assign the air conditioning and air renewal of the offices of the 4th floor to CL8.

7.4.1.4. Secondary BSF's Pumps

Identically to the designed heating system, the same limitation has occurred for BSF's secondary pumps, which could not be added to the HVAC scheme. Also equivalent (and opposite) to the heating system, the pertinent hot water coils have been removed from the AHU's.

7.4.2. Modelled system

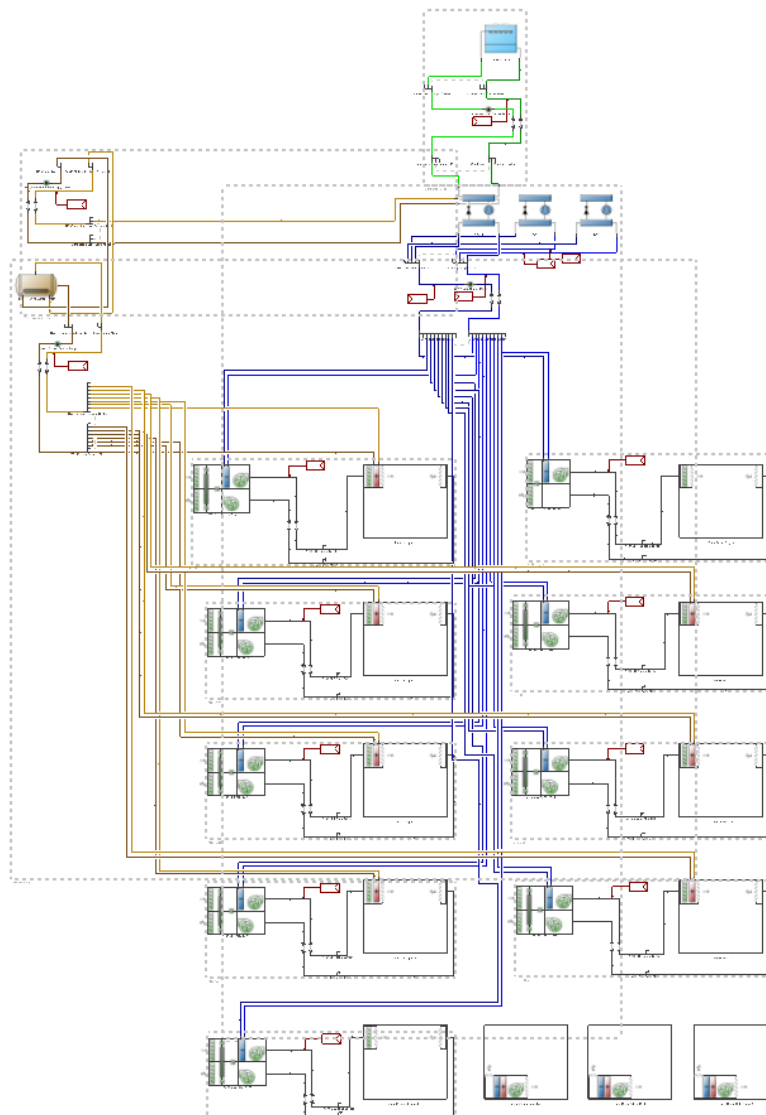


Figure 75: Final modelling of the cooling system

7.4.2.1. Air-Cooled Scroll Chiller with Heat Recovery RF-HR

Equivalent to the definition of heat pumps BC1 and 2, with the RF-HR cooling tower the same procedure has been followed using the curve fit tool to obtain the three performance curves.

These are the three applied performance curves:

- CAPFT: Cooling Capacity as a function of Temperature curve (Biquadratic)

$$\text{CAPFT} = 0,908867 + 0,041337x + 0,000228x^2 - 0,000022y - 0,000129y^2 + 0,000442xy$$

- EIRFT: Energy Input Ratio (EIR) as a function of Temperature curve (Biquadratic)

$$\text{EIRFT} = 0,73617 - 0,00869x + 0,00074x^2 - 0,00513y + 0,000643y^2 - 0,00065xy$$

- EIRPLR: EIR as a function of part load ratio curve (Cubic)

This last performance curve EIRPLR, on one hand, produced problems in the execution of simulations, and it was known beforehand since its creation that it was far from the correct functioning with respect to reality thanks to the value of R2 provided by Energy Plus (exactly 39.58, which compared to those obtained in the first two curves with values of 0,998, showed its defects).

For this reason, it was decided to select from the available EIRPLR performance curves in the DB libraries, the one corresponding to the equipment with the closest characteristics to RF-HR. The chosen model for this third curve has been the Carrier 30RB130 with a cooling capacity of 444.7 kW and a EER of 2.8.

The rest of the parameters belonging to the functioning of RF-HR were introduced from the technical specifications of such model (check point 2.1 of the Annex document).

7.4.2.2. Air to Water Heat Pumps BC1 and BC2 (Cooling Mode)

Following the same procedure explained in section 7.3.2.1, the following performance curves have been created:

$$\text{CAPFT} = 0,89976 + 0,028865x + 0,000287x^2 - 0,002748y - 0,000092y^2 - 0,000173xy$$

$$\text{EIRFT} = 0,837381 - 0,019838x + 0,001488x^2 + 0,003478y + 0,000712y^2 - 0,000898xy$$

And as in the other cases, the same problems have occurred with the third of them, choosing in this instance the one corresponding to the Carrier model 30RB100 with

336,5kW of cooling capacity and a EER of 2,8.

The rest of the parameters belonging to the functioning of BC1 and BC2 in cooling mode were introduced from the technical specifications of such model (see section 2.1 of the Annex document).

7.4.2.3. Heat Recovery Loop

In order to be able to incorporate the heat recovery from the RF-HR, two elements were necessary: an accumulation tank for the hot water generated and a connection loop between the water-cooled chiller RF-HR and the tank.

Equivalent to the heating system, simulations were carried out dimensioning the volume of the tank through “autosize” and with zero volume to check the effect produced.

Given that the obtained results of temperature and humidity and the consumptions of the AHU's and refrigeration equipment were kept constant, it was decided to model the tank with volume 0, supplying instantaneously the hot water generated towards the post-heating coils (as it really happens in the Campus).

7.4.2.4. Zone Groups

Defined as VAV reheat, in contrast to the heating system, post-heating batteries had to be defined.

To this end, in certain thermal zones in which more than one classroom, computer room, or set of laboratories are located, the volume of necessary air to be supplied for renovating and air conditioning has been multiplied depending on the number of englobed classrooms, as well as the heating powers of each of the coils included in said thermal zone have been added together.

7.4.3. Obtained Results

Once the HVAC system in charge of cooling has been modelled, the calibration process is carried out by adjusting different parameters until the results that most closely resemble the real annual consumption (which will be shown later at point 7.5) are obtained.

The set of obtained results from the hourly annual simulation can be viewed through the EnergyPlus results viewer in the attached file *Results Aulari – Cooling System.drs*.

For its analysis, the same criterion has been followed as in the heating system to evaluate the created model.

In this case, the reached values of unsatisfied hours to be cooled during occupation and the consumptions associated to the equipment in charge of air conditioning together with lighting and interior equipment are (check Figure 76):

Time Setpoint Not Met					End Uses	
	During Heating [hr]	During Cooling [hr]	During Occupied Heating [hr]	During Occupied Cooling [hr]		Electricity [kWh]
0GROUND FLOOR:COMMON AREAGR.FL.	3410.75	726.50	817.50	0.00	Heating	0.00
0GROUND FLOOR:SALADEGRAUS	1010.50	1426.25	14.25	2.00	Cooling	119952.32
0GROUND FLOOR:OFFICEGR.FL.	675.75	1271.25	46.50	0.00	Interior Lighting	238233.72
0GROUND FLOOR:RECEPTION	1651.75	755.00	140.75	0.00	Exterior Lighting	0.00
1FIRST FLOOR:CLASSROOMS1.11.2	832.50	1959.25	1.00	23.25	Interior Equipment	21072.29
1FIRST FLOOR:DATA RACKS X1 S TFL.	2972.25	2247.50	594.50	105.50	Exterior Equipment	0.00
2SECOND FLOOR:CLASSROOM2.1	2233.25	1519.75	52.50	0.00	Fans	57313.50
2SECOND FLOOR:COMPUTER LABS2.11.2	1601.50	1315.50	39.00	0.50	Pumps	7352.66
2SECOND FLOOR:CLASSROOMS2.22.32.4	947.25	2071.75	2.50	41.50	Heat Rejection	1841.96
2SECOND FLOOR:CLASSROOM2.5	613.75	2217.50	5.50	45.25	Humidification	0.00
2SECOND FLOOR:CLASSROOMS2.62.72.8	807.50	2007.50	4.50	7.75	Heat Recovery	20048.20
2SECOND FLOOR:COMPUTER LAB2.3	1147.50	1710.75	18.00	12.25	Water Systems	0.00
3THIRD FLOOR:LABORATORY3.1	1130.50	2242.75	16.25	31.50	Refrigeration	0.00
3THIRD FLOOR:LABORATORIES3.93.10	867.50	2119.00	23.00	5.25	Generators	0.00
3THIRD FLOOR:LABORATORIES3.23.4	832.50	2569.00	9.00	73.50	Total End Uses	465814.65
3THIRD FLOOR:LABORATORIES3.53.8	791.50	2467.75	13.25	23.50		
4FOURTH FLOOR:OFFICES4.14.2	1759.25	2089.75	211.50	26.25		
4FOURTH FLOOR:OFFICES4.34.10	1776.50	1864.00	180.00	12.50		
4FOURTH FLOOR:OFFICE4.11	2370.50	2005.75	369.75	57.25		
4FOURTH FLOOR:CLASSROOMS4.14.2	1339.50	2099.00	8.00	11.75		
4FOURTH FLOOR:CLASSROOMS4.34.4	713.25	2624.25	10.50	36.00		
4FOURTH FLOOR:DATA RACKS X4 THFL.	1125.25	3097.50	190.75	145.25		

Figure 76: Unsatisfied cooling hours during occupancy (red zone) and final electric consumptions of the cooling system

Firstly, analysing the final consumption table, it is observed that, as expected, the consumption values of lighting and interior equipment are the same as those obtained in the modelling of the heating system: **238.233,72 kWh per year of interior lighting** and **21.072,29 kWh per year of interior equipment**.

In second place, the total cooling consumption reached will be the sum of the rest of elements: cooling (own consumption of RF-HR, BC1 and BC2), Fans (associated to the AHU's and fan-coils of office ground floor and racks rooms), pumps (set of pumps in charge of pumping on one side the cold water towards AHU's and on the other those associated to the heat recovery loop), heat rejection and finally the heat recovery of the AHU's.

Adding together the aforementioned, it is obtained a **total annual consumption of cooling of 206.508,64 kWh**.

Going on to analyse the achieved comfort in the different air-conditioned thermal zones, it is highlighted the unsatisfied hours reached in the two rack rooms of the first and fourth floors (105 and 145 hours respectively) and those linked to the set of laboratories 3.2-3.3-3.4

(73.5 unsatisfied hours in a year).

Another important aspect to underline, which can be observed in the results file (file to be consulted: *Results Aulari – Cooling System.drs*), is the fact that it was not necessary to activate the cooling mode of the heat pump BC2 (on the other hand, the pump BC1 was activated on certain days of the year), therefore at no time (following the operating ranges explained in point 6.3.2.2 of this document) has been reached the 60% of the cooling capacity of BC1.

Equivalent to the previous analysis of the heating system, graphs of different representative days of how the cooling system works are shown below (both in this document and in the attached Annex).

In this case, the results of May 14th at 9 am and 11 am are shown (the following 4 pm and 8 pm of the same day can be found in the point 3.2.1 of the annex).

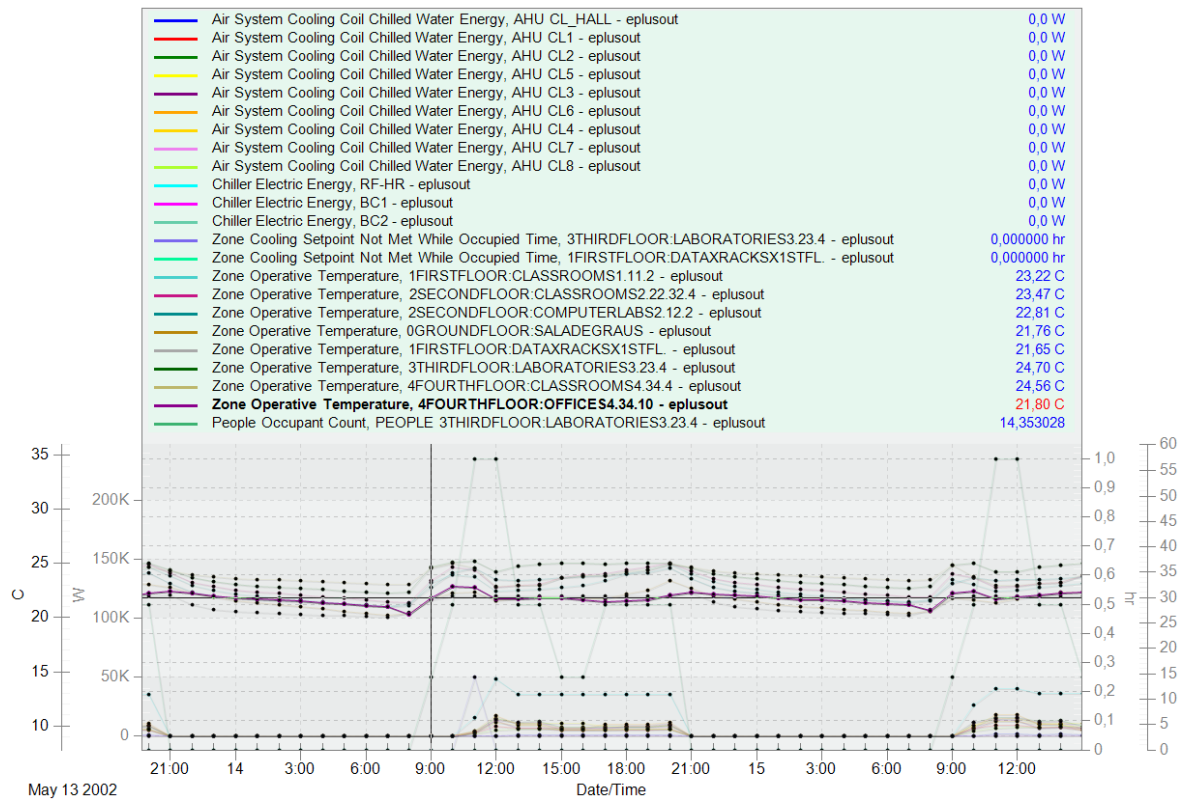


Figure 77: Obtained results on 14th May at 9 am

Firstly, it is observed that at nine o'clock in the morning none of the air handling units are activated, given that the temperatures of the thermal zones studied have not reached sufficient levels to start cooling.

However, it is from this hour that begins to increase the number of present students in all areas (especially in classrooms, computer rooms and laboratories), fact that produces the activation of the AHU's in order to renew the indoor air on one side, and secondarily, begin to cool these areas due to the heat released by the students.

The following image (Figure 78) reports the reached energy values in the cooling coils of the AHU's, needed to cool at 11h in the morning the shown spaces in order to not exceed the stipulated 25°C of comfort for the months in which the cooling should be used.

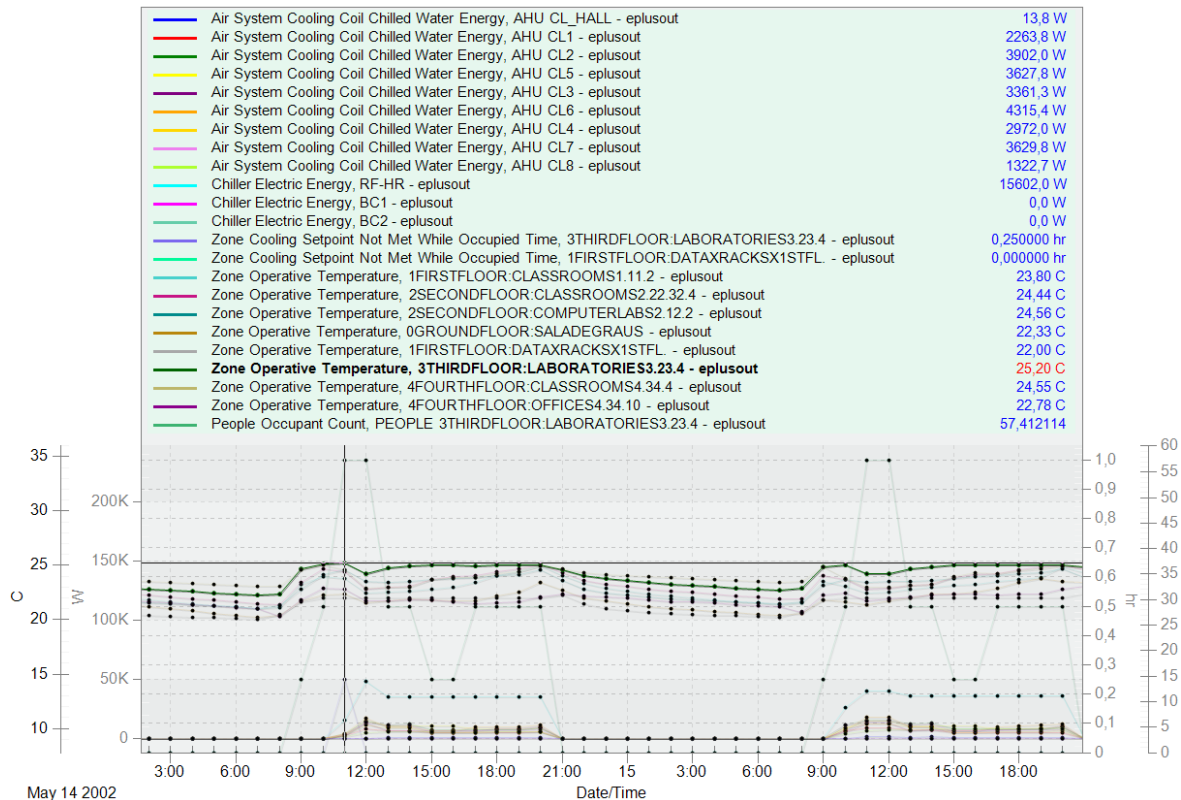


Figure 78: Obtained results on 14th May at 11 am

However, as can be seen in the image above (Figure 78), the AHU CL3 has not had enough cooling capacity to maintain the "comfort" considered by the ASHRAE model, although we would fit within the ranges described on section 7.2.1 of 25°C ± 1°C).

Analysing another day, looking at point 3.2.2 of the Annex document, there can be found the results of September 16th, a day in which it has been necessary the activation of heat pump BC1 (therefore 60% of the cooling capacity of the RF-HR unit has been reached). As can be seen in the operating temperature values, they have been maintained in the established range, respecting at the same time the comfort model AHSRAE.

The same situation can be observed on the next attached day in the Annex (point 3.2.3), in

which it was not necessary to activate the BC1 pump in cooling mode.

Additionally, another important aspect to be taken into account is the discomfort that has occurred in the racks rooms located on the first and fourth floors of the Campus.

This equipment is in constant operation and whose air-conditioning is of vital importance to ensure its correct development. This is why the fan-coils associated with each room have been stipulated with a set temperature of 22°C (below the 25°C marked as general comfort in the summer months).

It is for this reason that the ASHRAE model shows high hours of discomfort in this period of time. Although at certain moments the temperature may be as desired, if the humidity produces that the operating point "falls" outside the region considered as Comfort, DB would consider that time as unsatisfied.

However, if we look at the attached images (and also at the results file) the operating temperature of these zones (DataRacks1stFl and DataRacks4thFl.) it can be seen how the desired 22°C have been achieved.

Lastly, as in the analysis of the modelled heating system, if the results are consulted through the EnergyPlus visualization tool (file to be consulted: *Results Aulari – Cooling System.drs*), it can be observed the number of air changes per hour [ach] for each thermal zone by activating the option “Zone mechanical ventilation air changes per hour” to the zone that wants to be consulted.

7.5. Energy consumption comparison DB model – Reality Campus

Summarizing the total annual consumptions obtained through the created DB model, and comparing it with the real consumptions:

DB MODEL			REALITY		ABSOLUTE ERROR	RELATIVE ERROR
Use	Electricity [kWh]	Percentage [%]	Electricity [kWh]	Percentage [%]		
Heating	124.603,51	21,10	140.715,20	22,75	-11,45%	-1,65%

Cooling	206.508,64	34,98	215.486,10	34,85	-4,17%	+0,13%
Interior lighting	238.233,72	40,35	230.939,70	37,35	+3,16%	+3%
Interior equipment	21.072,29	3,57	31.203,90	5,05	-32,47%	-1,48%
Total	590.418,16	100%	618.344,90	100%	-4,516%	0%

Table 7: Energy consumption comparison

From the obtained values of absolute and relative error, on one side it can be observed how the biggest differences have been produced with the consumptions associated to heating (absolute error of 11,45%) and interior equipment (32,47%).

Concerning the difference reached in heating, it can be mainly due to the simplifications introduced in the modelling of the air to water heat pumps BC1 and BC2 in heating mode, the operation of which could not be represented in the most reliable way.

With regard to the absolute error obtained in the interior equipment, the occupancy schedules created for the computer rooms may not have been precisely adjusted to the current use that students make of them.

However, observing the achieved results of relative errors, it can be concluded that the calibration process has allowed to resemble to a great extent the representation percentages of the main uses of the Campus, and consequently the model created through Design Builder can be considered sufficiently robust and reliable to the reality for being able to extract valid conclusions through its results, which will be of great help for the improvement proposals.

8. Improvement Proposals

8.1. Introduction

Based on the analysis of the results obtained in the two modelled systems, together with the previous comparison between the overall energy consumption results of the DB model and reality, it was decided to present two proposals aimed at reducing these consumptions and increasing the energy efficiency of the studied building.

The first of these consists in the replacement of the current luminaire set of the building with LED type that will drastically reduce the installed power ensuring the same levels of current lumens.

The second proposal is of renewable nature and focuses on the same direction as the first. This is a complementary measure that, based on the new energy situation achieved through the application of the LED system, aims to further reduce the consumption associated with interior lighting.

It consists on using the outdoor space located in front of the TBS area on the 5th floor to locate a set of photovoltaic panels.

8.2. First proposal: Implementation of LED type luminaires

8.2.1. Current lighting system

The current lighting system will be described below in order to be able to compare the initial situation with the implementation of this first proposal.

The building as a whole is made up of 6 types of luminaires with different functionalities, these are the following:

1. Continuous strip fluorescent luminaire recessed in false ceiling 1x35W.
2. 70W bathtub type luminaire.
3. Sealed luminaire with diffuser with two fluorescent tubes of 36W (2x36W).
4. Fluorescent lamp of decorative mono-tube luminaire with anodised aluminium chassis with two fluorescent tubes of 58W (2x58W).

5. Fluorescent lamp of a decorative mono-tube luminaire with anodised aluminium chassis with a fluorescent tube of 36W (1x36W).
6. Decorative downlight with two fluorescent lamps of 26W (2x26W).

From point 4 of the Annex (page 75) can be found the plans of each one of the floors of the Campus with the corresponding described luminaries.

The current inventory by floor is attached to determine the total installed power:

8.2.1.1. Ground Floor:

Luminaire Type	Power [W]	Number of units	Installed Power [W]
1	35 (1x35W)	25	875
2	70	11	770
3	72 (2x36W)	20	1.440
4	116 (2x58W)	21	2.436
5	36 (1x36W)	5	180
6	52 (2x26W)	7	364
Total Gr. Fl.			6.065 W

Table 8: Ground floor installed power

8.2.1.2. First Floor:

Luminaire Type	Power [W]	Number of units	Installed Power [W]
1	35 (1x35W)	33	1.155
2	70	12	840
3	72 (2x36W)	6	432
4	116 (2x58W)	40	4.640
5	36 (1x36W)	3	108
6	52 (2x26W)	3	156
Total 1st Fl.			7.331 W

Table 9: First floor installed power

8.2.1.3. Second Floor:

Luminaire Type	Power [W]	Number of units	Installed Power [W]
1	35 (1x35W)	43	1.505
2	70	2	140
3	72 (2x36W)	4	288
4	116 (2x58W)	149	17.284
5	36 (1x36W)	50	1.800
6	52 (2x26W)	8	416
Total 2nd Fl.			21.433 W

Table 10: Second floor installed power

8.2.1.4. Third Floor:

Luminaire Type	Power [W]	Number of units	Installed Power [W]
1	35 (1x35W)	4	140
2	70	2	140
3	72 (2x36W)	4	288
4	116 (2x58W)	179	20.764
5	36 (1x36W)	43	1.548
6	52 (2x26W)	8	416
Total 3rd Fl.			23.296 W

Table 11: Third floor installed power

8.2.1.5. Fourth Floor and Fifth Floor

Luminaire Type	Power [W]	Number of units	Installed Power [W]
1	35 (1x35W)	20	700

2	70	2	140
3	72 (2x36W)	12 (4 th) + 32 (5 th)	3.168
4	116 (2x58W)	144	16.704
5	36 (1x36W)	55	1.980
6	52 (2x26W)	8	416
Total 4th + 5th Fl.			23.108 W

Table 12: Fourth and fifth floor installed power

Adding each of the total floor powers, it is obtained a total installed power of: **81.233 W**

8.2.2. Application of the proposal

From this point onwards, it has been searched through the ITEC (*Instituto de Tecnología de la Construcción de Catalunya* or Institute of Construction Technology of Catalonia), LED type luminaire models that allow achieving the same lighting characteristics as the current ones and at the same time reducing the installed power.

The ITEC is an independent non-profit-making organisation that carries out its work in the area of operations intended to further the progress of the construction sector in Catalonia.

They have established a price bank (called BEDEC) in which are established all the quotes that can be found in any construction project, which are very useful to have an official reference about which are the current prices of both materials and workmanship.

The investment budget for this first proposal is structured in 3 sections: replacement of interior lighting, safety and health, and waste management. No taxes have been incorporated in the current quotation.

1 INTERIOR LIGHTING						
Luminaire type	Unit	Concept	Units	Price	Total	
1		Replacement of continuous fluorescent strip luminaire recessed in a 1x35W false ceiling, at a height ≤ 3 m, by a linear aluminium recessed LED luminaire, with 18W power, 2500 lm luminous flux, IP44 protection, adjustable 1-10 V, surface mounted.				
			125,00	82,59 €	10.323,75 €	
2		Replacement of 70W bathtub type luminaire , at a height ≤ 3 m, with LED type stainless steel projector luminaire, 28 W luminaire power, 3500 lm luminous flux, IP44 protection, 1-10 V adjustable, surface mounted				
			29,00	66,07 €	1.916,09 €	
3		Replacement of sealed luminaire lamp with diffuser, plastic tub with 2 fluorescent tubes of 36 W (2x36W) , type T26/G13, rectangular, with polyester chassis, electronic ballast, IP-65, mounted suspended from the floor, by a LED type lamp of 28 W of power , 3200 lm of luminous flux, IP44 protection, adjustable 1-10 V. It includes cancellation of the reactance and the fluorescent tube primer.				
			80,00	107,35 €	8.587,92 €	
4		Replacement of fluorescent lamp of a decorative mono-tube luminaire with anodised aluminium chassis and metal louvre diffuser, with 2 fluorescent tubes T26/G13 of 58W (2x58W) , with electronic ballast, installed suspended, by a LED type lamp of 44 W luminaire power , 3700 lm luminous flux, IP44 protection, 1-10 V adjustable. It includes cancellation of the reactance and the fluorescent tube primer.				
			533,00	68,31 €	36.410,83 €	

5	Replacement of fluorescent lamp of a decorative mono-tube luminaire with anodised aluminium chassis and metal louvre diffuser, with 1 fluorescent tube T26/G13 of 36W (1x36W) , with electronic ballast, suspended, by a LED type lamp of 18 W of power , 2500 lm of luminous flux, IP44 protection, adjustable 1-10V. It includes cancellation of the reactance and the fluorescent tube primer.	156,00	52,70 €	8.220,98 €
6	Replacement of a decorative downlight type luminaire, with 2 fluorescent lamps of 26 W (2x26W) in horizontal position, with ferromagnetic ballast, G-24-d3 lamp holder, with a recessed diameter of 160 to 200 mm and a height of up to 85 mm, recessed in the ceiling, by a decorative downlight LED recessed luminaire with a useful life of 50000 h, circular shape, 19 W power , specular aluminium optics with UGR =19, luminous efficacy of 60 lm/W, with non-adjustable electrical equipment, insulation class II, aluminium and transparent glass body and IP54 degree of protection, recessed.	34,00	198,58 €	6.751,72 €
TOTAL INTERIOR LIGHTING				72.211,29 €

2 SAFETY AND HEALTH					
Ref.	Unit	Concept	Units	Price	Total
		Application of the safety and health plan in the worksite, according to the safety and health study of the project and current regulations.	1,00	1.444,23 €	1.444,23 €
TOTAL SAFETY AND SECURITY					1.444,23 €

3 WASTE MANAGEMENT					
	Unit	Concept	Units	Price	Total
		Implementation of the waste management study	1,00	1.500,00 €	1.500,00 €
TOTAL WASTE MANAGEMENT					1.500,00 €



MATERIAL EXECUTION BUDGET..... 75.155,52 €

INVESTMENT OF PROPOSAL 1 TO REDUCE ELECTRIC CONSUMPTIONS ASSOCIATED WITH INTERIOR LIGHTING

Ref.	Unit	Concept	Price	Percentage
		INTERIOR LIGHTING	72.211,29 €	96,08%
		SAFETY AND HEALTH	1.444,23 €	1,92%
		WASTE MANAGEMENT	1.500,00 €	2,00%
MATERIAL EXECUTION BUDGET.....			75.155,52 €	100,00%
Useful building area			4.554,00 m².	
Investment cost / m² of useful area			16,50 € /m².	

Luminaire type	Current Power [W]	LED Power [W]	% Power reduction
1	35 (1x35W)	18	-48,57%
2	70	28	-60%
3	72 (2x36W)	28	-61,11%
4	116 (2x58W)	44	-62,07%
5	36 (1x36W)	18	-50%
6	52 (2x26W)	19	-63,46%

Floor	Current installed power [W]	LED installed power [W]
Ground Fl.	6.065	2.465
1 st Fl.	7.331	2.801
2 nd Fl.	21.433	8.550
3 rd Fl.	23.296	9.042
4 th Fl.	20.804	8.230
5 th Fl.	2.304	896
Total	81.233 W	31.984 W

Table 13: Obtained results after applying Proposal 1

Applying the value obtained through DB of annual consumption of interior lighting, and knowing the price per kWh that currently exists in the Spanish state (0,1246 €/kWh), the necessary years to amortize the proposed investment are then calculated as follows:

	Current situation	After applying Proposal 1
Installed Power [W]	81.233	31.984
Interior lighting consumption [kWh]	238.233,72	93.800,15
Cost per year [€]	29.683,92	11.687,50

Table 14: Cost per year after applying Proposal 1

As a result, an annual saving in electricity associated with interior lighting of **17.996,42 euros** is achieved. If we divide the total material execution budget of 75.155,52€ between the 17.996,42€ of annual saving, we obtain an amortizing period of the initial investment of **4,18 years** (considering the used kWh price as constant during this period of time)

8.3. Second proposal: Implementation of Photovoltaic Panels

The application of this second proposal has been considered on the basis of the new situation achieved from the replacement of current luminaires by the LED type models described in the previous section.

For this reason, the calculations shown below have been made based on the consumption that would be achieved with the new LED lighting system.

The calculations of the proposed photovoltaic installation have been carried out following the established method by the Institut Català de l'Energia (Catalan Energy Institute, a public entity of the Generalitat de Catalunya) specified in booklet 4 (Photovoltaic solar energy) of the collection of technical documentation provided by the said institution.

Initially it is necessary to calculate the necessary energy that must be produced from the annual consumption obtained once the substitution of the luminaires has been applied. This will be divided by the overall performance of the installation which is considered to be 85%.

Considering 313 days/year to be covered by the LED luminaires, having a yearly consume of 93.800,15 kWh (check Table 14 of the last page), the daily consumption would be 299,681 kWh/day:

$$\text{Needed Energy} = \frac{\text{Expected daily consumption}}{\text{Overall efficiency}} = \frac{299,681 \text{ kWh/day}}{0,85} = 352,566 \text{ kWh/day}$$

Next, the global daily solar radiation incident on inclined surfaces of the studied area [MJ/(m²*day)] must be calculated. To do this, the values indicated in the Atlas of Solar Radiation of Catalonia will be used, specifically for the municipality of Barcelona.

At point 5.1 of the Annex the table of the Atlas is attached with the indicated value that has been used. Considering an inclination of 30° for the PV (Photovoltaic) panels and an orientation of 0° with respect to the South (the following table is for orientations of 30°, in the case of the studied panels if they were put in the same orientation that the building would be to 7° with respect to the South), it is obtained a global daily solar radiation of 17,65 MJ/(m²*day), which in other units is 4,7655 kWh/(m²*day).

Once the incident solar radiation in kWh/(m²*day) is known, it will be divided by the standard radiation power used to calibrate the PV modules (1 kW/m²), thus obtaining the equivalent amount of PSH (peak sun hours) or equivalent number of hours at nominal power.

$$PSH = \frac{\text{Incident solar radiation}}{\text{Standard calibration power}} = \frac{4,7655 \text{ kWh}/(\text{m}^2 \cdot \text{day})}{1 \text{ kW}/\text{m}^2} = 4,7655 \text{ h/day}$$

The number of PV modules required is then calculated as follows:

$$\text{Number of needed PV panels} = \frac{\text{Needed Energy } [Wh/\text{day}]}{\text{Module peak power } [Wp] \times \eta_{\text{field}} \times \text{Solar radiation } [PSH/\text{day}]}$$

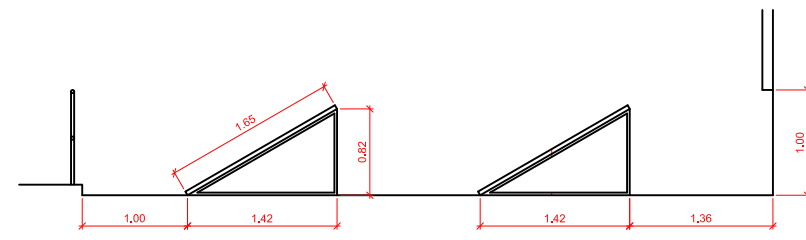
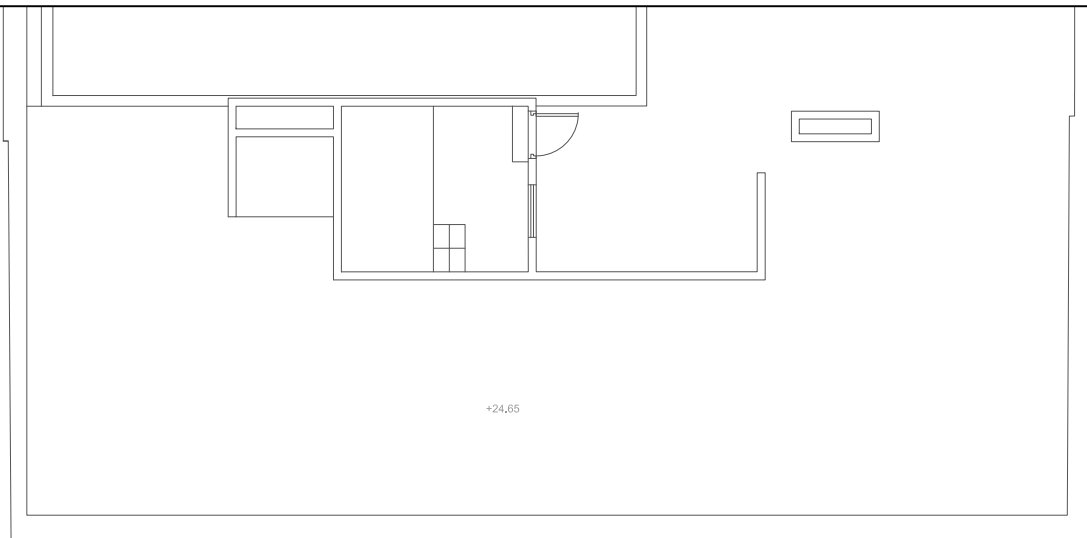
$$\text{Number of needed PV panels} = \frac{352.565,86 \text{ Wh/day}}{280 \text{ Wp}/\text{module} \times 0,8189 \times 4,7655 \text{ h/day}} = 323 \text{ PV panels}$$

The chosen model has been the CS6K-280P of the CanadianSolar brand (the technical specifications can be found at point 5 of the Annex). With this, the peak power is 208W per module and the field performance includes the losses due to the dirt of the modules and the negative effects produced by the fact of using connected panels which, due to the manufacturing processes, are not exactly of the same power.

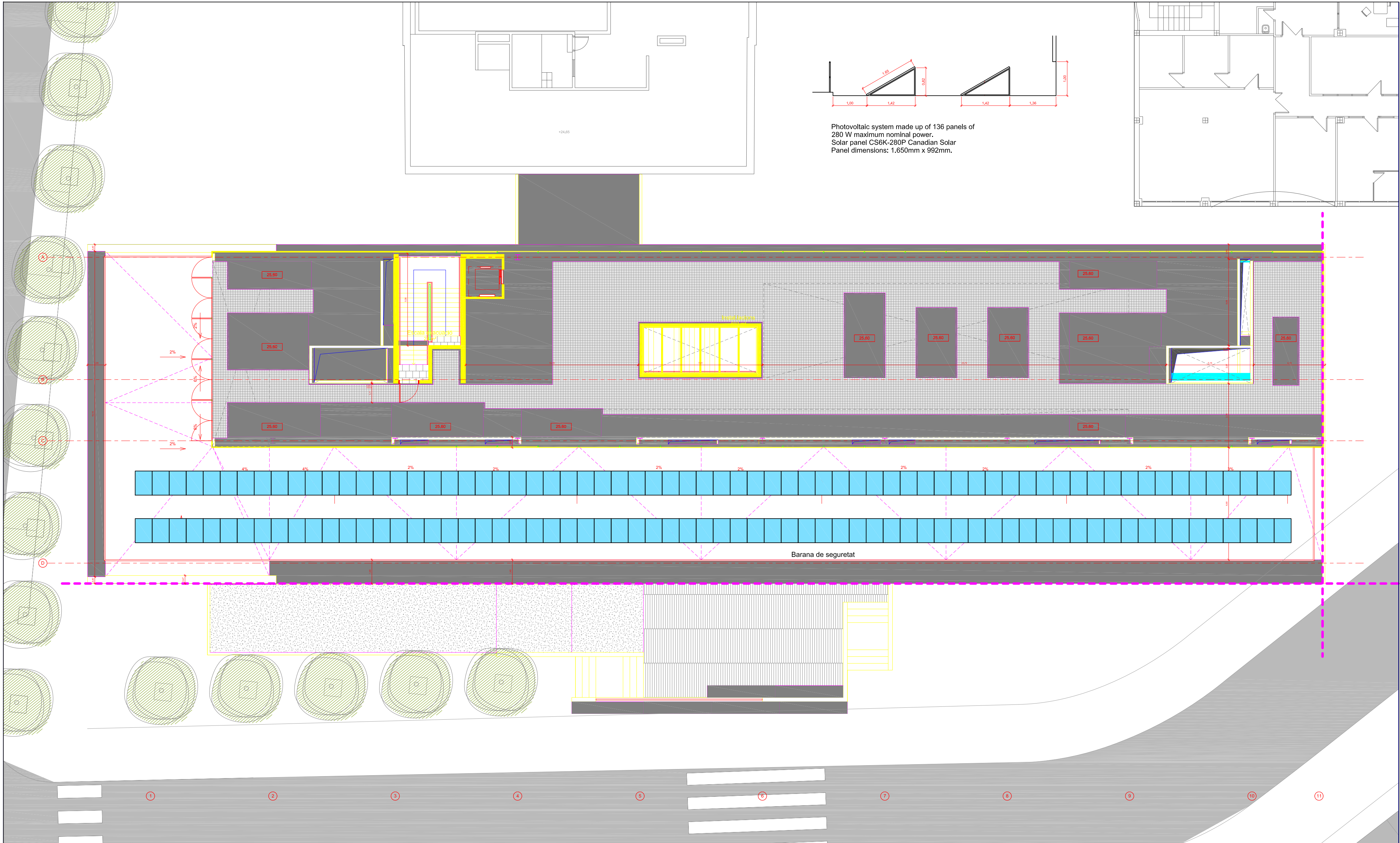
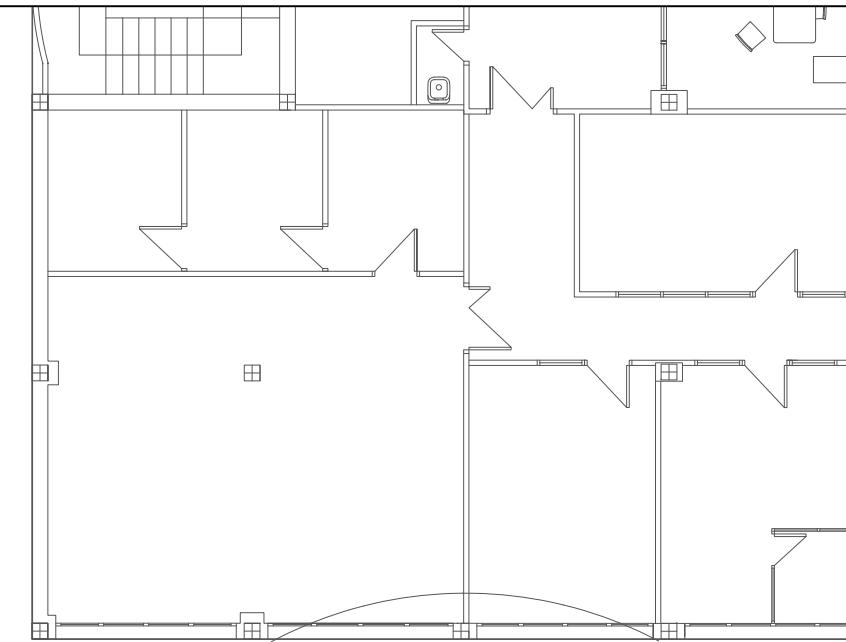
With it, the dimensions of each one of them are known and it is possible to determine from the available surface of the roof of the 5th floor (the zone located outside in front of the TBS, check) the maximum number of panels that can be implemented, which will be of **136 PV panels (which represents the 42,105% of the needed PV panels to cover all the current lighting consumption)**.

Since the objective is to reduce to the maximum the consumption associated with interior lighting, it has been decided to implement this number of panels.

On the following two pages we find, first of all, the plan of the fifth floor with the distribution of the PV panels once installed, and on the following page there is attached the material execution budget of the proposal.



Photovoltaic system made up of 136 panels of 280 W maximum nominal power.
Solar panel CS6K-280P Canadian Solar
Panel dimensions: 1.650mm x 992mm.



2 PHOTOVOLTAIC SYSTEM				
Ref.	Concept	Units	Price	Total
01/01	Installation of PV system with dynamic power control, maximum total nominal power 38,080 Wp, formed by a set of 136 photovoltaic modules CS6K-280P Canadian Solar's of 280 Wp of unitary power with an energy efficiency higher than 17.11%. Made of polycrystalline, mechanically fixed on aluminium structure. Catchment area of 222,6 m ² . Including 2 three-phase 400V output inverters with a unit power of 15 kW and an efficiency of more than 96,5%. Total output power 38.000W. DC protections with fuses and surge protector together with AC protections with magneto-thermal and differential switch. Includes a control and monitoring system with network analyser. Placed on the flat roof of the 5 th floor.	1,00	44.212,85 €	44.212,85 €
01/02	Inverter for grid-connected photovoltaic system, three-phase. Nominal input power 60.000 W. Nominal output power 54.000 W. Nominal input voltage 230 V. Maximum efficiency from 95 to 95,5%. Protection degree IP-20 placed.	2,00	17.952,15 €	35.904,30 €
01/03	Stationary battery kit for photovoltaic installation of 48 V, with 24 stationary battery modules for photovoltaic installation OPzV type. With gel electrolyte. Nominal voltage 2V and 3500 Ah C100. Hermetic and free of maintenance. Positive tubular electrode. ABS body. High stability to charge and discharge cycles, installed with the pertinent connectors between the coils.	1,00	25.624,56 €	25.624,56 €
TOTAL PHOTOVOLTAIC SYSTEM				105.741,71 €
3 SAFETY AND HEALTH				
Ref.	Concept	Units	Price	Total
02/01	Application of the safety and health plan in the worksite, according to the safety and health study of the project and current regulations.	1,00	2.114,83 €	2.114,83 €

TOTAL SAFETY AND HEALTH 2.114,83 €

INVESTMENT OF PROPOSAL 2 TO REDUCE ELECTRIC CONSUMPTIONS ASSOCIATED WITH INTERIOR LIGHTING

Ref.	Concept	Total Cost	Percentage
01	PHOTOVOLTAIC SYSTEM	105.741,71 €	98,04%
02	SAFETY AND HEALTH	2.114,83 €	1,96%
MATERIAL EXECUTION BUDGET.....		107.856,54 €	100,00%
	Useful building area	4.554,00 m².	
	Investment cost / m2 of useful area	23,68 €/m²	

With the 136 PV panels installed, an annual energy saving of **39.494,8 kWh/year** is obtained. Applying the same price per kWh used in the first proposal of 0,1246€/kWh, an **annual saving of 4.921,05 €** is obtained.

Therefore, the initial investment (considering constant the Spanish electricity price during this period) would be amortized after **21,92 years** (obtained dividing the total material execution budget of 107.856,54€ between the 4.921,05€ of annual saving).

Initially it can be considered an investment not as economically viable as in proposal 1 (which was amortized in only 4 years), in spite of it, in Spain the price of electricity has increased in the last ten years by 76% (data extracted from a study carried out by FACUA (Spanish Consumers Association) made on more than 50.000 occupied houses, from which it can be concluded that the average Spanish user has paid in the last 12 months 400€ more than what he paid in 2005), reason why considering the electricity price constant is the most conservative position to be adopted.

If prices continue to increase with the current trend, the profitability of this proposal will be improved, giving greater consistency to its application. Additionally, the chosen model for the PV panels has a 25 year guarantee

The following results are therefore achieved through the implementation of this proposal:

	After applying Proposal 1	After applying Proposal 2
Interior lighting consumption [kWh/year]	93.800,15	54.305,35
Cost per year [€]	11.687,50	6.766,45

Table 15: Obtained results after applying Proposal 2

8.4. Improvement proposals conclusions

From this point on, the reader may wonder why no other type of improvement measures have been considered that would allow to reach the same results, and instead it is given so much importance to reduce the energy consumption associated with lighting.

This other type of measures could be focused on improving the thermal envelope of the building, such as: improving the insulation of the east façade, which is the enclosure that offers higher thermal transmittance, or changing the current glass for others that provide greater insulation with respect to the exterior.

However, being a recently constructed building (it only has 6 years since its inauguration) whose envelope both from the point of view of enclosures and glazing was designed at the time with appropriate criteria, make it very difficult to find weaknesses in this field that can be improved.

In addition, if such improvements were applied to the building, its high price would not be profitable until long term, giving an annual energy benefit compared to the initial investment well below the desired.

On the other hand, improvements regarding the current technical building system have been considered. However, the robustness offered by the studied system, the structure with which it was designed and the elements that compose it (centralized and automated management system, heat recovery in the cooling tower, equipment of high economic value with little antiquity, presence of post-heating batteries in the thermal zones, use of lighting control in classrooms,...) increase the difficulty for finding efficient measures from the energetic point of view but above all economic that could improve the current TBS.

Continuing with the previous reasoning, it is important to highlight the information provided by the created model. The obtained results from DB simulations in both heating and cooling systems, confirm the efficiency and the proper functioning of the technical building system.

These are the reasons that led the author to decide to present these two proposals focused on the reduction of electricity consumption associated with interior lighting, an objective that has been satisfactorily met with a decrease of the initial consumption of **183.928,37 kWh**, going from **238.233,72 kWh** per year to an annual consumption of **54.305,35 kWh**, which represents a **reduction of 70,47% (interior lighting)**.

Analysing the total consumption values, the initial **590.418,16 kWh** would be reduced to **406.489,79 kWh**, a **reduction of 31,15%**.

9. Conclusions

In this thesis, the Health Sciences Campus of the University of Barcelona has been analysed from an energy and constructive point of view. In order to carry out this analysis, the building was modelled using the software Design Builder.

Such tool has provided sufficiently solid energetic results in comparison with the real consumptions of the building, a fact that allow us to draw the following conclusions.

The studied building is equipped with a technical building system that has the sufficient capacity and flexibility to maintain all the thermal zones of educational use under the conditions of temperature and humidity intended both in summer and winter periods.

On the other hand, the building is composed of a thermal enclosure that allows it to maintain the desired comfort conditions in periods of the year in which the use of the climate equipment is not that necessary.

However, based on the obtained results through annual hourly simulations, it has been verified the large consumption associated with interior lighting. Despite having light control sensors in the main thermal zones (teaching areas, computer rooms and laboratories), the annual lighting energy consumptions are equal to 230.939,7 kWh (238.233,72 kWh in the DB model once the calibration process has been completed).

Based on this fact, it has been decided to propose two measures aimed at reducing this consumption. The first of them consisted of replacing the current lighting system (based mainly on the use of fluorescents) with a LED type system that would drastically reduce the installed power, maintaining the required illumination levels.

The application of this proposal would reduce annual consumption to 93.800,15 kWh (taking as a reference the obtained value of DB, because the number of hours in which each type of installed luminaire was turned on was unknown), generating an annual energy saving of 144.433,57 kWh.

In addition, a second proposal was presented which sought to deepen this reduction. To this end, the implementation of 136 PV modules has been proposed for the external area of the roof of the 5th floor, the instalment of which would allow decreasing the 93.800,15 kWh reached in the first situation to 54.305,35 kWh. This set of measures would decrease the overall consumption of the building by 31,15%.

With the achievement of these values, it can be considered that the main objective of the thesis has been reached, which was to carry out an energy audit and generate viable improvement proposals that would allow the building to increase its energy efficiency.

On the other hand, a secondary objective was to learn using a tool initially new for the author, Design Builder. Despite the difficulties encountered during its learning, and the limitations that has produced in its modelling (especially in the HVAC system) it is considered a very useful tool for the construction sector that allows detailed modelling that can become very helpful for future applications.

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Finally, thanks to my family and friends for their unconditional support.

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