USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

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OPERE

OPERACIÓN EFICIENTE DE REDES DE ENERGÍA

Implementation of Energy Management Systems in Electric and Thermal Grids

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Chapter 1

Preface

Pollutant emissions production associated with electric and thermal generation in large consumption centres represents an environmental problem. Proper management along with energy efficiency and responsible consumption are the solution to this problem.

According to European Directive 2010/31/EU on energy efficiency in buildings, 40% of total energy consumption in the EU corresponds to buildings and this percentage is increasing since the sector is on expansion. Therefore, reduction of energy consumption and use of energy from renewable sources in the building sector are an important part of the necessary measures to reduce emissions of greenhouse gases. This directive also shows that:

— It is necessary to lay down more concrete actions to leverage the huge potential for energy savings in buildings.

— Measures to further improve the energy efficiency of buildings should take into account climatic conditions and local peculiarities, as well as indoor climate environment and profitability in terms of cost - effectiveness.

OPERE project arises with the aim of introducing efficient management systems, both thermal and electrical energy networks, in existing complexes with large energy consumption in order to reduce the environmental impact of this type of buildings. It is intended to prove its viability through the implementation of an energy management project in some of the great facilities that the University of Santiago de Compostela has in Campus Vida.

OPERE is a joint Project that lasted for three years. University of Santiago is the prime mover and it formed a consortium with EnergyLab, Energy Efficiency and Sustainability Technological Center, whose mission involves identification, developing, promoting and spreading technologies, processes, products and consumption habits contributing to the improvement of energy efficiency and sustainability through its applications in the industry, household products, transport and building..

The University of Santiago de Compostela, with more than five hundred year of existence, is an institution which gives its knowledge and leadership in the academic, research, technology and management scopes at the service of the society. It is constituted by two campus placed in two of the main cities in Galicia: Santiago

de Compostela and Lugo. Every year the University has around 30,000 students, more than 2,000 teachers as well as the management staff, consisting of about 1,200 people.

The technological and research offer of the University is distributed within the variety of centres, departments and research groups funded for such purpose, many of whom have been involved within OPERE project. The Human Resources team at the USC involved in the project consists, mainly of researchers at the Technological Research Institute, researchers at the Centre for Research in Information Technology, Technical Infrastructure Area, Technical unit of energy and sustainability, Staff of the Vice Rector for Research and Innovation and employees hired specifically for the project.

Figure 1.1 Third panel of experts LifeOpere.

OPERE project has as main objective to set efficient management systems in energy networks, both thermal and electrical, in existing installations with large energy consumption. OPERE project aims to optimize thermal and electrical energy management of the installations that the University of Santiago de Compostela has in Campus Vida, so that with proper management and optimization of installations both the environmental impact associated with large energy consumption of the USC and its costs can be reduced.

1.1. MAIN EXPECTED RESULTS

The expected results of the Project are the following:

- Getting a modular and easy replicable energy networks management system to be implemented as an energy optimization action in other energy intensive centres different to the current project.
- 30% Reduction in energy consumption associated with thermal generation.
- 35% Reduction in the production of polluting emissions associated with the electrical and thermal generation.
- Getting a 35% in economic savings, which will allow to obtain an analysis of profitability in energy networks management systems implemented in other energy intensive centres different to the current project.
- Reaching the main stakeholders after project implementation and execution in order to get a socioeconomic and environmental relevant impact.

This publication includes the results obtained during a total period of three years when the Project was implemented. These results come from the development of every project's phase which has been driven by all the project participants.

Chapter 2

Energy Assessment in OPERE Complex

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This chapter contains the description of an energy diagnosis process in an already existing building complex customized to OPERE complex. Activities described in it, are included in the preparatory action of the project.

2.1 ENERGY DIAGNOSIS AS PART OF AN ENERGY AUDIT

Energy diagnostic is an activity framed in the energy audit process in buildings. According to the RD 56/2016 February 12th, an energy audit can be defined as a systematic process aimed to obtain an adequate knowledge about the existing energy consumption in a building or group of buildings, with the purpose of determining and quantifying the energy saving possibilities with an effective cost.

The diagnosis or energy analysis tries to capture a closer image to the real consumption profile in a building, to identify and study the improving proposals concerning the reduction of the energy consumption

This way, the next pages will explain the works made into OPERE Project during the first four phases following the framework below,

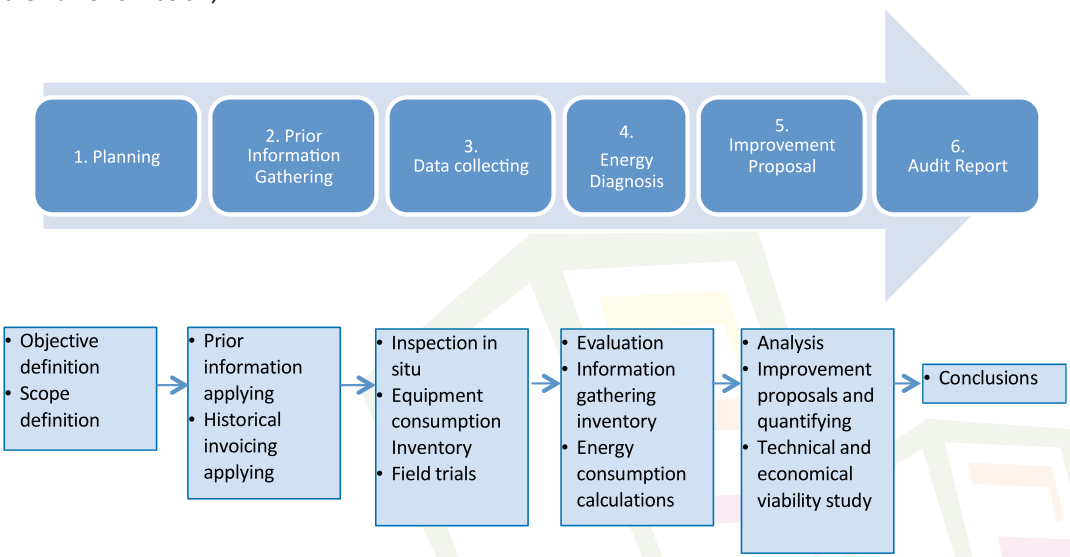

Figure 2.1. Energy diagnosis as a part of the energetic audit.

2.2 OBJECTIVE AND SCOPE DEFINITION

The first step to approach this type of projects is to fix the objectives the energy diagnosis pursues, since these may condition significantly the methodology. In this case, the energy diagnosis objective in OPERE complex materializes in:

— OPERE Complex system Characterisation

— OPERE Building complex constructive characterisation.

— Uses and Users

This action must be aligned with the project global objectives which are the next ones:

- 30% reduction of the energy consumption associated to thermal generation
- 35% reduction of the pollutant emissions associated to thermal and electrical generation
- 35%Reductión in operating cost

For this and in the energy diagnosis, factors affecting the energy demand and operation cost inside OPERE, have been analysed, among them:

- Thermal behaviour in the building.
- Building climate control.
- Flow distribution networks.
- Heater and heat exchange elements.
- HDW production, accumulation and distribution.
- Electric production.
- Electric system, from the beginning and/or transformation till its internal distribution.
- Indoor and outdoor lighting, as well as the possible natural sunlight use.
- Electric engines and its regulations.
- Electric generation groups, capacitor battery.
- Uses and users.

In the energy diagnosis scope equipment cataloguing and distribution systems till the service level and/or floor is established as an objective

2.3 PRIOR INFORMATION GATHERING

Once the objectives, established, the study of the building is addressed to the gathering of the information available. This highly varying in quantity and quality according to each case.

The data collection is an iterative process that starts with prior information gathering of the building. Once this information is analysed, the fieldwork and the on-site data collecting, which will be later analysed to make possible proposals of improving, are planned..

Figure 2.2. Data collecting process in energy diagnosis.

The characterisation works in OPERE complex were started with an initial gathering of the documents available about the buildings within the Complex. With this aim, all documents available about electric infrastructures and climatisation of the building were gathered together with the Technical office from the USC; remarking:

- System plans
- Building original project and Thermal systems
- Scheme of the climatisation principle in the systems and HDW
- Monthly maintenance reports and thermal performance certificates of cogeneration boilers.
- Historic consumption memory. Gasoil, natural gas and electricity
- Invoices and energy costs.

2.4 ON-SITE DATA GATHERING

Information gathered previously is extended to presence data collecting by technical visits made by the technical team. When doing the visit to our facilities, it is necessary to be aware of details and conditions in which systems are because it might motivate an improvement proposal. Among other aspects, fieldwork must allow:

- To make sure each system in the building achieves a suitable service level room temperature, HDW temperature, illuminance level, etc.
- To notice if there are design or execution errors in system or building implementation.

— To check equipment date back, especially those which have a remarkable energy consumption.

— To analyse the maintenance conditions of the systems

— To look for leakage presence, bottlenecks, corrosions, envelope moisture.

During this phase, a presence review of the main systems in the building:

I. Outside enclosure inspection, glazed enclosures inspection, skylights inspection, thermography analysis in outside enclosures

Figure 2.3. Enclosure and glazing thermography details, OPERE Complex.

II. Overall building inspection, a main intake, capacitor bank transformation center, uninterruptible power supply system, generator groups.

Figure 2.4. OPERE Complex electric installations detail.

III. Inspection of cogeneration systems , cogeneration circuits, thermal generation units, pumping groups, control cabinets and monitoring systems, …

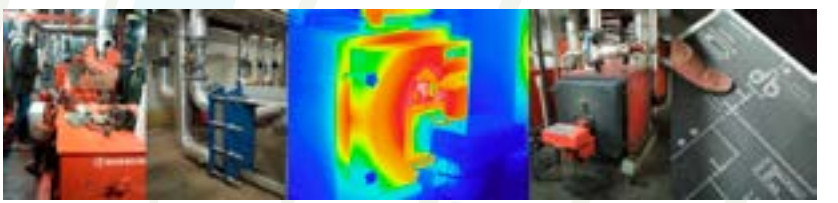

Figure 2.5. OPERE Complex thermal installations detail.

2.4.1 FIELDWORK VERIFICATION

Data collecting in situ goes with a series of an especial measurement campaign. These verifications allow to analyse the OPERE complex thermal and energy performance, as well as document data collecting validation.

The fieldwork carried out has been the next:

- Thermographic generation and heat distribution equipment, enclosures and electric systems verification.
- Temperature floating in the complex verification.
- DHW accumulation tanks loss verification.
- Enclosure thermal transmittance characterisacion verification.
- Heating spectrum flow and HDW circuits verification.

2.4.2 USES AND USERS HABITS SURVEY

In order to analyse users' habits in OPERE complex, an interview campaign to managers and users in the different buildings of the complex is made.

The surveyed users' typology has been as follows:

- Working staff
- Students
- Residents

Question categories included in surveys and interviews are summarised in the following chart:

Use Habits		
Building	Time of use	Frequency
Installations		
Illumination:		
Natural illumination	Artificial illumination	
Climatization:		
Comfort conditions in summer	Thermal conditions in winter	Air stream and other problems
Interior Ambient quality		
Acustic Level (Noises)	Smells and Air quiality	Other pathologies

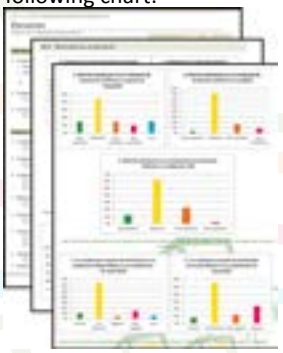

Table 2.1. Uses and users enquiry. Type of questions.

2.5 ENERGY DIAGNOSIS

Energy diagnosis aims to analyse document gathering to characterise well the energy use in the complex.

Through an accurate work, first values characterising the original energy state in the building are obtained. Examples of this processed information can be:

- Establish total load curves by a consumption summation
- Electric consumption distribution according to tariff periods (times, valley, flat and peak).
- Setting up a year retail through annual series.

— Consumption allocation among the different areas with energy demand.

— Energy indicators establishment (e) monthly temperature average (ºC)/ monthly heating and/or air-conditioning consumption (€).kWh/m²).

2.5.1 OPERE COMPLEX DESCRIPTION

OPERE Project is implemented over the Monte da Condesa complex in USC South Campus. This building was design and built as Maternity ward in Santiago de Compostela within the scope and ground from Santiago de Compostela University. Although it was promoted in 1978, this was never opened nor used with its original. purpose

Between 1980 and 1990, the reform of the already existing buildings for different university uses was carried out Nowadays, Monte da Condesa building complex involves these buildings: The School of Optics and Optometry, Physics University, Monte da Condesa building or the Transfusion Centre from Galicia, among others.

Figure 2.6. Monte da Condesa panoramic view.

Total surface built is about 25.000 m², distributed in 6 floors, basement and semi-basement, in which the following centres are located:

Floors	Surface (m²)	Uses		
SEMI-BASEMENT	1.957	PARTICLE PHYSICS	GENERAL INSTALLATIONS	ARCHAELOGY DEPARTMENT
GROUND	3.740	PHYSICS ENLARGEMENT	UNIVERSITY CANTEEN	
1	5.309	RESIDENCE II	OPTICS AND OPTRICIANS SCHOOL	
2	5.070	RESIDENCE II	OPTICS AND OPTRICIANS SCHOOL	
3	1.858	RESIDENCE I		
4	2.058	RESIDENCE I		
5	2.058	RESIDENCE I		
6	1.770	RESIDENCE I		
TOTAL	23.820			

Table 2.2. Floor distribution and centres in Monte da Condesa complex.

Grouped by their typology of different uses of the centres, it has been proved that most average of the whole surface goes to teaching and residential use:

Uses	Surface (m^2)	Average (%)
Residencial Use	12.833	54%
Teaching use (clases and offices)	7.862	33%
Administrative use (offices)	917	4%
Restaurant services	1.168	5%
Technical areas, stores, etc.	1.040	5%

Table 2.3. Uses, distribution and built surface in Monte da Condesa complex.

In the same parcel there is the Transfusion Centre from Galicia, managed by Xunta de Galicia, which is not included in OPERE Project.

2.5.2 SYSTEM CHARACTERIZATION

OPERE complex has central electric and thermal systems placed in the semi-basement.

In the following sections, each one of the services in the complex is analised.

2.5.2.1 DISTRIBUTION AND ELECTRIC SUPPLYING SYSTEMS

The building has its own processing centre and generator groups placed in the semi-basement which supply service to the different departments through a general low voltage board where different electric indoors distribution networks are connected.

The electric supplying in the centre is guaranteed by a net distribution of 20 kV, as well as by generator groups which give automatic service when the electric grid falls.

From the general switchboard with protection and measure placed in the basement, different low voltage systems, connected to each one of the 15 main distribution switchboards, are distributed in each plant or service, intended mainly to inside and outside illumination among other uses.

2.5.2.2 COGENERATION SYSTEM

Inside Monte da Condesa complex, one of the six cogeneration plants USC has in his South Campus is placed. Monte da Condesa, is placed in one of the Engine Room and Boilers annexes in the semi-basement.

This plant uses a simple cycle with a gas motorgenerator with a total electric power of 300kW and a maximum thermal power of 319kW. The heat available in the cooling circuit for high temperature in the engine is used to generate hot water through a water-water exchanger, which supplies hot water for heating, hot water for sanitary use to Monte da Condesa complex. Furthermore, the exhaust gas use is made by a gas recovery unit placed in the engine room.

Cogeneration is connected by a processing centre medium tension ring from USC and its operation is needed to guarantee the energy supplying to the USC.

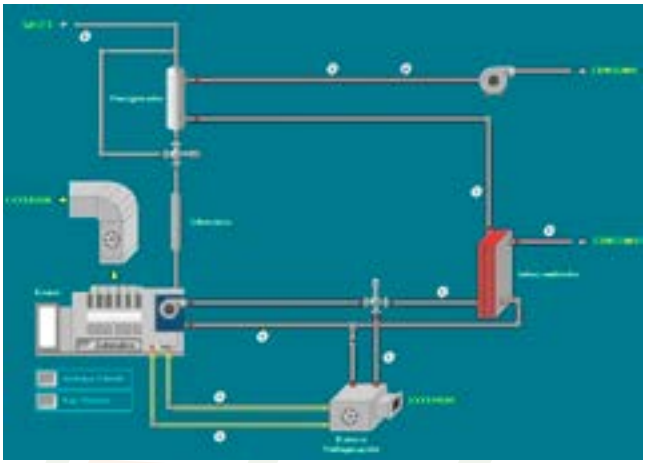

Figure 2.6. Cogeneration principle scheme. Source: USC.

2.5.2.3 CENTRAL THERMAL GENERATION SYSTEM

The system of A central thermal power generator for heating hot water and a HDW generator in Monte da Condesa complex is also centralized in the boilers room in the semi-basement.

The systems consists of a thermal use of hot water from the cogeneration plant which is piped in an impeller collector for being distributed later to each one of the individual systems like::

1. Heating system in the Optics and Optometry School and Physics University enlargement .
2. Heating system in MC2 Residence.
3. Heating system in MC1 Residence.
4. HDW generation in MC1 Residence.

In one of the sub-systems there is an independent circuit that can work either with the heat from cogeneration alone, or with its own generation systems, or with both circuits in parallel.

The scheme of the system principle is as follows:

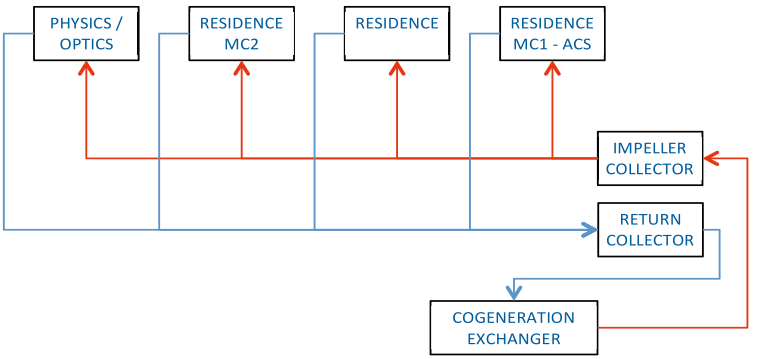

Figure 2.7. Scheme of the heating and HDW system in Monte da Condesa.

Heating by hot water systems, works with upward circulation and double tube wiring with thermal emission by steel plate radiators type convector panel. The circuits are sectorised by areas and/or floors.

Each one of the heating, systems can work either fed by the heat from the cogeneration with a single circuit connected to the primary, or by additional diesel boilers contribution in case the one from the cogeneration is not enough. Another way of working is possibly using the diesel boiler only. For instance, in the case of the system in Physics and Optics(only heating), the principle scheme is the following:

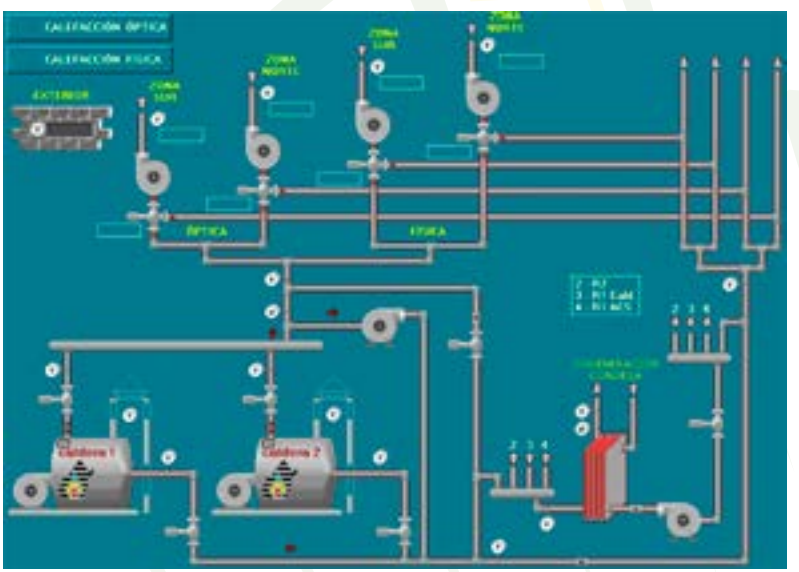

Figure 2.9. Heating installation principle scheme in the Optics School and Physics enlargement.

The total power in the gasoil boilers for heating is 2164 kW, which are delivered the next way, by services:

Circuit	Power (kW)
PHYSYCS/OPTICS	809,4
Residence MC2	465
Residence MC1	889.5

Table 2.4. Heating power installed in Monte da Condesa.

The system also supplies HDW to university Residences, for which provide two boilers with a power of 581kW. The HDW circuits have a thermal accumulation in five accumulator tanks of 5000 L with a storage of 25000 L. The HDW circuits are also prepared to thermal use from cogeneration connecting to the thermal exchanger where it connects with the primary energy supply.

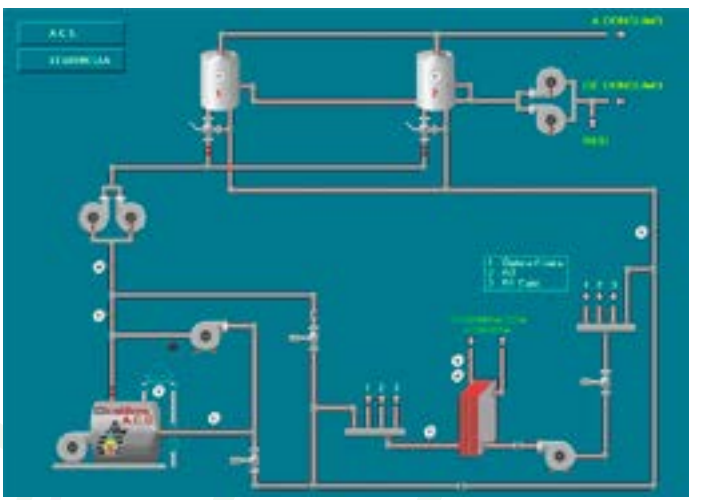

Figure 2.10. HDW generation principle scheme for residence mc1

2.5.2.4 ENERGY MANAGEMENTSYSTEM

Monte da Condesa complex has the SCADA system control developed over a AS1000 system by Siemens Building Technologies. This SCADA allows, respect to climate control and illumination, state different independent working times for the Optics School, Physics enlargement and University Residence.

Electrically, the SCADA enables the management of all illumination zones with different times and electric water meter.

2.5.3 BUILDING CHARACTERIZATION

Since its change from Hospital to University complex, the building enclosure has remained free of important or hidden defects which could make necessary its substitution.

Outside walls are made of double hollow brick, with expanded 4 cm polystyrene isolation.

The main covering is type non accessible inverted terrace with fiberglass roof sealing of 50 mm and expanded polystyrene isolation with high mechanical resistance.

Respect to outside carpentry, this is made of anodised aluminium and the most usual glass is double glazing with 6 mm air chamber in 4-6-4 configuration.

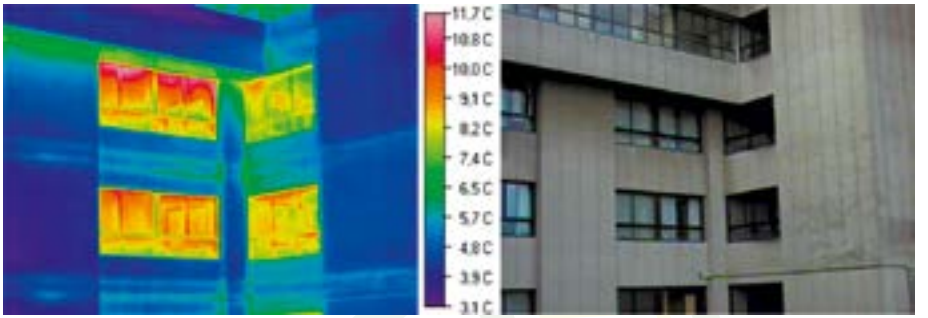

Figure 2.11. Infrared thermography where thermal forged bridges and glazing losses are evaluated. University residence zone.

Circuit	Termal Transmitance (W/m^{2}K)	Limit Value CTE 2006 (W/m^{2}K)
Cerramiento tipo CE1 muro de fachada	0,664 W/m^{2}K	0,95 W/m^{2}K
Acristalamiento hoja simple 6 mm	5,73 W/m^{2}K	4,4 W/m^{2}K
Acristalamiento con hoja doble 4/6/4	3,4 W/m^{2}K	4,4 W/m^{2}K
Cubierta plana	0,976 W/m^{2}K	0,53 W/m^{2}K

Table 2.5. Thermal transmitance value comparison in OPERE Complex respect to thermal transmitance limits required by the BTC 2006 in Santiago de Compostela.

Thermal transmittance values for outside walls and glazing has been proven in general, very similar to those required in the CTE 2006, except in the covering and glazing without Air Chamber.

The thermal transmittance calculated over the original project values were proven by thermal closing transmittance trials type CE1, for a 4 day monitoring period, being the transmittance value of 0.692 W/m^{2}K:

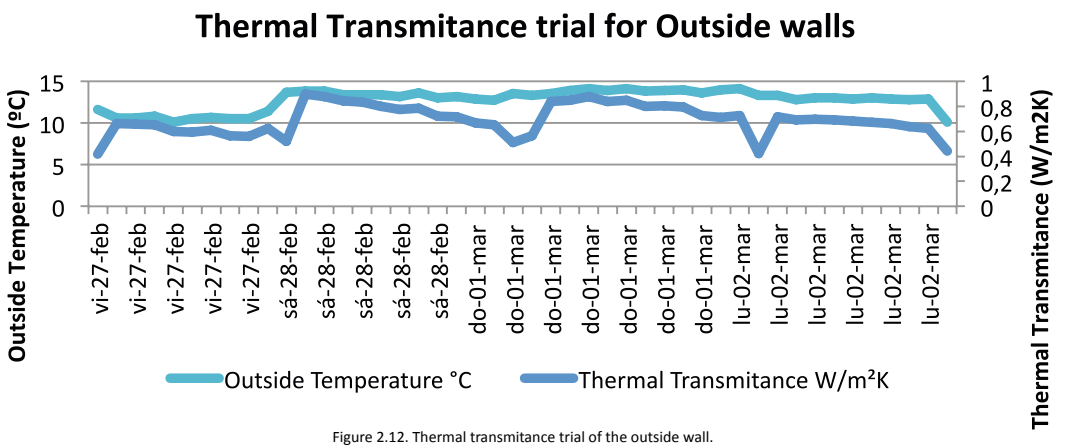

Figure 2.12. Thermal transmitance trial of the outside wall.

In general, the enclosure is in suitable conditions. However, punctual maintenance actions are observed, either because of a programmed maintenance or because a continuity breaks in certain points, especially in the faÇade coating.

So, the main attention point would be focused on simple glasses glazing removal, roof isolation improvement and faÇade thermal bridge removal.

2.5.4 CONSUME DISTRIBUTION

The final energy delivering average in OPERE complex is a 25% in electric energy and a 75% in gasoil.

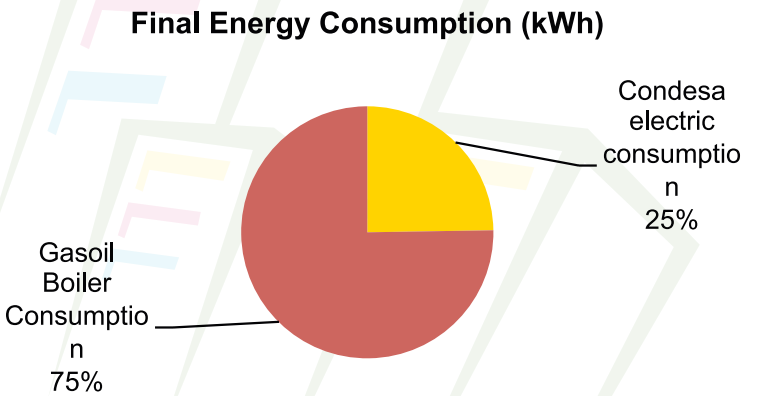

Figure 2.13. Final energy consumption.

The monthly consumption evaluation of final energy shows seasonality in heating demand:

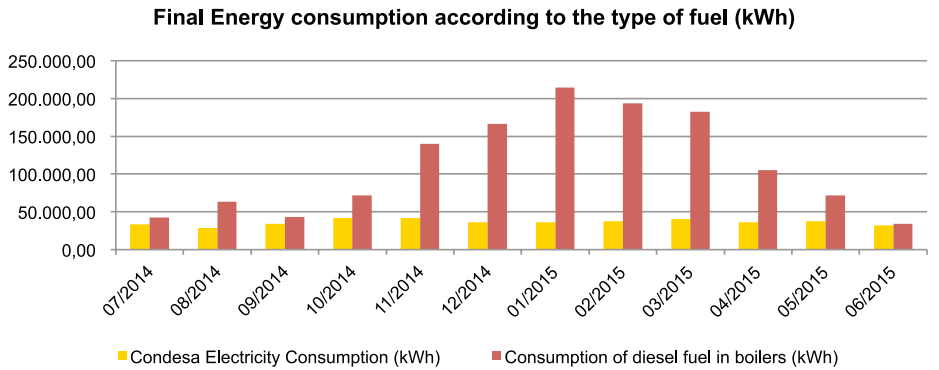

Figura 2.14. Consumo de energía final por tipo de combustible

Respect to the energy consumption distribution according to their uses, this is delivered among, electricity consumption (strength and illumination indistinctly), heating and HDW, as follows:

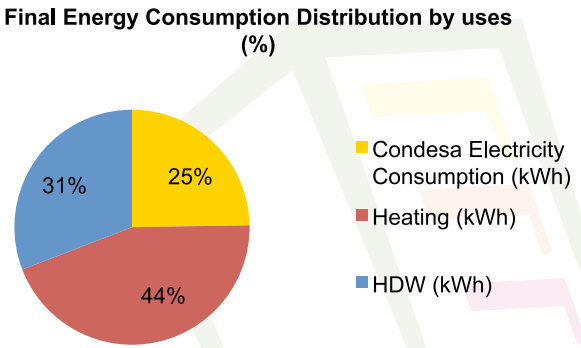

Figura 2.15. Final energy consumption by uses

This proves that the main energy use in the complex is the heating with a 45% of final energy consumption.

2.5.5 ENERGY SIMULATION

As a supporting tool for energy diagnosis and search to improve energy efficiency, an energy simulation of the building complex has been developed with the following procedure:

— Constructive characterisation of all the buildings in the project
— Geometric modelling and energy simulation of all the buildings in the complex (DesignBuilder/EnergyPlus)

- According to enclosure typology
- According to spatial position
- According to internal load

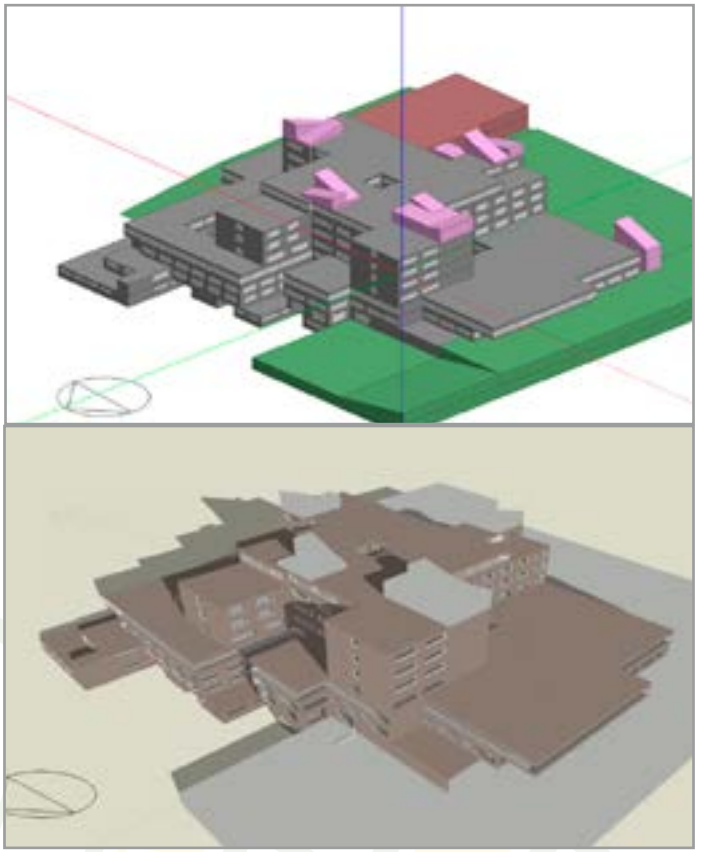

Figure 2.16. OPERE Complex geometric modeling in building design software Design Builder.

— Specified HVAC Model

— Energy meter calibration simulation based on consumption data.

— Energy basis establishment line in each of the equipment as it will be shown in the next chapter:

- Value better saving measurements.
- Compare the projected savings with the obtained ones
- Obtain energy optimisation in the resulting system

In the next chart, the simulated energy demand against real monitoring consumption in heating and HDW for OPERE complex:

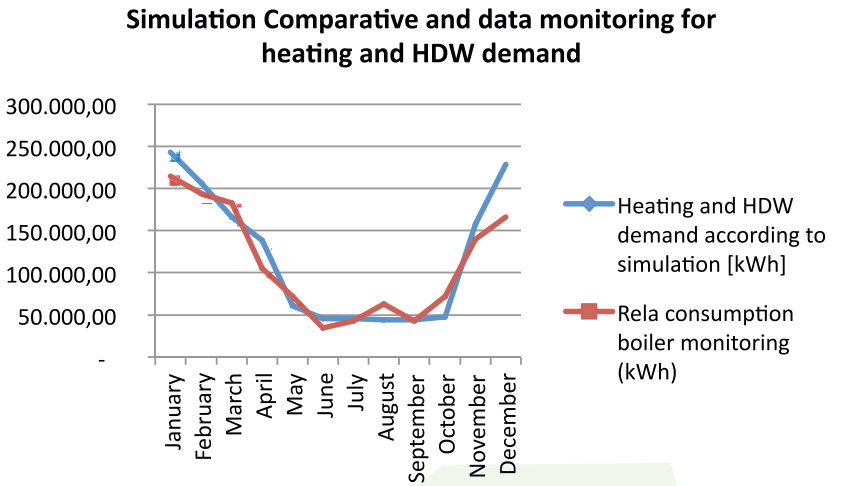

Figure 2.17. Simulation comparative and data monitoring for heating and HDW demand against calibrated energy simulation.

2.6 CONCLUSIONS

In general, it is proved that OPERE complex is an important energy consumer, whose main use is for heating and HDW with a 75% of final energy consumption.

From the constructive point of view, the building does not show remarkable shortcomings in energy efficiency, with thermal isolation levels similar to those required by the Building Technical Code in its 2006 version.

Respect to thermal systems, the cogeneration use is improvable since the impeller and return collectors connect services with uses and different temperatures (heating and HDW) motivating a study to improve the right use of heat generated in natural gas cogeneration to be done.

Chapter 3

Energy and Thermal Network Optimisation

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Juan I. Rodríguez Fernández-Arroyo

This chapter shows the reports and analysis performed to accomplish the thermal and energy optimisation of the OPERE complex. It is based on the energy assessment, whose conclusions are previously presented in the Chapter 2.

3.1 ENERGY OPTIMISATION STRATEGIES

The main strategies to reduce general energy consumption are including in the following categories:

— Reduction of energy demand

— Improvement of the efficiency in the generator systems

— Disminution of energy losses

— On site energy production

— Improvement of monitoring and energy management

Conceptually, it is common to start by considering actions to reduce energy demands that are usually followed by the use high-efficiency systems and renewable energies to -finally- optimise the control system.

Anyway, it will be necessary to consider the property needs and interests, so the final proposal will not always be the one with the highest energy savings or the shortest amortisation period.

3.2 METHODOLOGY TO DEFINE PROPOSALS FOR IMPROVEMENTS

The proposals for improvement or energy saving measures (ESMs) must be evaluated according to three phases: firstly, a description is accomplished to set the extent and calculate the investment; secondly, it is

calculated the impact of the measure to determine its savings for the building and -finally- the investment viability is analysed according to the estimated returns to calculate the proposal's profitability.

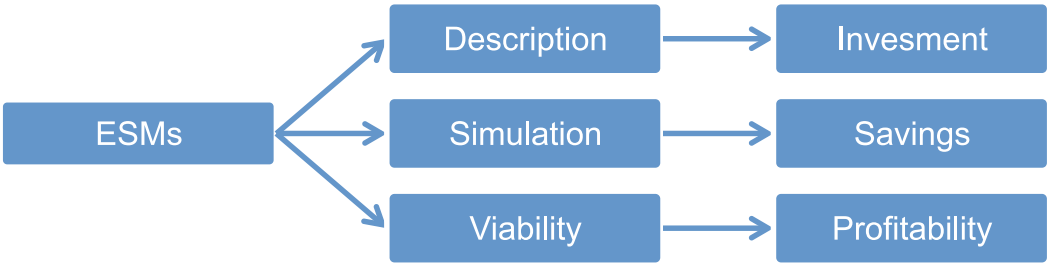

Figure 3.1. Process to define the Energy Saving Measures.

Once the possible improvement has been identified, the first step to analyse its technical and economic viability consists in describing it, considering the own features of the analysed building. Therefore, it is necessary to prepare a detailed study or draft to evaluate -in an accurate way-the obtained savings and the magnitude of the investment.

The following step is to evaluate the obtained savings with suitable accuracy; the exactitude of the calculation depends on the considered measure and also on the level of detail of the study.

The analysis can involve everything from simple calculations to the use of specialized software, which analyses the building performance every hour after the improvement implementation.

— In this case, as described in Chapter 2, thermal energy simulation of OPERE complex has been used to estimate energy and economic savings.

3.3 PROPOSAL FOR IMPROVEMENTS

To prepare the proposal for improvements, the characterisation accomplished during the energy assessment is taken as a reference.

The energy saving measures presented in the OPERE project can be classified according to the kind of infrastructure they affect, in the following way:

— Thermal Improvements

— Electric Improvements

— Enclosure Improvements

The analysed improvements are hereinafter detailed:

3.4 THERMAL IMPROVEMENTS

3.4.1. SECTORISATION OF THERMAL GENERATION ACCORDING TO SERVICES AND FINAL USES

Currently, in spite of heating and HDW hydraulic systems are independent, demands are indistinctly fulfilled by shared boilers, so it is not possible to control and quantify thermal demands in every system.

The location of the different generating units in the same room allows to perform a set of modifications in the generation circuit, so the thermal generation power can be adjusted to the energy demand and its final uses, using control strategies in the whole system and minimizing the operating hours to get a better efficiency in the whole system.

With the purpose of optimising the system's efficiency to guarantee a better functioning of the cogeneration system, it is proposed:

- Sectorisation according to services and final demands, grouping buildings and zones with similar demands, separating HDW generation from the hot water for heating one.
- The zones and floors subsectorisation through independent circuits and control system, as far as possible.

Therefore, it is tried to provide any single consumption with service through a circuit redistribution, separating every single thermal supply -heating and HDW- including common consumptions if possible.

3.4.2. REPLACEMENT OF THE EXISTING BOILER

To main action to perform on the thermal generators is the replacement of existing equipment by other more modern elements which get a better thermal performance. If equipment increases its efficiency, energy consumption will decrease as well as the costs related to conditioning in the OPERE complex.

Nowadays, the installed equipment in the boiler room of the OPERE complex, which supply heating and HDW, is the conventional diesel boiler.

The biggest limitation of this kind of boilers is the fumes' temperature and, therefore, the water temperature in the boiler which cannot be under the gases dew temperature. This is why that in spite of the fact that the full load performances are usually acceptable, they cannot be adjusted to the demand variation in an efficient way, which means a malfunction in low-load performance.

It is suggested installing condensation boilers, which allow to take profit of the combustion gases latent heat to get a level of performance beyond 100% (obtained from the combustible LCV), as it has a big exchange surface inside the boiler and allows to get the lowest return temperature. In addition, this equipment can adapt to the demand variation in the whole operating range so the obtained efficiency will be higher than the obtained by the current boilers.

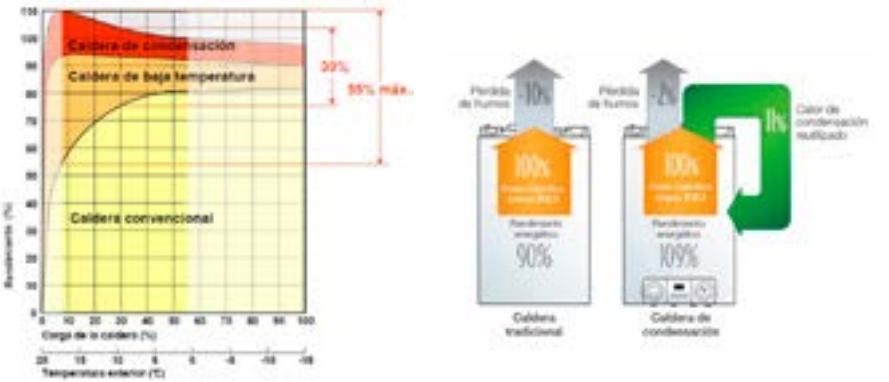

Figure 3.2. Conventional condensation boilers partial-load (30%) performances at a low temperature (left) and performance comparison between a conventional and a condensation boiler (right).

The boiler replacement advises, in addition, the replacement of the current combustible (diesel) by natural gas. These are some of the main reasons to do it:

— It improves the boiler's thermal performance. It means that the system will require less maintenance.
— High energy efficiency in its combustion.
— Lower levels of polluting emissions, which means environmental improvements.
— Lower combustible price. Not affected by external conditions.

Thermal power to be installed has been estimated through the thermal simulation for the typical winter conditions and the building energy model.

The energy demand profile is presented in the following table:

Building	Thermal Load	
	Heating (kW)	HDW (L/día)
Residence I	401,57	15.529
Residence II	262,55	9.931
Optics and Physics Faculties	417,23	0
Other	15,62	0
TOTAL	1.096,97	25.460

Table 3.1. Thermal loads of the Monte de la Condesa university complex design.

The design of the thermal load has been estimated for an outdoor temperature of 0.8 ºC, a wind speed of a 10,4 m/s, for a heating setting temperature of 22 ºC.

The volume of HDW, previously estimated, has been calculated according to the number of existing rooms, as it is described in the Table 4.1 of the CTE HE4, to set the reference demand at 60 ºC, adapting the obtained value according to the available consumption data.

3.4.3. BUFFER TANKS INSTALLATION

The main function of the accumulator and the buffer tanks is to store energy in the form of hot water, being used as an intermediate element between demand and generation. In that way, the generation system can operate in a more stable way, as it does not have to fulfill peak demands in specific times of the year.

The increasing in the storage capacity would involve the following advantages:

— It provides an important power reserve

— It reduces the stops-and-go processes of the heating groups, increasing their operational performance

— It reduces the thermal leap in regard to the supply setting temperature

It is intended to install a set of accumulator after the plate exchanger of the hydraulic circuit in the cogeneration system, so the cogeneration equipment works on the tanks and not directly on the boilers' circuits. In this way, cogeneration will heat not only the HDW accumulators, according to the provided regulation. It will allow to reduce the stop-and-go processes of the thermal conventional systems when temperature suddenly changes and the heat demand is low. At the same time, it will allow to extend the functioning time of the equipment to periods when it is currently off.

According to the thermal simulation, the resulting year theoretical demand of 1544.757 MWh/year with heating and HDW. The following table shows the simulation conditions and the demands fulfilled by the systems in monthly intervals. In addittion, it also shows the residual heat that could be stored, in case the generation worked with a rated capacity:

Month	Demand	Residual Heat
January	244.116,26	29.071,76
February	206.670,16	24.339,29
March	154.352,81	50.295,99
April	125.234,31	63.781,24
May	82.064,74	75.280,01
June	62.404,57	69.043,56
July	61.088,49	80.991,26
August	57.086,52	0,00
September	59.429,29	73.811,80
October	65.313,69	79.603,28
November	189.552,10	38.640,71
December	237.446,68	28.730,44

Tabla 3.2. Monthly thermal energy (kWt) demanded by the OPERE project and the residual heat (kWt) thta could be stored when the thermal hourly supply of cogeneration is 295kWt in simulation conditions. Source: Energylab.

The storage volume goal will be enough to keep the water hot until its use in order to supply the heating and /or HDW in the buildings peak demands, during a 2-hour period. This would allow to soften the demand variations, as well as optimise the cogeneration functioning hours, according to the electric pricing and the variation in heating and HDW in buildings.

The final thermal storage capacity will be around 20000 L, enough to store two cogeneration functioning hours at rated capacity.

3.4.4. OPTIMISATION OF THE COGENERATION SYSTEM

The cogeneration plant is based on a GUASCOR engine-generator, model FGLD 180. The technical features of the cogeneration engine working under 100% rated load, are the following:

POWER	kW
Natural Gas Consumption	781
Electric Power	301
Engine Water Calorific Power	190
Exhaust Gases Calorific Power	129
Total Calorific Power	319

Table 3.3. Technical features of cogeneration engines.

With the purpose of optimising the status and the performance of the facilities and guaranteeing the optimal performance of the cogeneration system, the following strategies are proposed:

- Optimising the functioning schedules of the cogeneration plant according to the operating costs, increasing-as possible- the functioning hours of it.
- Increasing the usable thermal demand by adding the thermal demand of other departments or adjoining buildings.
- Increasing the number of functioning hours and optimising the energy and economic efficiency from the engine's functioning hours by adding buffer tanks, described in the previous point.
- Improvement in the thermal performance of the engine through the replacement of several elements in the equipment.

Optimisation of The Cogeneration Functioning Schedule

Currently, the equipment's operating conditions depend on the electric billing period (electric pricing 6.1 with time discriminating), whose distribution is represented in the following table:

MONTH	1	2	3	4	5	6	6	7	8	9	10	11	12
HOUR	JAN	FEB	MAR	APR	MAY	JUN(1ª)	JUN(2ª)	JUL	AUG	SEP	OCT	NOV	DEC
0	P6												
1													
2													
3													
4													
5													
6													
7													
8	P2		P4	P5		P4	P2		P6	P4	P4	P2	
9						P3				P3			
10	P1						P1					P1	
11													
12													
13	P2											P2	
14													
15													
16													
17			P3			P4				P4	P3		
18	P1											P1	
19													
20													
21	P2						P2					P2	
22			P4								P4		
23													

Table 3.4. Peninsular electric calendar. Pricing 6.1

The critical billing periods are linked to the summer months, April and May (P5), first fortnight of June (P3-P4), second fortnight of June and July (P1-P2), August (P6), September (P3-P4), when the engine must be turned off because of the dissipation problems caused by the low demand of heating, therefore, only HDW production must be considered.

The cogeneration system must not work, between midnight and 8 am, as described in its cogeneration statute.

In order to contrast the current functioning programming, a study has been accomplished on the costs and the economic/operational profitability and also on the thermal available use of cogeneration, according to the hourly demand simulated by the OPERE complex. In this way, operating costs of cogeneration depend on the combustible (natural gas) supply costs, self-consumed energy (not coming from the network) costs, and the cogenerated thermal energy cost, that is used in the conditioning and HDW systems.

With these supply costs and the available information about energy and thermal performance of the cogeneration system, the operating return of the system has been studied, in every different electric pricing period. The economic operative of the plant has been summarised with a colour code in the following table:

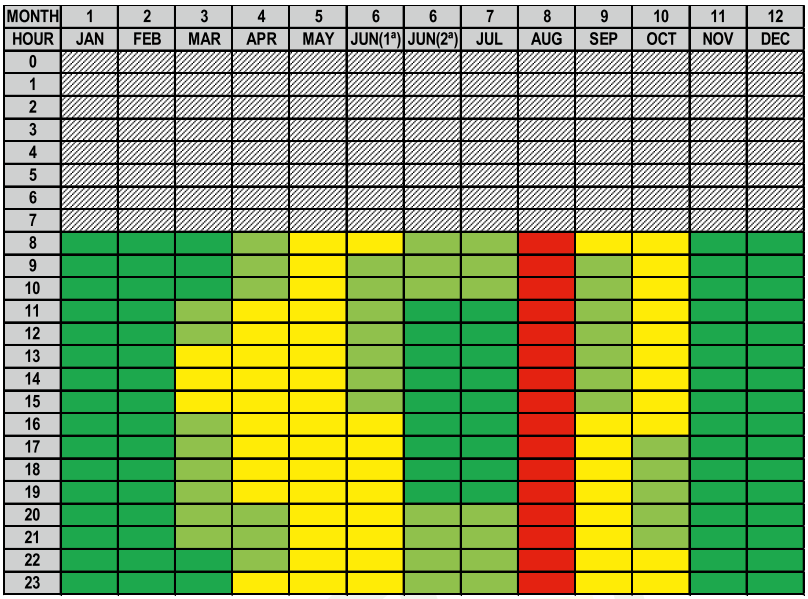

Table 3.5. Current operating return of the plant during the different periods, according to the simulated demand data. (Source: EnergyLab)

In this way, it has been proved that the plant's operating is profitable in January, February, March, November, December and the 2nd fortnight of June and July. However, its profitability is limited in April, May, 1st fortnight of June, September and October, when the system must be turned off, if there is not thermal demand.

In order to optimise the functioning hours, considering the estimated data, the following suggestions are proposed:

— For March and April, the increase in the thermal storage capacity in the buffer tanks would allow to move some of the thermal demand from the early morning to the central hours, when thermal demand is lower. This will allow to increase the current thermal use from values around 35-40% to higher values, so the plant's operating return and energy efficiency would also increase.

— In the months of May, 1st fortnight June, September and October, the combination of no-beneficial electric pricing periods (specially P4 and P5) with low thermal use periods causes that the plant's operating return is limited during these months.

— Furthermore, it must be guaranteed that the boilers and HDW are turned off from midnight to 8 am, always with suitable stored capacity to fulfill the HDW peak consumption between 8 and 10 am, to move the thermal and HDW generation, currently performed at night, to those hours when the cogeneration plant is functioning.

3.5 ELECTRIC IMPROVEMENTS

The proposed improvements related to the electric part, are, basically, focused on improving energy efficiency in the lighting system, as, in the tertiary sector, this consumption means an average of 15% and 40% of the total energy expenses.

To select the energy improvement measures, the following factors, which affects energy consumption in the lighting system, have been considered:

- Minimum lighting level. (UNE-EN 12464-2 standard)
- Control and regulation devices
- Operation scheme and conditioning system
- Lamps efficiency
- Losses (consumption) of auxiliary equipment
- Luminaire efficiency

3.5.1. REPLACEMENT OF LOW-EFFICIENCY LAMPS BY LED HIGH-EFFICIENCY LAMPS

Lighting Monte da Condesa complex is principally performed through tubular fluorescent lamps, all of them of the type T8, with power of 18 W, 36 W and 58 W.

Building	T8 (18W)	T8 (36W)	T8 (58W)	Total Lamps	Total Installed Power (W)
Physics Expansion	-	574	-	574	25.877
Partycles Physics	224	68	-	292	7.776
Condesa Residence	192	895	-	1.087	42.811
Optics School	-	789	316	1.105	60.158
Total	**416**	**2326**	**316**	**3.058**	**136.622**

Table 3.6. Inventory of lamps in the Monte da Condesa buildings (onlyT8. Source: EnergyLab))

*Including auxiliary power of ballasts.

It has been considered to replace T8 existing lamps directly through equivalent direct replacement LED tubes, so it will no necessary to replace the whole luminaire. High-efficiency lamps suggested for every single existing power are the following:

Cod.	Technology	Existing Power (W)	New Power(W)	Power Savings	Aprox. Price
T8FL18	T8FL	18	11	41,67%	32,00 €
T8FL36	T8FL	36	16	55,56%	44,00 €
T8FL58	T8FL	58	24	58,62%	61,00 €

Table 3.7. LED T8 Replacement lamps suggested according to the original lamp's power (Source: EnergyLab)

Besides the power linked to the existing lamps, it is also necessary to consider the power consumed by the auxiliary equipment (generally electromagnetic), which can mean an additional consumption of 20% of the lamp's total.

3.5.2. INSTALLATION OF PRESENCE MONITORING SYSTEMS AND USE OF NATURAL LIGHT

The installation of automatic controls in the lighting system regulates the illuminance (lux), according to the available natural light, with savings estimated between 30% and 80% in lighting consumption in zones where it can be used.

The OPERE complex has a huge glass Surface, with a great orientation, without many exterior shading elements so the possibility of using natural light is high.

It is also proposed to install natural light and automatic disconnection controls in high occupancy spaces with continued use. The most favourable spaces for this kind of systems have been identified: teaching classrooms, and labs with a minimum 30 m² size. The sporadic use zones and the areas occupied during daytime (offices and residence rooms).

3.5.3. MONITORING. INSTALLATION OF MEASURING EQUIPMENT

It is difficult to advance in the improvement of the conditioning system energy efficiency if its value is unknown. This is why it is suggested a consumption accounting in all the thermal system through the monitoring with measuring equipment, in order to get more control on energy efficiency.

— What is not measured does not exist, so it cannot be improved.

3.5.4. IMPROVEMENT OF THE OPAQUE ENCLOSURES

The amount of energy required to keep the university complexes at a comfortable temperature depends on its thermal insulation. A badly thermally insulated building is hotter in summer and colder in winter.

There exist several ways to rehabilitate the building's thermal enclosure: from the inside, from the outside or from both. All of them include a huge choice of solutions which may be more or less efficient.

With the purpose of optimizing the status and efficiency of the facilities, it is suggested:

- Calculating the energy savings of the improvement of the opaque enclosures through an exterior thermal insulation system (ETIS).

With an ETIS system, the external part of the building is covered and insulated, adapting the lining to the building's geometry. Therefore, its correct installation allows to solve thermal bridges and reduce the dissipated energy. It will get an important reduction of the combustible consumption for heating and cooling as well as energy savings between 25% and 35%, depending on the initial conditions.

Among others, the main advantages of the ETIS systems in regard to interior insulation systems can be summarized in:

— Minimisation, optimisation and simple correction of thermal bridges.
— Better use of the thermal inertia of the enclosure and the building elements.
— Simpler and faster installation.
— Minimum interference for the building users.

3.5.5. IMPROVEMENT OF THE GLAZING

Currently, the university complex has huge glazed surfaces in its perimeter, it includes three kinds of translucent enclosures:

— Aluminiun carpentry without thermal bridge breakage and single glass.
— Aluminiun carpentry without thermal bridge breakage, double glazing and air chamber.
— Double aluminium carpentry with double glazing with air chamber.

The double glass systems reduce the heat losses in a half in regard to the simple glass, with more energy savings and equivalent reduction of CO_2 emissions.

With the purpose of optimising the facilities' status and performance, it is suggested:

— Replacement of carpentries by carpentries with thermal breakage and the replacement of windows with single glass y low emissivity double glazing.

3.6 SUMMARY OF ANALYSED MEASURES

The following sections describe, in a brief way, the analysed energy saving measures which also considers economic saving and payback (PB).

In addition, the saved energy rate is also included (kWh), together with the investment cost (€), which represents the energy savings for every single Euro invested.

3.6.1. IMPROVEMENT MEASURES FOR THERMAL SYSTEMS

Nº	Measures	Heat. Savings	HDW Savings	Emissions Savings	Indicator (kWh/€)	PB
I.	Sectorisation according to Service	-	-	-	-	-
II.	Boilers Replacement	15%	7%	25%	0,94	6,9
III.	Installation of Buffer Tanks	11%		11%	5,01	2,5

Table 3.8. Summary of the suggested rehabilitation measures for thermal facilites. (Source: EnergyLab).

3.6.2. IMPROVEMENT MEASURES FOR ELECTRICAL SYSTEMS

Nº	Measures	Electric Power Savings	Emissions Savings	Indicator (kWh/€)	PB
I.	Replacement of High Efficiency Lamps	32%	32%	2,2	3
II.	Lighting Controls	6%	6%	1,09	6

Table 3.9.Summary of the improvement measures suggested for the electric system (Source: EnergyLab)

3.6.3. IMPROVEMENT MEASURES FOR THE BUILDING ENVELOPE

Nº	Measures	Heat. Savings	Emissions Savings	Indicator (kWh/€)	PB
I.	Improvement Envelope Enclosures	23%	23 %	0,24	>25
II.	Improvement Glazing	30 – 35%	30 – 35%	0,65	20

Table 3.10. Summary of the suggested envelope rehabilitation measures (Source: EnergyLab).

3.7 ANALYSIS OF THE SPECIFIC OPERE OPTIMISATION PROPOSAL

Considering the results of the analysis performed on the suggested improvements on the project, according to the USC needs, it has been decided to perform a reform in the centralised heating and HDW systems, in order to improve energy efficiency and increase the use of the heat available in cogeneration.

The resulting system will be centralised, as the previous one, with a set of actions, like the following:

- Change in the used combustible, as well as the replacement of diesel boilers by natural gas condensation boilers.
- Integration of buffer tanks and instant hot water production to get a high volume of water to the use and recover the cogeneration thermal energy.
- -New collectors and valves, as well as high-efficiency impeller pumps and energy and water consumption accounting in every single zone (separately).
- Improvement of recovery of the thermal energy from the existing cogeneration process.
- Regulation and automaton of the complete system. Reformation of the cold-water supply.

The whole thermal energy production system will be reformed. It is considered to be a comprehensive process which will act on everything related to the boiler and tanks.

3.7.1. BOILERS REPLACEMENT

One of the most important actions is the replacement of diesel boilers by natural gas condensation boilers. This reform is performed to reduce emissions and get economic savings. Diesel boilers are quite spoiled and their efficiency is low.

The natural gas boilers to be installed have the following features:

- Brand: DE DIETRICH
- Type: C 630-1140 ECO
- Useful Power (50/30ºC): 1.148 Kw
- Useful Power (80/60ºC): 1.060 Kw
- Efficiency (50/30ºC): 106.4%
- Efficiency (80/60ºC): 98.4%

The installed boilers rely on a similar power to that existing in the building, as any reform is performed inside and it has been used until now so it is necessary to use the same power range.

3.7.2. STORAGE

The following required action in the boiler room of this building, is the removal of the existing hot domestic water accumulators and the implementation of new buffer tanks.

Five of them will be buffer tanks and, in addition, they have inner heating coils to produce instant hot domestic water, avoiding legionella risk and getting great electric and maintenance savings. HDW will be immediately produced through the corrugated heating stainless steel coils inside the tank. The cold water will enter the low part of the coils and, as it is ascending through their inside, it is getting hotter until it exits their higher part.

The other 5000l tanks will be only buffer tanks. The goal of their installation is to increase the storage volume in order to increase- as well- the energy recovered from the cogeneration engine's cooling. These accumulators are connected with the higher part of the condensation boilers, to keep the minimum water temperature to its proper functioning. In this way, the middle-low part is not polluted and all the volume is available to store the recovered energy once the cogeneration engine works.

Figura 3.3. Boiler and accumulator rooms after the reform process. Source: USC.

3.7.3. COGENERATOR ENGINE

One of the most importat actions of the whole reform is the improvement in the use of the thermal energy generated during the cooling process of the cogeneration engine. When it works in the full-load mode, 319 thermal kW are generated. Currently, the energy fed into the system through a plate exchanger and later

directly injected into the heat pipeline of every zone-is being used. Nowadays, the heat recovery is low because of the high temperature during the functioning of the current system.

The recovery of heat produced by the cogeneration engine is performed in two phases:

— First, in the engine's liners, which are able to generate - while they are functioning- 190 kW thermal.
— Second, in the chimney heat recovery unit, with a recovery capacity of 129 thermal kW.

Nowadays, the existing problems is that the high return temperature towards these recovery units is too high and causes an important rise in temperature, which is too much at the exit of the recovery unit. As a consequence, the recovery unit power is rarely used. In addition, when the temperature keeps increasing, the engine liners recovery is also wasted.

After the reform, the return temperature from the facility will be much lower than now. As a consequence, the use of the recovery will be better as the recovery capacity will always be used.

3.7.4. NEW HYDRAULIC SYSTEM

The whole hydraulic system will be performed according to the new approach: impeller and return collectors of the existing heating circuits, with all the electronic high-efficiency circulation pumps. Furthermore, energy meter boxes will be installed in every zone to control individual consumption.

Figure 3.4 New facility blueprint.

Chapter 4

Software Tools for Energy Management in OPERE

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The goals of the OPERE project (LIFE OPERE) include energy, economic and environmental optimization in the Monte de la Condesa University Complex, set as reference building for the project. In order to get this purpose, several measures are required, among them, the development of an energy management system. These systems are designed to get a continuous improvement in the employ of energy by the efficient use of it consisting in a reduction in consumption, associated financial costs and greenhouse gases emissions, as it is showed in the Figure 4.1.

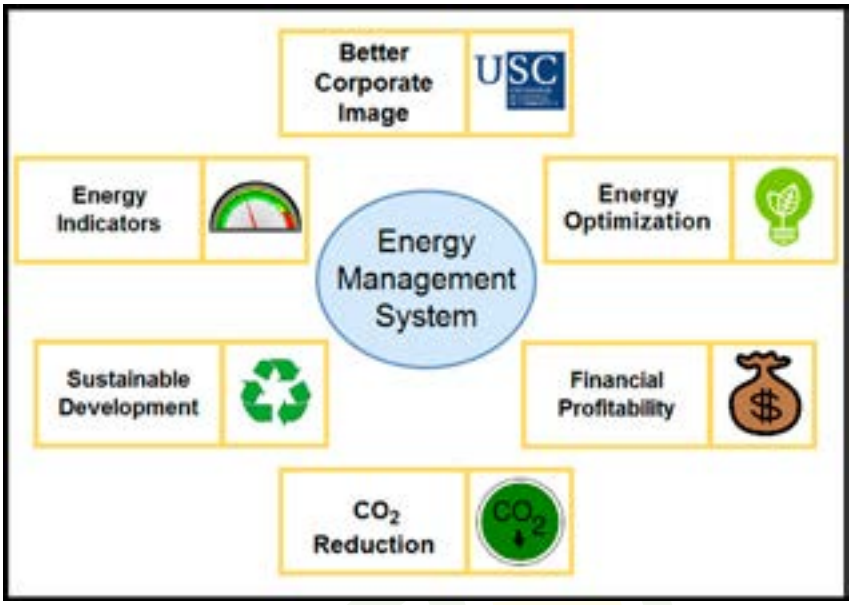

Figure 4.1. Benefits from Energy Management System.

The University buildings are included in an inmotic system that relies on a SCADA software to control and display all the different elements in the facilities. The instant information provided by this system is not enough to accomplish an analysis on the facilities' performance over time, so it is necessary to develop a set of software modules to provide EMS (Energy Management System) with support. The described functionality- which requires facilitating the analysis of energy flows in the different systems- involves an important dependency on data gathering and storage that allow to study the above-mentioned flows over time. In this way, during the development of the project, a set of software elements have been implemented in order to increase the capability of the SCADA system with the purpose of providing IT (Information Technology) support to the Energy Management System. The developed modules are, specifically, the following:

- An acquisition module to access the data associated to the different sensors and actuators that form the building facilities.
- A data storage module in a persistent system.
- A module for data dissemination that offers information through a set of APIs in order to ease the access to data.
- A module with a set of tools to display and accomplish analyses on the data.

The developed system obtains the buildings' information through the BACnet (BACnet) communications protocol on the Ethernet network deployed at the University. The collected information - both from regular checking of buildings and the transmission of events performed by them- is stored in the relational database, whose model has been specially designed to guarantee flexibility and efficiency. Since that moment, information is disseminated to final applications through a set of modules that offer an API on Http focused on

the offer of services that may be demanded by different final applications. In order to supply these services, most of the modules (not all) perform optimized consultation on the database. This approach helps to optimize the access to information or a complete change in its pattern, regardless of the final applications, which will still access the information through the same API of the service. As final part of the developed system, a set of applications has been implemented to access the suggested APIs which are gathered on a web portal which eases the access to all of them.

The following sections describe every single aspect of our energy management system, which was mentioned in the last paragraph.

4.1. SOFTWARE ARCHITECTURE

In order to implement the software tools of our energy management system, it is required a software architecture design that allows to ease maintenance, auditability, flexibility and interaction with other systems. Figure 4.2. was designed with this purpose.

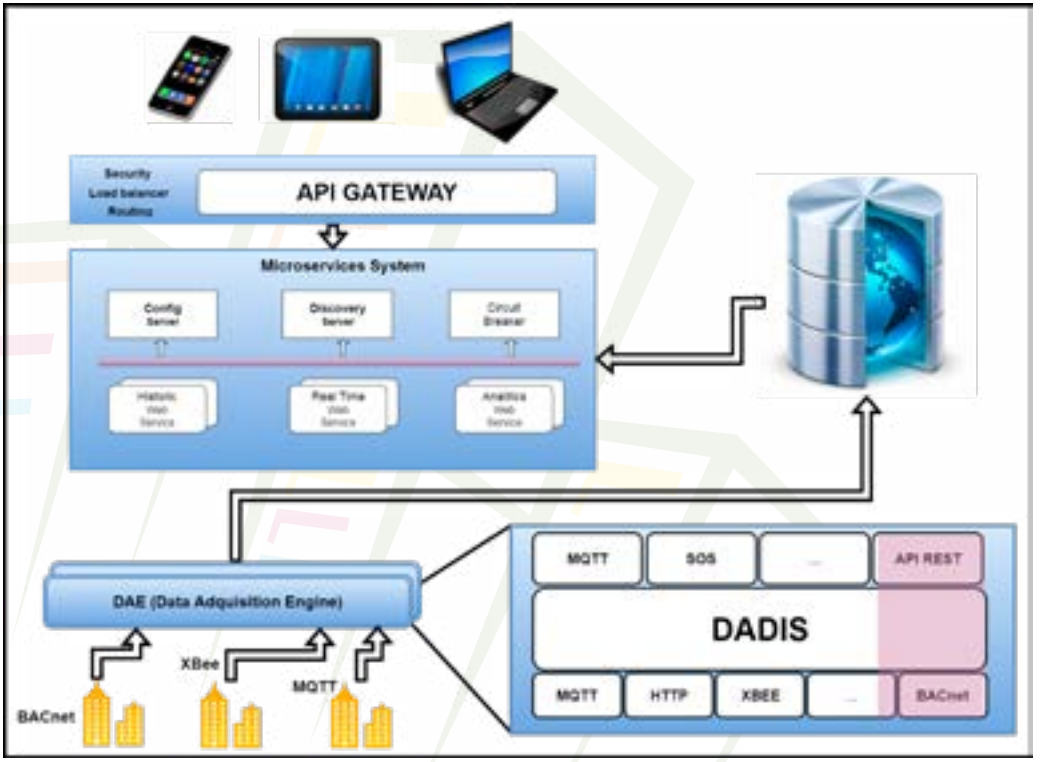

Figure 4.2. Global Architecture

The showed architecture is divided into four logical abstraction layers, associated -all of them- to the main required functionalities:

- An acquisition layer is in charge of communication with the buildings and the collection of data from sensor and actuators.
- A storage layer persists data in a database to enable the later access to them.
- A dissemination layer that offers the data to other components of the system or external applications.
- A presentation layer that includes all the user's interfaces.

4.1.1. ACQUISITION

A specific architecture has been designed for the acquisition layer, considering the following restrictions:

- The data from the building can be obtained both synchronously and asynchronously, this means that this is done through the BACnet communication protocol. It is possible to connect regularly to the buildings and ask for data waiting for the answer (synchronous option) or to be informed about every change by the devices, which have been previously programmed to do it (asynchronous option).
- Besides BACnet, there is an interesting option of using sensors (wired or wireless) with other technologies in the buildings and include them in the data collecting process in a transparent way.
- Data consuming applications must be able to get data both thorough the "Request/Response" mechanism (synchronous option) and through "Publish/Subscribe" (asynchronous option), according to the needs.
- The data flow out the application must be performed through a standard interchange format: Xml, Json, etc.
- With these restrictions, the architecture showed in the figure 4.3 was designed. It was called DADIS (Villaroya, Mera, Regueiro, & Cotos, 2012) (Data Acquisition and Dissemination Service), and it is used to the specific implementation of the acquisition layer in the global architecture.

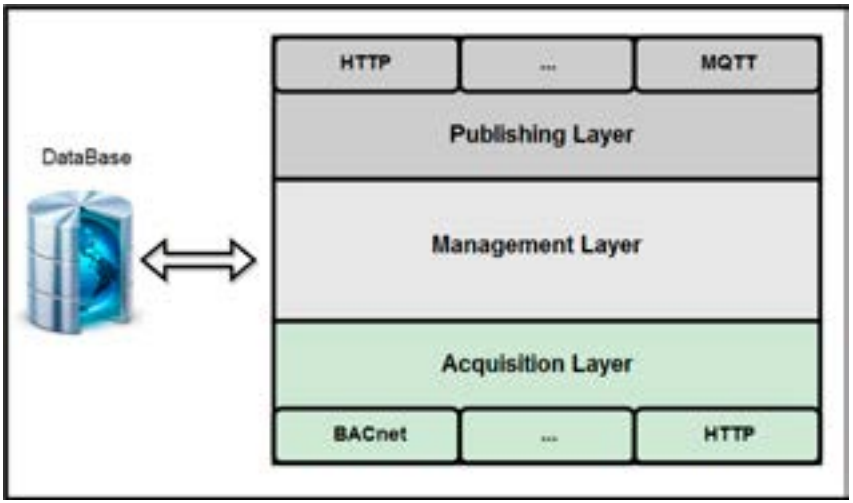

Figure 4.3. DADIS Architecture.

DADIS was built as a monolithic piece of software that, as well as the global architecture, shows a layered architecture. The lower layer, the data acquisition layer, is in charge of the communication with other sensors and actuators by the use of the corresponding protocols, the intermediate layer allows the persistent storage of information and the upper layer performs the communication with user's applications.

DADIS is a flexible architecture, developed to gather the possibilities of the whole project in a monolithic element. Unfortunately, although its capabilities allow us to use it for flexible acquisition of information and the storage of this DB or the access through the dissemination layer, its monolithic nature limited its use due to the need of skipping from the different university networks - a fact that was not considered in the initial architecture- , optimizing and increasing flexibility of the dissemination layer. For this reason, the original DADIS module was simplified and its role in the project was limited as part of the general architecture in the acquisition and storage layer.

In the simplified implementation of DADIS for the project, the "Adapter" design pattern has been extensively used in order to provide a tool with a general purpose, flexible to include both new data acquisition synchronous and asynchronous channels and publishing services. In addition, the use of the "Observer" pattern in the layer in charge of communication with user's applications allows the included publishing services to be implemented both following the model client/server and the model publisher/subscriber. Considering this, it is clear that DADIS provides several useful functionalities for the global system:

- Flexible incorporation of new data collection devices that provide information through different communication channels.
- Flexible incorporation of new publishing services that can be added in a simple way, without affecting other server parts.
- Persistent and parametric measure storage.
- Incorporation of new management systems to accomplish tasks linked to remote management in a flexible way.

The DADIS implementation has been developed in JAVA programming language with the support of several associated libraries and frameworks.

- For acquisition, the BACnet adapter was implemented with the support of the BACnet4J (BACnet4J) library. Both synchronous (collecting data every 10 seconds) and asynchronous (with a previous subscription to values or status changes) have been used.
- For storage in database, the Java's JPA specification, which allows to use every single SQL database engine in a transparent way and without changing the code, provided that the data model described later by this document is respected.
- For data publishing, the model "Request/Response" was implemented through the HTTP protocol, using the RestFull paradigm and selecting Json as data exchange format. The framework SparkJava (Spark Java) was used to do it.

4.1.1.1. BACNET PROTOCOL

The University owns an intelligent building management system to act on the structures in a remote way from a centralised position, in a control centre that belongs to the energy and sustainability area of the University. For the communication between the Scada building actuation and control tools and the automatons that control the buildings, it is used a set of elements that employs BacNET protocol as communication system.

BACnet is a communications protocol, an international standard of data communication used in automation and Building Management Systems (BMS). It is an open technology, as every manufacturer can use this protocol to transfer data from the connected devices: pump, valves, boilers, coolers, sensors, etc.

It is specifically designed for building automation and it is highly scalable so it is suitable for both small communication systems (domotics) and big ones (inmotics): hotels, hospitals, airports, industrial systems, etc.

With BACnet, the operator can control the connected devices from a remote position, including the start-stop, changes in the operating mode and configuration. The L BACnet devices also offer a huge choice of services such as data transfer, scheduling, monitoring, alarms, etc.

BACnet is mainly used in the same building applications:

- Heating, ventilating and air conditioning (HVAC)
- Lighting control
- Security systems and fire alarms
- Lift control
- Building Access control
- Energy management and control

The Figure 4.4 shows a typical configuration where it can be seen the flow from the installed devices in the buildings to the Scada application which is executed in the computer to allow us to act on them.

Figure 4.4. BACnet Protocol.

The BACnet protocol is used in the OPERE project to communicate with the buildings and get information about the status of devices associated to several systems: HVAC (Heating, ventilation and air conditioning), lighting and power supply.

4.2. INFORMATION STORAGE

A relational storage system has been selected as a support for information storage, specifically, the PostgreSQL database engine, the decision is based on the following features:

- It is an Open Source and can be used for free with the PostgreSQL License (PostgreSQL License, s.f.), similar to BSD or MIT.
- It has got good documentation and a huge community that supports it.
- The OPERE team has had a satisfactory experience with it.
- There are great complementary tools: clients to consult, management, authentication, authorisation tools, etc.
- In general, it can be adapted to the project's needs and, specifically, it fulfills the efficiency requirements.

4.2.1. DATA MODEL

As the system could not have been limited to a unique communication protocol- BACnet in this case-, a new model has been developed to show the complexity of sensorisation environments. For this reason, a flexible data model is proposed to store different measures obtained through different data collection devices that provide all the information from the monitored building. The model also storages the information required to reach every signal independently from the communication protocol followed by the involved devices. Protocol that-obviously- will be solved in the previous layer.

In spite of the required flexibility, it has been implemented an essential model that could be generalised to other protocols but-in this case- it has been specialised in the used BACnet model. The model includes the following elements:

- **Facility.** It refers to the section or part that is being considered at the moment to distinguish one from the others.
- **Device.** It refers to the equipment that acts on the buildings' facilities performing different tasks.
- **Property.** All the elements that are analysed in the facilities: temperature, status of the valve, etc.
- **Measure.** The element that links the devices with the properties measured in the facilities.
- **Uom.** This element refers to every unit linked to measures.
- **Observation.** It refers to the value for every single time which has a specific property associated to every measure. Observations can be divided into two different types according to the kind of values considered in every case.
    - **BooleanObservation.** It is used to storage values associated to status when they are binary: open/closed, on/off, etc.
    - **MeasureObservation.** It is used to storage numerical values associated to measures obtained from devices.

As the used model has not been optimized to the BACnet protocol, there have been some performance problems during the development of the project so the model has been modified to guarantee a suitable response to the reading and writing speed required by the project. These are the performed optimization operations:

- The storage of synchronous and asynchronous signals has been separated into two different tables because synchronous writing data rate is much higher.
- Tables have been created to include the last datum from every kind of observation and status which are updated every time they obtain a new information. This allows tot get a quick access to the last registered value for every measure as this is something often required.
- A different database instance is used for every single building. This allows to distribute the charge and the storage to adjust them to the available computational resources.
- The table that storages the synchronous data every 10 seconds (the one with the biggest growth) has been partitioned into a set of specific tables, one for every single month. This allows quicker searches as the tables are smaller.

— Several indexes have been included according to the requirements of the usual searches in order to improve access time. A standard time for usual searches has been reduced from 400 seconds to less than 1 second just using the suitable indexes.

Finally, the model showed by the Figure 4.5 has been obtained.

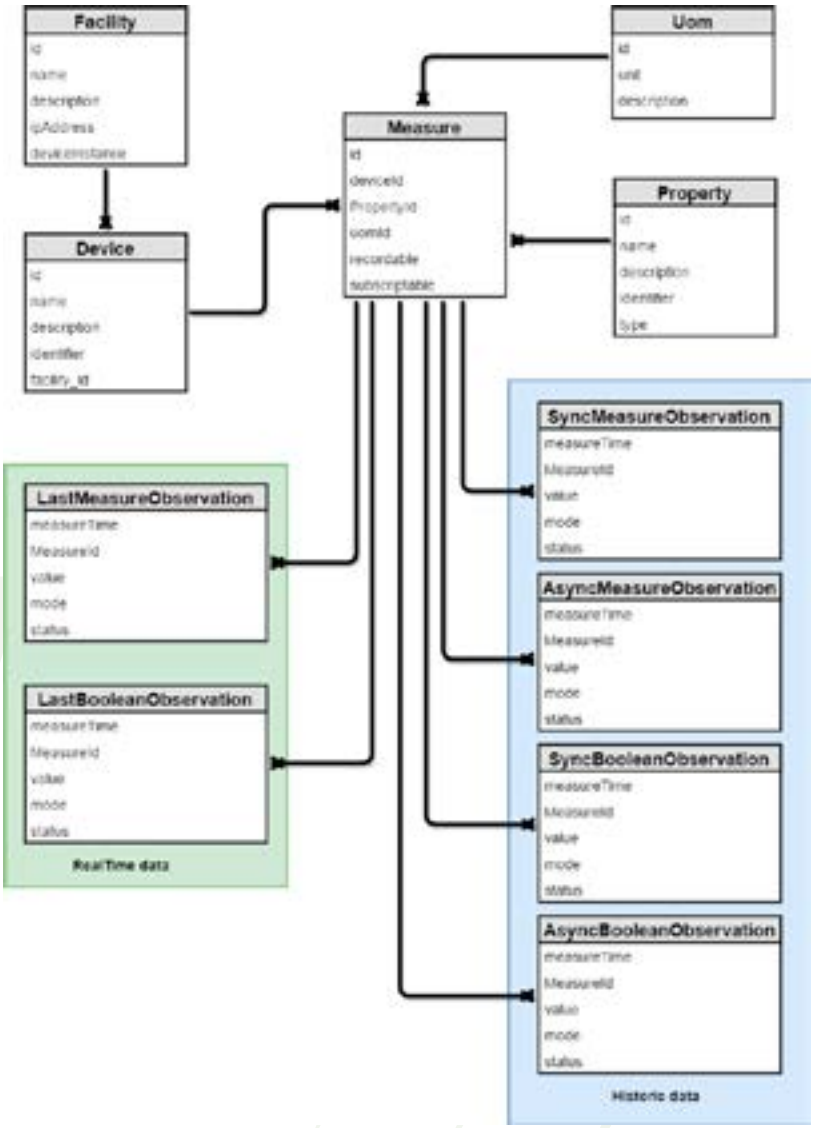

Figure 4.5.Data Model.

4.3. DISSEMINATION: DATA ACCESS SERVICES

In order to allow the access to data stored in the database, a set of applications has been developed. This will provide the services to offer the data through the APIs Rest, specifically designed to every service and implemented on the HTTP data exchange protocol in JSON format.

Firstly, the development of these services was designed for a monolithic application, which -in fact- took advantage of the upper layers of the described DADIS module. However, this model was discarded as the project's evolution took us to an environment in which information could be stored in different databases present -even- in different machines. Furthermore, the presentation layer required applications with very different needs that could be easily replicated, - even by only one operator-, by only opening more tabs or instances of a browser. As a consequence, the possibility of developing a layer based on microservices was analyzed and it offered several advantages:

- Possibility of scaling different APIs separately: It is obvious that some APIs will have more computational demand than the others.
- It is possible to have a different database for every microservice and this allows to optimize the Access in every case and distribute them into different servers according to their needs and performance.
- It is not necessary to consider other different functionalities when we work with every specific functionality so we get a completely decoupled system.
- It is possible to set the parameters for security, scalability, configuration, etc. in an independent way with every microservice.

The infrastructure in which the system is deployed has a very particular feature related to the fact that-due to security matters- the building and device data network (building network) is partially isolated from the corporative University network (administrative network). It is possible to access the administrative network from the building network but not in the opposite direction, as it is showed in the Figure 4.6.

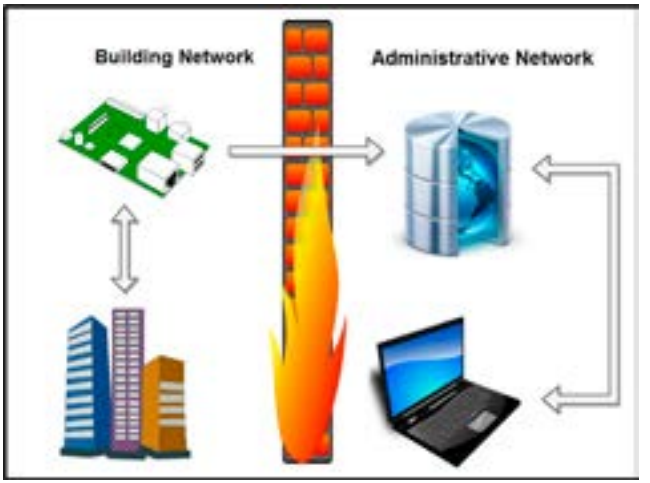

Figura 4.6. Arquitectura de red.

The problem appears because data and services must be available on the administrative network in order to allow operators to access them. This situation forced the division of the DADIS module so an instance uses the acquisition layer in the building network while the other uses the dissemination layer in the administrative network to provide the applications of the presentation layer with data. Later, as it has been mentioned, the implementation of the dissemination layer was redesigned on an architecture based on microservices, instead of the monolithic architecture of DADIS, by using the Spring Cloud (Spring Cloud) development framework, which provide us with a set of basic functionalities previously implemented in the architectural model chosen:

— Centralised configuration server. This server allows to get the configuration of all the APIs in a centralised point and the server provides configuration parameters required by every microservice.

— Service discovery. This service allows the microservice to join a “Yellow pages” service where they can interact with each other in a simple and transparent way, without knowing details about where and how are they being executed.

— Service API Gateway. This component centralises the access to APIs in a unique point, so it receives all the requests to redirect them to the corresponding microservice.

Bearing this in mind, it has been developed a set of services to Access the available information about the facilities through an API.

The **“BuildingServ”** service provides basic information about the buildings which are being monitored by the University. This service is used by the applications of the presentation layer as an entrance to the dissemination layer, given that access information is required to access any building information, this exactly what service provides.

"CoreServ" service provides Access to the data related to the different sensors and actuators (observations and status) in the buildings. The asynchronous observations and the statuses are transmitted according to the time frequency set in the database. The synchronous observations (updated in the database every 10 seconds), are showed every 10 minutes in order to reduce the data while it keeps a suitable frequency for the display tool.

The **"ScheduleServ"** interacts directly with the buildings (no through the database) in order to supply the functionality of getting schedules linked to different elements with an associated calendar: boilers, lighting, HDW, etc. Through this service, it is possible to display the values of the current schedules of the different elements in the building or accomplish changes on them and save them in the buildings' automatons to be configurated later.

The **"GridServ"** service allows to perform CRUD operations (Create, Retrieve, Update, Delete) on "Backend" to store and recover configuration parameters of the mosaic and tables display screen, described later.

The **"RulesServ"** service allows to accomplish CRUD operations to manage the rules showed by the rules screen. It eases communication with "Backend" in order to create, edit, read or eliminate rules that will be later executed by the rules execution engine in a regular way. The rules execution engine will be later described in this document.

4.4. PRESENTATION

With the purpose of allowing the users to display the building status through the data collected and some analysis on them to find improvements in energy efficiency, it has been created a new web application that requires a set of tools for the data collected in the buildings and stored in the database that can be accessed through APIs that connect with the services described in the previous section.

The main users of the application are part of the energy efficiency staff of the University and they are going to use the application mainly in personal computers, but a great effort has been made to get a responsive implementation. This means that the visual appearance can be adapted to every kind and size of screen in all the different devices: mobile phones, tablets… just in case they may be used in other devices different from PCs in the future. In order to provide "responsive" features, the chosen framework was Bootstrap (Bootstrap), a free Open Source tool.

An important part of the screens that are part of web tools developed include some kind of graphics to show the data associated to the sensors and actuators of the monitored facilities. In order to ease the integration of the mentioned graphics in the screens it is used the Highcharts (Highcharts) library, it facilitates the creation of web environments with a huge choice of different graphics: time series, bars, pie charts, etc.

The selection of Highcharts as a graphic creator library was made according to the following criteria:

— The OPERE development team has previous experience in the generation of graphics with this kind of library.

— The library graphics catalogue includes all the types we need for our application.

— The library is Open Source and is free for no commercial uses.

— There exists good documentation about the library with a huge community.

The general idea behind the development of tools for data display is to offer a set of useful screens with graphics based on the data stored in the database so the operators can evaluate the status and performance of the facilities over time. The access to data from web tools is performed through AJAX calls to the server by using the implemented APIs to Access every single implemented service described in the previous section. The user can interact with the tools to configure some of the parameters of the data request such as signal selection, time interval, among other aspects, to see the data which the user is interested. Once data have been obtained and represented, a visual analysis can be performed to determine the time evolution of the parameters or to compare them. In the case the tool's functionalities were not enough to fulfill the users purposes, there is an export functionality to perform a more exhaustive analysis of data, the supported export formats are the following: image files in different formats, csv files or Microsoft Excel files.

Down below, the main screens that form the display tools as well as their functionalities are described.

4.4.1. 24 HOURS GRID TOOL

We can connect with the web portal through a browser and then we are redirected to the screen linked to the Grid tool. Its screen allows to generate a mosaic of graphs with time series previously configured by users to get interesting data for them.

This screen allows to configure the signals we want to display through a set of panels and then the data of those signals can be displayed for the last 24 hours while they are updated with the new real-time data coming from the buildings.

The first step is to configure the different panels to be generated. This panel include the following functionalities:

— The panel is given a name to identify it.

— Every panel is given different graphs with their own title and they are distributed on the panel to create a mosaic.

— The signals to be showed in every graph are selected. It is possible to mix signals form several buildings. In addition, it is possible to modify the name of the signals, select the reference vertical axis (right or left) and change some visual parameters.

All this configured information is stored in the "Backend" through the "GridServ" service so when user connects to the application the previously parameterized configuration is applied and it shows the configured display. The Figure 4.7 shows its appearance.

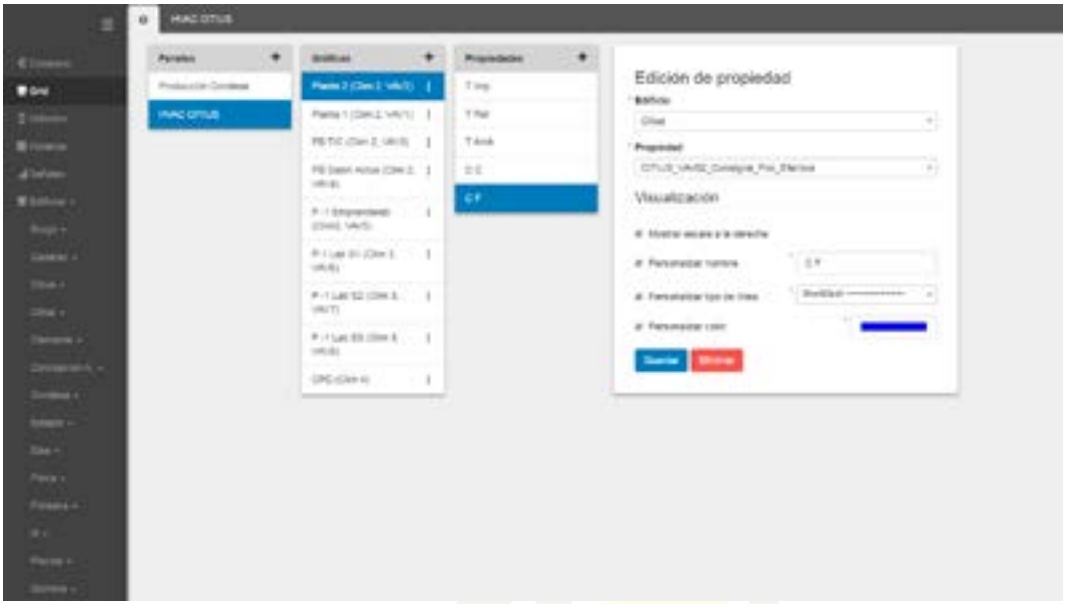

Figure 4.7. GRID screen configuration.

Once the graph panels have been configured, they can be displayed. The functionality related to display allows to select the different generated panels so different tabs are created on the screen to show the content of every panel. When a tab is selected, it shows the signals corresponding to the last 24 hours, these data are updated with new data from the buildings and stored in a real-time database. A typical display is showed by the figure 4.8.

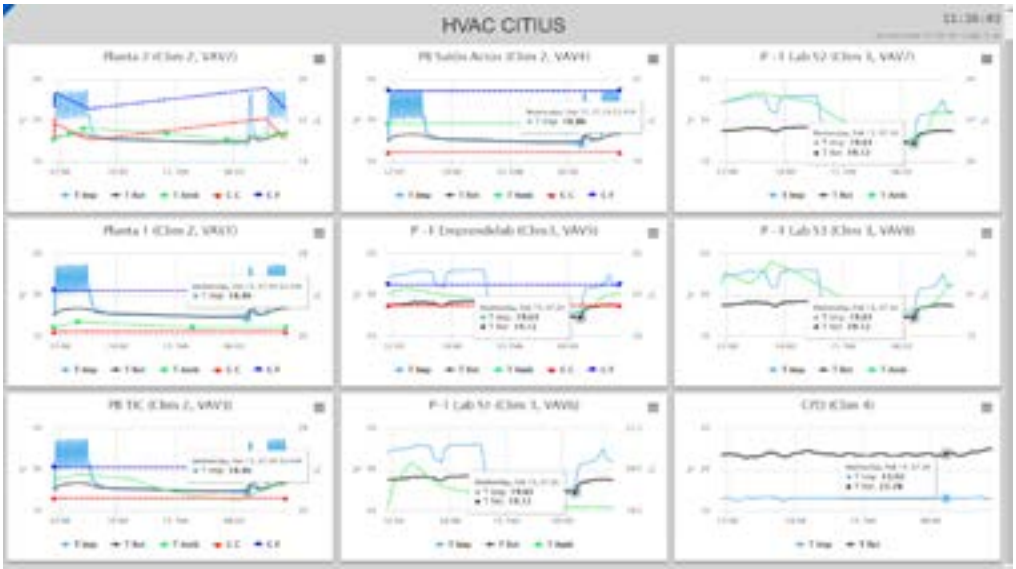

Figura 4.8. GRID screen display.

As it is showed in the figure 4.8, the tool does not only allow to show all the tables simultaneously, but also to place the cursor at every spot to get extra information from the drop down data (the specific value of the signal in the chosen moment), available in all the graphs.

4.4.2. DATA HISTORY FOR SEVERAL BUILDINGS

Other of the available tools on the side menu is the one to display the data history screen, one of the most important functionalities. It allows to access the data history from the buildings sensors and actuators by choosing the interesting signals and a specific time period. The screen can also be used to create tables with time series corresponding to the signal selection and the time period selected by the user.

This functionality allows the operator to analyze the evolution of the value of different signals over time. It provides knowledge about the performance of the buildings' facilities both through the display of a signal's evolution or a signal comparison (even from different buildings). In order to get information stored in the database to feed the screen, it is necessary the "CoreServ" service, described before, through its associated API.

The main functionalities associated to the screen are the following:

— Research on the building's signals to select the interesting one. It is possible to combine different signals from distinct buildings.

— Selection of the time interval on which base the tables.

— Possible graph about the operating time of a status in minutes.

— SynchroniSation between all the elements tables: tooltip, zoom and positional mark, to ease the visual comparison of signals.

— Data export to different formats: SVG, CSV, XLS, PNG, JPG

Besides the general data history display screen, the menu also includes a simplified version of the screen that limits the display to the data from a specific building.

Figure 4.9 shows the usual appearance of a data history display.

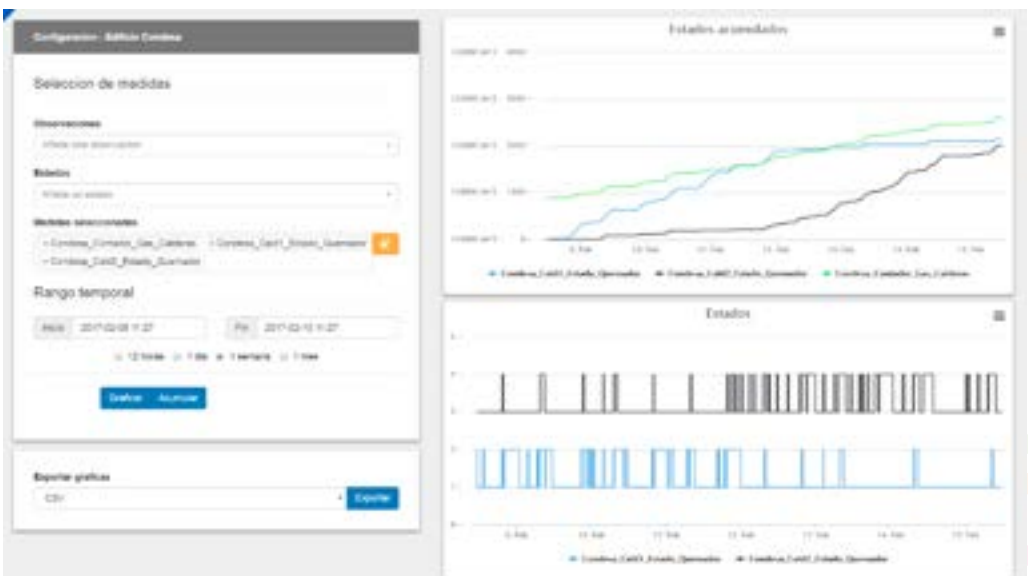

Figure 4.9. Data history screen.

4.4.3. SIGNAL LIST

The following tool is available on the portal's side menu. This screens provides a list of available monitored signals. The list is showed as a table for every single building and it also includes the latest data of every signal, the date and the values stored in the database.

As in the previous case, this application relies on a simplified version for the signals of a single building and other generic one which allows to combine- in the same table- data from different buildings.

The functionalities provided by the screen are the following:

— Possibility of searching for the signals and paging the results.

— Possibility of exporting data that are being displayed in a precise moment to different interesting formats: csv, Excel or pdf files.

The Figure 4.10 shows the usual appearance of the screen.

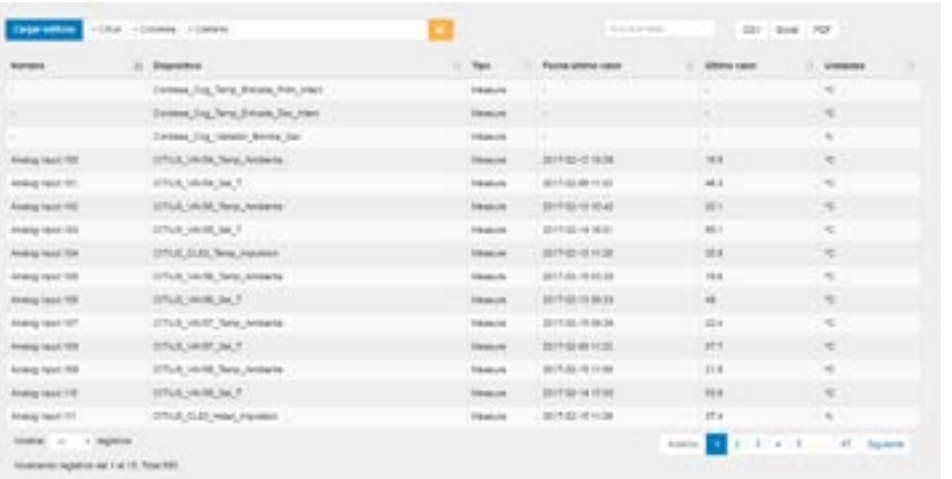

Figure 4.10. Monitored signal list.

4.4.4. TOOLS FOR THE PILOT BUILDING

The pilot building associated to the (Monte de la Condesa) project shows a set of distinctive features in relation to other buildings in the University, specifically, it has a cogeneration engine which produces electric and thermal power from gas consumption. Furthermore, thermal energy is stored in a set of tanks installed with that purpose, so energy can be later used on- demand. In addition, it also includes a useful control panel that provides monthly consumption associated to the building needs (gas, electricity and water). For this reason, it also includes a tool to display both monthly consumption and the specific buffer status over time.

The first commented tool offers an overview screen with the building consumption which includes the following elements:

- A section with a picture of the building and some basic information about it.
- A three-tables set that shows the gas, energy and water total consumption levels during the last 30 days.
- A table about the monthly gas consumption for the last 6 months.
- A table about the monthly heat consumption in the different building's sectors in the last 6 months.
- A table about the monthly water consumption in the different building's sectors in the last 6 months.
- A widget showing the meteorological conditions around the building. These data are provided by the local meteorological agency, MeteoGalicia (MeteoGalicia).

The Figure 4.11 shows the usual appearance of the screen showing consumptions.

Figure 4.11. Condesa CMI screen.

This concept can be extended to other buildings and it is possible to change the time element so we can see daily, weekly or annual overviews as well as the monthly one.

Another screen has also been associated to the pilot building to show the buffer tanks. Buffer consists of 10 tanks with a capacity of 5000 litres/unit to store hot water. The purpose is to keep them monitored in an individual way. Every single tank has temperature probes at the top, in the middle and at the bottom part in order to know the inner temperature on different levels and calculate the useful thermal power stored in the tanks.

A screen has been developed to show the values of different parameters during the last 24/48 hours or the last week. Its purpose is to obtain a visual overview on the present buffer status, which-in an indirect way- provides an idea about the balance between production and thermal consumption. The considered parameters are the following:

— Time series about tanks' temperature at the top, in the middle and at the bottom during a specific moment.

— Time series about the average temperature in every segment of the tank (top, middle, bottom).

— Time series about the thermal energy stored in the tanks, showing its usefulness according to the following criteria:

  - If there are less than 500 kWh of stored energy, it is not useful to supply neither heating nor DHW.
  - It is not possible to store more than 2000kWh because -from that limit- the tanks' temperature is too high to cool the cogeneration engine.

— The present percentage of useful thermal power.

Data can be exported to CSV, Excel or image formats to perform operations on the graphs.

Figure 4.12 shows a screen capture associated with inertial monitoring.

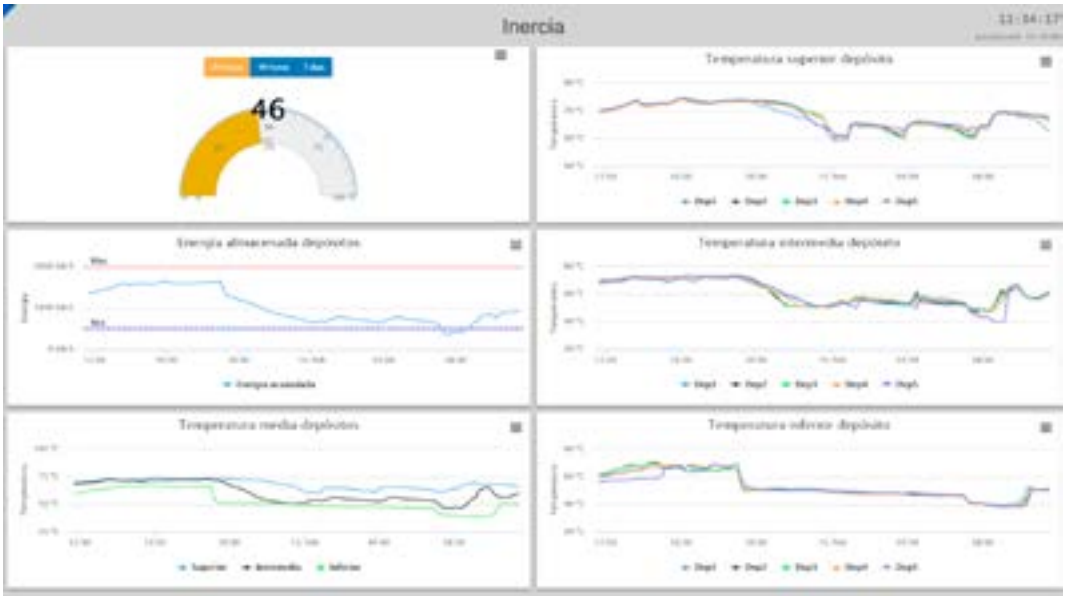

Figure 4.12. Condesa buffer screen.

4.5. OTHER TOOLS

Apart from the main functionality that is obtained with the functions previously described, there are also several satellite applications that are also useful for the goal fulfillment. They are mentioned and briefly described hereunder.

4.5.1. SCHEDULES MODIFICATIONS

Some of the devices in buildings, such as boilers and lighting systems, have a calendar associated to them in order to control -weekly- the authorisation periods to operate. In order to manage the configuration of these schedules in an efficient way, there is a screen to show this configuration in every single building.

Figure 4.13. Schedule management screen.

The schedule screen, showed in the figure 4.13, allows us to list the available schedules for every building and select them to be displayed on the week days; observing the authorisation and disavowal hours in an intuitive way.

The functionalities associated to this application are the following:

- Display of the different selected schedules associated to a specific building on a weekly calendar to evaluate and compare several of them.
- Possibility of modifying different schedules in a simple way through the intuitive actions with the mouse.
- Applying the schedule designed for a day to the rest of the week.
- Modifying and sending the schedules to the buildings to set them as the new timetables associated to the devices or cancelling the operation to go back to the initial status, before the modifications.

4.5.2. RULES EXECUTION SYSTEM

The possibility of programming alerts which will be sent to the control operators in the building if the performance does not match the set parameters has been identified as a useful functionality. For this reason, it has been developed an application that allows to insert a set of rules which consists of a group of conditions about the observations that- in case of being fulfilled, starts an associated action. In this case, the action consists in notifying the users through some of the following means: email, chat message through Hangouts (HangOuts) or chat message through Slack (Slack). The tool Drools (Drools) has been set as the inference engine for the rules evaluation.

The purpose of the application is to allow users to program the rules to warn them in case of problems or malfunctions in the facilities to know the events as soon as possible and take actions in order to minimise the impact noticed by the facilities' users.

The rules to execute are stored in a database and they can be accessed through the corresponding API.

Furthermore, there is a screen that lists the stored rules to allow users to check them. It also includes the following information about them:

- Associated name for every single rule that provides information about its task.
- A visual screen to confirm if the rules are or not active, as some rules can be deactivated to avoid being executed but they are still available.
- It is possible to check in which day of the week and in which periods rules are considered for the inference engine.
- Required conditions about observations to implement the rule.
- Display of the message sent to the notification system in case of the rule implementation. This is the action generated when a rule is implemented.

The Figure 4.14 shows the rules screen, a list of rules which are currently being -periodically- checked in the pilot building.

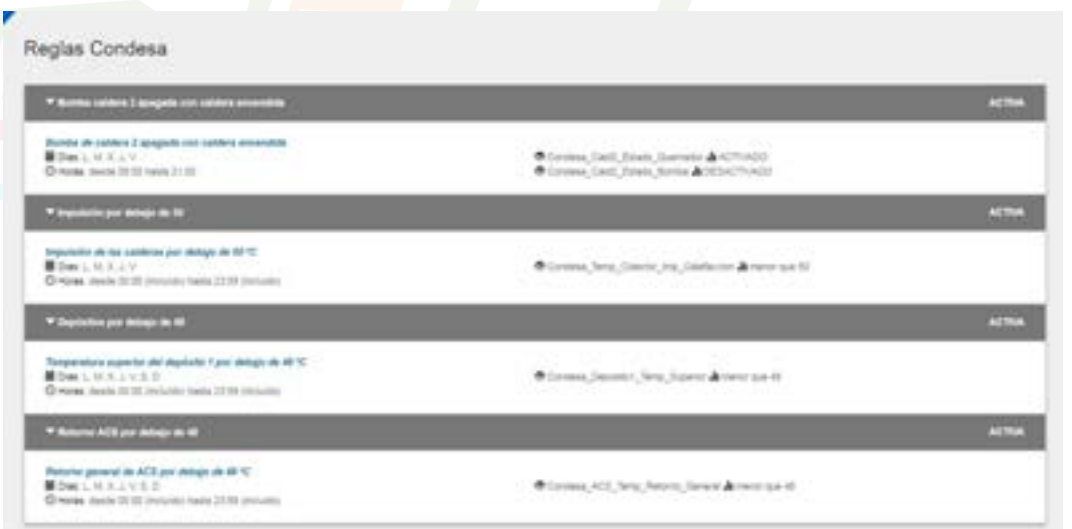

Figure 4.14. Rule display screen

Chapter 5

Implementation of an Energy Management System in Existing Facilities

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Juan E. Arias Rodríguez

5.1. INTRODUCTION

As it has been showed in the previous chapter, Energy Management Systems (EMG) are used to control and reduce energy consumption linked to the entity whose energy is being considered. This requires different human resources whose purpose is to set guidelines to do so. They are based on the analysis and action plans in synergy with the control tools and the extraction of processed fundamental information which supports the abovementioned guidelines (often based on Information Technologies, IT). Thus, EMG are linked to energy control of its associated elements, it means, systems or tools which must allow knowledge and management of the main energy flows involved in the process. On the other side, it has been showed that the OPERE Project has the aim of getting a reduction in energy consumption, expenses and pollution linked to energy generation of the Monte de la Condesa Complex. In the Chapter 3, a set of measures were suggested to achieve this goal. Their success must be evaluated and promoted through the operational setting up of IT tools for the EMG, as described in Chapter 4.

This chapter includes the implementation of supporting tools for the EMG. In order to perform it, this implementation must consider two types of infrastructure: the reform project accomplished in the MdC complex, and the support based on IT which allows to develop its functionalities (Figure 5.1). Both aspects, implementation of improving measures in the reform project and setting up of IT support- will be firstly described in this chapter. In this way, both the reform project execution, the civil work -including the implementation of the different energy systems as well as the adaptation of facilities- and the IT infrastructures required to implement the data storage, processing and monitoring tools of the EMS. Next, the Smart-grid -linked to energy systems of the project- and their control rules will be also introduced. In that sense, it must be underlined that the signals which feed the upper layer of the IT tool of the EMS come from the mentioned Smart-grid, in other words, from the automated acquisition and control system existing in the facilities (SCADA). These signals are processed and stored- as mentioned- using the IT infrastructure to get an optimal analysis. Next, the implementation and operability of the Energy Management Sytem Tool (EMST) will be described, setting its bases on:

— Supply or existing available energy sources.

— ransformation of that energy into useful energy through the corresponding generators.

— Energy consumption in the demanding and distribution areas.

From this structure, the EMST will be set as an energy processing, storage and analysis tool from the primary sources to its use, focusing on the interrelation between the acquired signals and its requirements to describe the performance of both systems and the general project. In this way, several elements of the system will be showed separately and the main information processed a priori to describe their functioning statuses, according to available signals. Considering all the previous elements, and through the mentioned history of the mentioned signals associated with the EMST, both operability to evaluate the basic functioning of the system during its start-up and the observations about this process. Finally, the first conclusions and performed improvements according them will be finally presented. This will be followed by a general functioning time scheme during the whole project's Demonstrative Period.

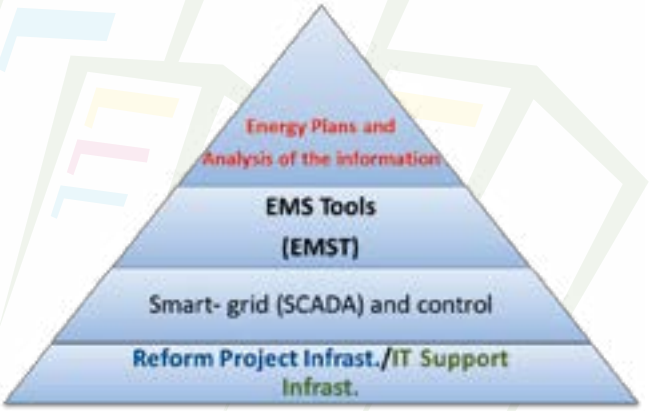


Figure 5.1. Energy Management System Constitutive Scheme.

5.2. EMS: SYSTEM INFRASTRUCTURE

As described in the introduction, this chapter will show the execution of the implementation process of the set of energy systems and elements linked to energy efficiency measures proposed in the Chapter 3. These systems are the ones in which tools -which support the EMS of the OPERE Project- are implemented. These tools are also designed according to the mentioned systems. Therefore, the mentioned implementation is, as it has been told in advance, one of the key elements of the EMS.

On the other hand, while members of the USC, EnergyLab and Magara Ingeniería S.L. took part as main actors in the previous proposal development, the civil work was accomplished by UTE FONCAFER SL Y CASTAÑO BASCOY SLU. This company was in charge of the start-up of all the systems involved in the actions. It has also received the material and executed the installation and the civil work.

Hereinafter, all the aspects and fundamental elements linked to that execution will be showed separately:

Civil Work

During the whole reform process, the boiler room was remodeled, thus it was divided into two rooms: one to install new boilers and other for the buffer tanks (Figure 5.2). During this process, enclosures were improved, cooling system was improved and the terrace on the room was waterproofed. In addition, a comprehensive modification was performed on the electrical systems of the used rooms and their control panels.

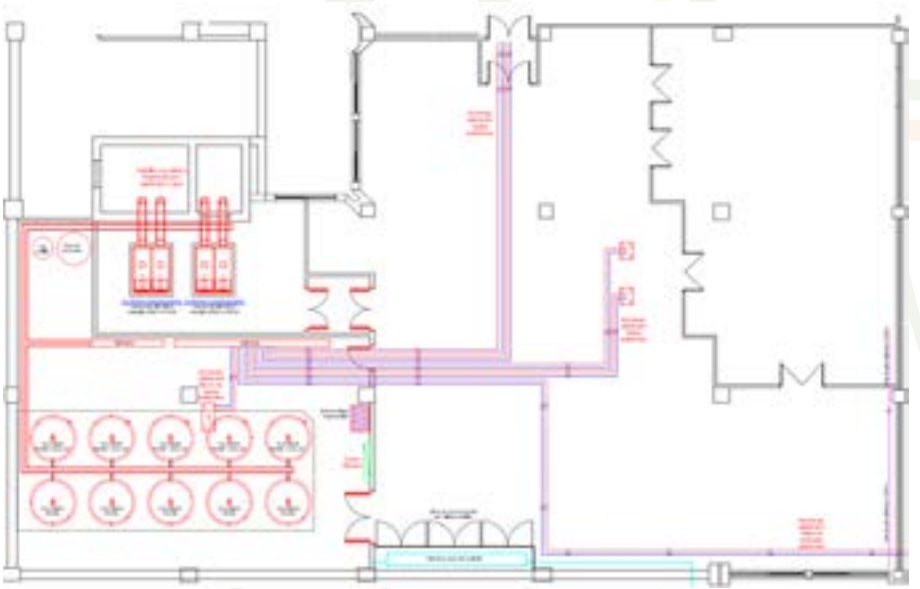


Figure 5.2. New Boiler Room Blueprint.

Natural Gas Installation

As it has been showed in Chapter 3, essential energy optimization measures of the systems include replacing diesel oil - previously used as combustible in boilers- with natural gas. The supply facility was already installed before the reform process, as this combustible was already used by the cogeneration engine which previously worked in the facilities. This change transforms natural gas into the unique primary source of energy in the building.

Implementation of Condensation Boilers

As it has been mentioned above, thermal production comes from the installation of two high-efficency gas natural condensation boilers whose power -in any case- is measured to be self-sufficient and fullfil the building's thermal demand. In this way, supply is guaranteed in case of malfunction in one of those boilers. The maximum power in each case is 1.148 kW.

The initial start-up of these elements was performed by the Centro Técnico Astyco S.L and it consisted in the adjusting their burners to get a percentage of oxygen levels smoke flows, carbon monoxide and smoke temperatures within the boundaries stablished by the manufacturer. It must be underlined that every single boiler is formed by two blocks which operate as boilers by themselve, this is the reason why there are four columns on the table. The obtained results were the following:

ANALYSED PARAMETER	Generator 1	Generator 2	Generator 3	Generator 4
Oxygen 0_2	5.4 %	5.4 %	5.4 %	5.3 %
Carbon Dioxide CO_2	8.7 %	8.7 %	8.7 %	8.7 %
Air Excess λ, n	1.34	1.34	1.34	1.34
Fumes Temp. T fumes	25.9 ºC	28.3 ºC	27.8 ºC	26.0 ºC
Air Temp. T air	18.6 ºC	19.5 ºC	19.1 ºC	18.2 ºC
DDifference TªΔT	7.3 ºC	8.8 ºC	8.7 ºC	7.8 ºC
Efficiency without condensation ηs	99.7 %	99.6 %	99.6 %	99.6 %
RRendimiento with condensation ηc	9.5 %	9.1 %	9.5 %	9.5 %
RTotal combustion efficiency n ηt	109.2 %	108.7%	108.8 %	109.0%
Carbon Monoxide CO	13 ppm	14 ppm	15 ppm	29 ppm
Reference Oxygen. Ref O_2	0.0 %	0.0 %	0.0 %	0.0 %
Corrected CO CO ref	18 ppm	18 ppm	20 ppm	39 ppm
Air intake	0.000 hPa	-0.020 hPa	0.012 hPa	-0.006 hPa
Result	0k	0k	0k	Ok

Table 5.1. Results of the combustion test performed in every boiler.

The test was considered as finished once all the equipment can work properly -with the complete installation performed- during a period from 24 to 120 hours, without any essential mistake, primary equipment shot (emergency stop) or critical alarm (high temperature with low oil pressure, high temperature with electrical windings, etc.).

Cogeneration Engine

The cogeneration is other energy generator existing in the building complex. It is designed -on the one side- to produce electric power which is fed into the University's ring circuit and -on the other-to recover some of its thermal losses in order to use them as a thermal source for the building. This last process was not being performed sucessfully, this is why an important modification was accomplished in the system. It basically consisted in adding thermal inertia accumulators, as it will be showed below.

Figure 5.3. Cogeneration Engine.

Improvement in The Thermal Recovery of The Cogeneration Engines: Buffer Tanks

The thermal recovery expected from the engine under full load depends on its liner cooling system, as well as on the exhaust fumes sector (170 y 115 kW, respectively). The engine operates only during periods of time when it is economically profitable (both daily and seasonally), or just the required by electricity demands. It is usually working between 8:00 and 00:00 h. Previoulsy, its thermal use was limited to the instant demand of the building, which was reduced during a significant part of the day. In this way, a deficient energy management was performed during low thermal demand periods, with important losses and problems in the engine's cooling and operating.

Figure 5.4. Inertia Tank + HDW Instant production.

In order to solve this situation, 10 buffer tanks have been installed to soften these effects, store energy when the building's thermal demand is low and provide it when the mentioned demand increases. In this way it is possible to recover and store more energy, and the result is a more efficient use, as the engine under suitable conditions and the boilers don´t need to provide as much energy. The mentioned energy is transferred to the engine recovery loop and to those linked to the buffer tanks through a plate exchanger (Figure 5.5). It is also added a pump with speed shifter in order to adjust the flow according to the return temperature, with the purpose of keeping the engine working in a more steady state and increase the temperature range.

Figure 5.5. Heat Exchange Zone between Cogeneration and Accumulation. The pump with speed shifter and the plate exchanger are also observed.

Production of Hot Domestic Water (HDW)

As far as hot domestic water is concerned, a change has been performed on the HDW production paradigm. Instant generation through a corrugated heat coil inside the five buffer tanks which allows heating while the water ascends across the tanks. In this way, HDW in a tight circuit, without storage, so anti legionella treatments are not necessary.

Reform of The Hydraulic Power System

Due to important changes in the systems, a hydraulic reform was accomplished in all the rooms of the production plants and -also- in all the water supply connections. This reform reduce losses related to water distribution and recirculation in a significant way. In contrast with the previous situation, the changes in the design of the system meant a centralisation of all the sectors in a unique impeller collector and a return manifold, among which different secondary circuits operate. These collectors are connected-respectively- to the higher and the lower -or medium- parts of the tanks, according to the operation status. In the same way, high efficiency circulating pumps and mixing valves were also installed.

5.3. EMS: IT SUPPORT STRUCTURE. MONITORING SYSTEM

The second main element in the base of EMS is linked to information technologies required to the suitable processing, treatment and storage of data involved in systems. As seen in Chapter 4- and it will be detailed in the section 5.4-, existing infrastructures consisted of a SCADA software system to automatically control and display the different element in the systems. It was not enough to the functions and power required by an EMS. To do it,the improvements described in the mentioned chapter were proposed in order to get the required features of the EMST, based on the pilot project's signals. As it will be later showed, they are specifically 303 signals that must be treated according to the all the in the Chapter 4, what demands some IT resources and infrastructure which are hereafter summarised here:

- Network infraestructure to connect with the monitored buildings.
- Machines that allow to execute data capture processes and send the information to storage systems.
- Servers for the databases that storage the collected information.
- Servers to deploy all the different APIs and web tools.

Under the network structure's point of view, and among the eventualities related to the system's implementation, it's verified that -in the University- is set a separation between the corporative and the specific network to manage the buildings; with the special feature of having visibility (in other words, it is possible to perform the connection) from the building management network to the corporative one, but not in the opposite direction. Due to this restriction, and also to the fact that operators need to access the information from the corporative network, it has been decided to install machines, involved in the data capture process, connected to the building network while, in the case of databases and the web tools, the connection has been set with the corporative network.

The data capture process does not involve a great computational load, as the buildings automatons are the ones that -under demand- collect data from the different sensor and actuator devices in order to send it to the ordering element. For this reason, several tests have been performed using both conventional desktops and laptops and low-consumption hardware such as Raspberry PI[1] , resulting- all of them-suitable to accomplish the process.

On the other side, information storage requires a great computational load and storage needs. This is why different servers- used to set databases on a University's private cloud- have been deployed. This allows to access a great choice of required resources, according to the demand, without the buying or renting extra equipment to perform the required tasks. The same strategy has been also used with servers that provide service to the different deployed applications and deployed on the same private cloud to which the University allows to access.

Below, a diagram to show the infrastructure used to the deployment of the different computational resources linked to the project:

1 (https://www.raspberrypi.org/) It is a ingle-plate computer developed by the s un computador de placa única desarrollado Raspberry Pi Fondation, with the purpose of stimulating computer science teaching in schools. In spite of this fact, it is completely efficient to perform data capture processes.

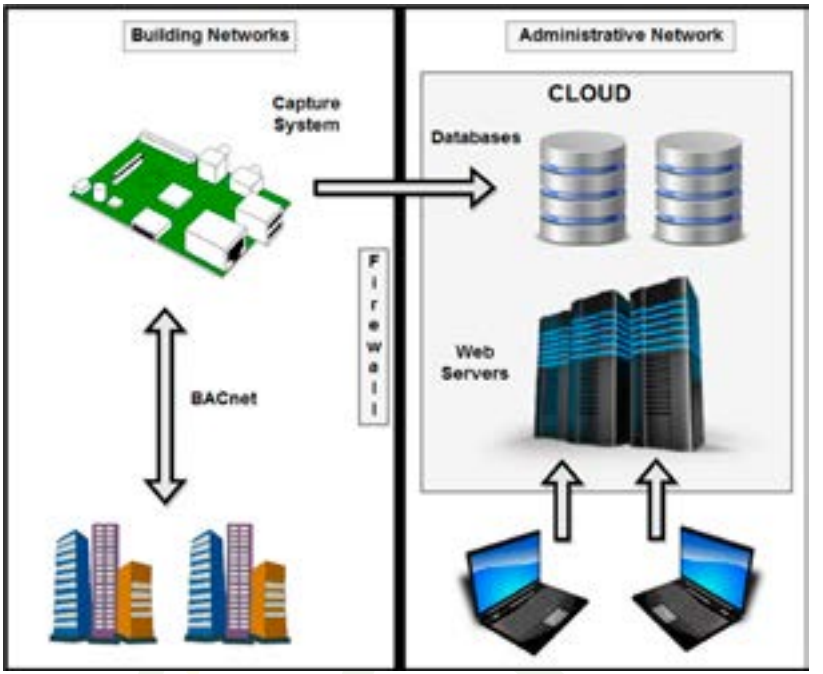


Figure 5.6. Scheme of the infrastructure used to implement and monitor the EMS.

The described infrastructure and showed in the figure allows to collect information from the building management networkd and make it available for the operators and users through software tools deployed on the University's corporative network. This allows the access from every machine connected to it. It is even possible to use an inverse proxy -provided by the university- to access from anywhere on the Internet.

The type of machines used to support the different described processes are described below:

To data acquisition, several Raspberry Pi, two laptop and a and an antique desktop have been used, as the computational requirements are not high. According the power of every device, this performs the data acquisition from one or several buildings. Two Cloud machines have been configured to host the servers. They have the following features:

- 2 1500Mhz cores
- 4 GB RAM
- 1 100GB hard disk
- Operative system Ubuntu Server 14.04

As the storage requirements are high, all those with 10 s sampling frequency are extracted at the beginning of every month to store them in a different hard disk.

As far as the equipment where the web applications are deployed, machines similar to the chosen ones have been configured for the database servers, although the RAM has been reduced to 3GB and the hard disk to 10 GB, as computational needs are lower.

This is how the require IT structures have been set, implementing at the same time an efficient, robust and usable storage and monitoring system.

5.4. EMS: EMS IT TOOLS.

Once the infrastructural bases of the EMS have been showed, in other words, the IT reform project and support, this section will describe the EMST by itself. The mentioned explanation will be divided into two main blocks: on the side, the description of the Smart-grid associated with the facilities, together with the operational rules and the sensorisation of its fundamental magnitudes, while, on the other side, it is also given a contextualised explanation about the EMST's requirements to fulfill its goals in a satisfactory way in the context of the Project and its EMS.

5.4.1. DESCRIPTON OF THE THERMAL SMART-GRID. SCADA SYSTEM.

The thermal Smart-grid and its regulation are managed through a control and data acquisition system of every SCADA systems (SCADA, from Sedical company), which will feed the monitoring of the EMST, showed in the previous section. This system performs the signal acquisition of the facilities and modifies the elements' functioning according to them. Due to this, during the implementation process of the reform project linked to optimization actions in the MdC complex, it has been necessary to reprogramme the existing automaton to perform the operations in correspondence with the new facilities and conceptions. It must be underlined that both in this sense and -also- in sensorisation, elements associated to the previous control system have - as far as possible- been recycled after remodeling and reprogramming processes. They have been adapted to the new needs. In particular, as the cogeneration system has not been substantially modified, and, furthermore, it includes its own automaton, the operating mode of this one has not been modified (although its management and energy use have -in fact-been modified).

SCADA provides the operators with display and control web tools in which different systems and components are schematized. Furthermore, their charactheristic variables are showed in real time as well as their energy consumption, showed by sectors. As mentioned in Chapter 4, this system is not enough to fulfill the requirements expected from a complete EMST, as it does not allow signal data storage and, in addition, it is not operational enough. For this reason, all its signals are used as an input of a higher-level system which can perform all the required tasks, completing the EMST, described and based on the 5.4.2.

Sensors and Signals Roster.

As mentioned in the section 5.3, the amount of signals associated with the Acquisition and Storage Module of the complex reaches 303. These can be itemised for the general user, in those cases which can be associated with the analysis-description of systems operating activities and also in those predominantly linked to the unique control of these. They are summarised and classified in the Table 5.2, and can be acquired both in a synchronous (sampled every 10 s) and in an asynchronous way, which are only sampled with a change in the values.

Category	Kind of Signals	Units.	Description
Thermal Supply (45)	Boilers Temperature	5	Of boiler supply and return to calculate its thermal leaps.
	Sectorisation Temperatures	12	Temperature of every sector's and impeller/return collectors to know their thermal leaps.
	Cogeneration Temperatures	4	All temperaturas linked to cogeneration around its exchanger, to calculate their thermal leaps.
	HDW Temperatures	9	All temperaturs related to HDW in the hemodonation centre and the Residence both those of every element as well as those of the supply and return collectors.
	Tank Temperatures	15	High, médium and low temperatures in every single buffer and HDW instant production tank.
Consumption (47)	Water, Gas and Thermal Energy	23	10 cold water, 2 hot water, 2 gas y 9 energy.
	Boiler and Burners Status	2	It allows to determine the operating time of boilers and burners.
	Electricity	22	Electricity consumption of every sector. Active, capacitive and inductive (kWh)
Control (211)	1Instructions 1Schedules 1Orders 2 Alarms 2 Statuses 2 Malfunctions 3Outdoor Temp.	211	All the other variable to know the status of the system all the time and guarantee that the analysed data are corresponded to correct funtioning schemes as well as identified time periods with abnormal data.

Table 5.2. Classification of Available Signals. In the Control Section signals are subdivided into different types: 1 Control, which set the operating mode; 2 Status, functioning and possible malfunctions in the elements; 3 Reference for the regulation and instructions.

Smart-grid Operational Rules

In reference to the rules of Smart-grid in the control of different essential elements included in generation systems (boilers and cogeneration), the programming of MCR Web automaton, from Sedical, activates the cogeneration engine when it is time to do it. It also regulates the flow of its pump according to the associated temperatures to get the optimal engine cooling. On the other hand, boilers are authorised at all times of the year, with their circulating pumps constantly activated at rated engine speed, in order to guarantee its optimal functioning to minimise the required energy use to keep necessary minimum required temperature at the top part of the tanks (which is the maximum value obtained from the maximum demanded for heating, among the different sectors, and the minimum required to keep the correct functioning of HDW).

On the other hand, the automaton allows to turn on or to turn off the pumps linked to every single heated sector and with HDW, according to schedules and instructions, as well as the use of mixing valves to regulate the setting temperature required in every case or sector.

The basic operation rules are summarised in:

— Service guarantee.

— Maximisation of cogeneration use/efficiency.

— Optimisation of buffer tanks.

— Management of setting temperatures according to the outdoor temperatures and compensation curves.

The first rule refers to the absolute priority of keeping the electric power and thermal energy supplying system in the MdC complex, under all circumstances independent of optimization concept as a criterion. As far as the second section, cogeneration must be operative, with the thermal energy use, as much as possible in the set schedule. On the other hand, how the third rule is performed through the maximisation of the energy with which the engine supplies every single tank, minimising the supply provided by the boilers to the indispensable minimum and maximizing- as well- the engine output temperature, in order to avoid cooling at the top of the tank caused by it, although this is often caused by a low flow.

Signal Verification.

As previously said, the EMS and its tools are fed through signals coming from sensors installed in the complex during the execution of the reform project, so it is essential that those signals work properly. The verification of this fact is verified through the signal searching performed by the SCADA system.

— There are no incongruities in the received data review with regard to the system from SEDICAL.

— On the other hand, it has been detected that forty signals are not showing the values expected from them. The criterion for it is that the signals show constant values or less than three received values:

- In the first group,it was confirmed that the two first detections, corresponding to the meter boxes, show some technical problem. In one of the cases, it is determined that the general water meter box is damaged, while in the other one, the hemodonation hot water meter box, analysed by inspection, works in a normal way, however, the values do not correspond with reality. This mistake is linked to the system, it has nothing to do with the elements checked in this test.

- The rest of signals, detected with constant values, are linked to operating instructions whose value had not required to be changed. It must be mentioned that the last detected signals, with constant value and without any identifier, correspond to network analisers that had not been in the system yet.

- As far as little variation signals are concerned, all of them correspond to fault, alarm or schedule signals so it was not expected to find changes in those signals.

5.4.2. EMS. INFORMATION AND TOOLS.

In this section, the EMST basis of operability will be discussed according to the energy flows in the systems and their characterisation, which is a key concept of the EMS. As mentioned in the introduction, the following scheme will be used as a base under the generation, flows and uses' point of view:

— Available energy sources.

— ransformation of energy into useful energy.

— Consumption in the demand and distribution zones.

Hereinafter, the scheme of the SCADA systems, that corresponds with the thermal energy generators, buffer tanks and circuits/sensors linked to them. The mentioned representation will be used to illustrate the different fundamental components of the reform project's facilities (from the showed scheme's point of view), as well as the main involved signals and their relevance in the facilities characterisation through the EMS.

Figure 5.7. SCADA Thermal and HDW Production Capture.

On the left part of the figure, it can be seen the two installed boilers with their impeller pumps, temperatures and associated valves; while, on the right side, the heat entrance from the cogeneration engine, the plate exchanger (which transfers energy from the primary cogeneration engine circuit to the secondary thermal energy circuit), temperatures and pumps with speed shifter. In effect, it can be seen how both generators inject energy in the higher part of the buffer tanks (represented in the central part), being the returns linked to the lower part of those tanks.

In terms of the energy thermal scheme showed at the beginning, the complete supply comes from natural gas, which is transformed into energy through generators with their correspondent efficiency. This energy is later distributed to buffer tanks and the consuming zones. As far as these zones are concerned, as commented in section 5.2, there exists a division between that linked to the heating and HDW consumption. The first is managed in a general way through a global impeller hot water collector connected to the high part of the tanks, while the second extracts energy from the tanks through an inner heating coil that instantaneously heats the water coming from the cold-water supply. The energy flow is - in both cases- finally distributed, in a sectored way, to the different consuming areas (see figure about heating sectors with signals, instructions and statuses), in other words, from those impeller collectors and HDW circuit. Regarding to HDW, given the big sizes and distances involved in the MdC complex there exists a recirculation circuit that is constantly operative, to get instantaneous obtainment of hot water in the consuming areas. Both that circuit and the plate exchanger used to heat recirculating water regularly, are represented at the top of the SCADA scheme in the Figure 5.7.

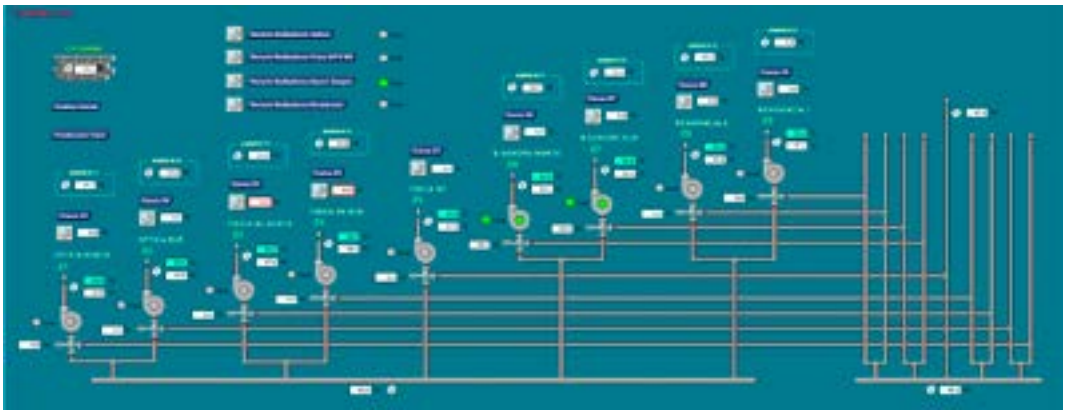


Figure 5.8. SCADA Heating and Sectors Capture.

In general, it can be considered that-after the reform project- there exists a primary circuit of energy provided by the generators and several secondary circuits that distribute that energy to the different consuming areas. (see Figure 5.9).

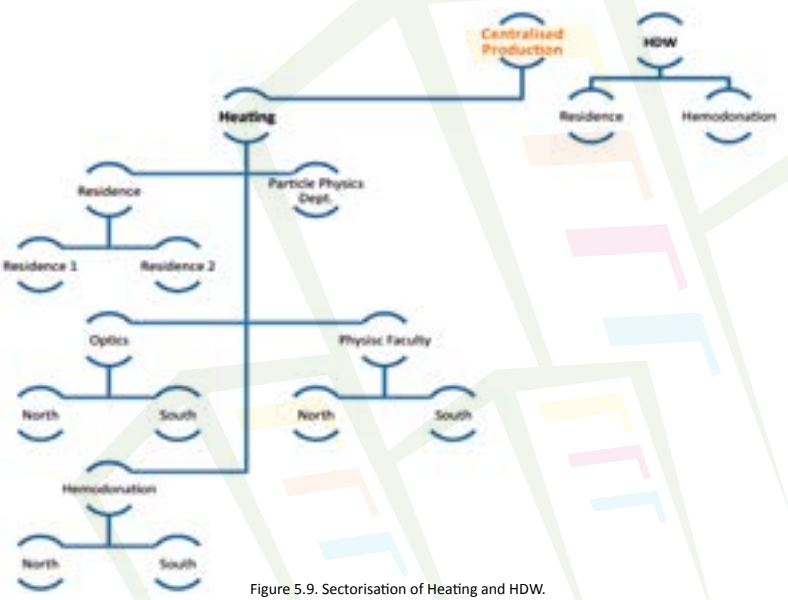


Figure 5.9. Sectorisation of Heating and HDW.

Sectorisation y sensorisation.

Giving more details about these last points, the sectorisation resulting from all the actions executed in the heating and HDW systems made possible the HDW availability in both the student residence (divided into two

blocks) and in the hemodonation bank with its water and energy meter boxes, whose energy is provided by the recirculation exchanger it has already seen.

On the other hand, as far as heating is concerned, the sectors of the student residences, hemodonation bank, Particle Physics department, School of Optics and physics Faculty consist -every single one- of one energy meter box, although -in some cases- there are two different sectors regulated in an independent way.

The Table 5.3 and the figure show how the meter boxes linked to that sectorisation are presented. Its relevance will be explained in the following section. It must be underlined that, besides the energy meter boxes showed by it, there also exist a water and natural gas meter box monitoring.

Sector	Meter Boxes
Residences 1 y 2	1 energy + 1 HDW
Particles Physics	1 energy
Optics Faculty	1 energy
Physics Faculty	1 energy
Blood Bank	1 energy + 1 HDW
Boilers	1 energy
Primary Cogeneration	1 energy
Secondary cogeneration	1 energy
HDW Exchanger	1 energy

Table 5.3. Roster of Energy and Consumption HDW Meter Boxes.

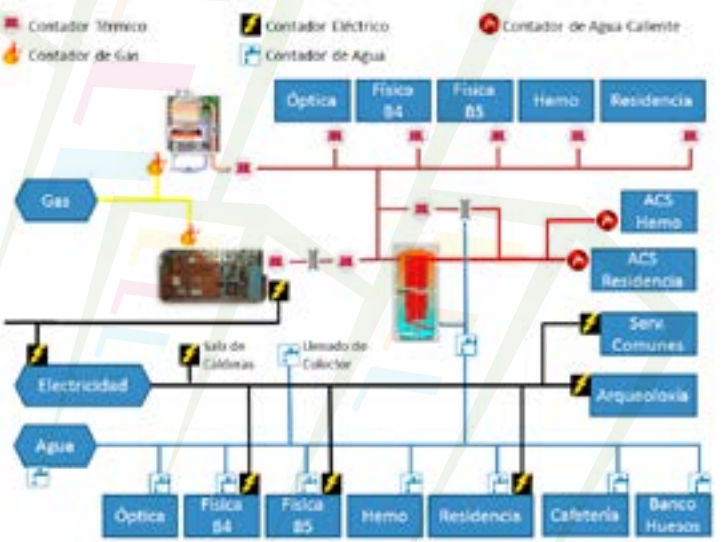


Figure 5.10. Meter Box Location

Energy Management and Signals

The EMS must be able to analyse and control every single part of the basic energy scheme: energy sources, flows, consumption. This is the reason why the EMST and the associated systems are fed according to the pyramid scheme showed in the Figure 5.1 of the introduction. As it has seen, it is crucial to have the possibility of performing this in a retrospective way, not only instantaneous, as -in this last case- there are not options to analyse and get a detailed report on time systems' performance, detection of possible problems, as well as general optimization of systems and the EMST itself.

Besides this, the description and analysis capacity required by the EMST is essential to evaluate the main elements of the OPERE Project, considering both high-scale analysis and higher level details. In this sense, it is essential to control the flows associated to energy sources, the quantity of energy injected into the facilities by generators (performance), the way in which it is distributed to the different elements and sectors, the energy use performed by them as well as the goal fulfilment, both under the efficient energy production and management's and the demands required by the facilities.

In order to do so and extract that high-level processed information for the EMST, it is necessary to have a set of variables and potentially descriptive signals of the systems' operation status, which will be treated by the mentioned EMS to perform its required characterization, control and optimization tasks. Under this point of view, the available SCADA signals had been classified in two types of non-exclusive signals, according to the required goal: analysis and control. Among the first ones, it must be underlined the role of those which are required to the fundamental researches on energy flows which were previously commented, in other words, following the energy scheme: the consumed gas meter boxes in every single generator, the meter boxes to control the energy provided by generators, the temperatures associated to every single involved sector/element or flow. In this sense, for example, as explained, the consumption of the primary energy source and the production of this -which is extracted in every case- can be useful to quantify the volume but also the efficiency obtained from the generators (boilers and cogeneration), quantify the obtained improvements regarding the previous situation to perform a later evaluation of them. This not only characterises the systems' functioning but also performs a monitoring on the success of the optimization actions implemented in the project, as well as find strategies to improve the current situation according to the observations and check -iteratively- the effects of these strategies. This is EMS idiosyncrasy.

Specifying the fundamental elements of the installation: energy generators (boilers and cogeneration), thermal energy accumulation and heating systems and HDW, the relationship between systems' evaluation basic needs and the sensorisation/available resources, can be explained on the following way:

— ***Energy production:***

- Boilers. As showed, in this case is essential to know the primary energy source that comes into them, through the gas meter boxes as well as the produced energy, the flow and return temperatures (as they condition its performance), the involved times (statuses) or the pumps operating.

- Cogeneration. To evaluate its operating mode and efficiency, it is necessary to know the primary energy supply received by it, the energy production in its circuit, the primary circuit contribution to the secondary one involved temperatures or times and statuses of pumps.

— ***Energy Accumulation.*** Buffer Tanks. In this case, it is required a thermal stratification of their inside so, as it has been previously mentioned, energy from generators is added to the higher part and the returns are added to the lower one. The medium and lower part are specifically used to store energy from the cogeneration engine. This is why it is really important to sound and analyse the tanks' temperatures on the three levels, as well as the useful thermal use stored in them (calculated form these measures) and consider the set temperatures and respect them.

— ***Energy Consumers.***

- Heating: The fundamental signals which are involved in heating systems require to know energy consumption sin the different sounded sectors, required/reached temperatures (instruction, impulsion and return in the different sectors), as well as the status of the pumps which propel all that energy according to the schedules and instructions. In the same way, all the signals linked to proper functioning of the facilities and comfort (temperature sensors installed in different sectors) are also required.

- HDW. In this case, it is required to know the involved water and energy consumption, as well as the obtained service temperatures, which must be in compliance with the law. To perform this characterisation, there are water meter boxes and temperature sounding lines, which allows to calculate water and energy consumptions directly and indirectly, respectively, through the energy flow and the thermal leap. There is also an energy meter box to calculate the energy injected into the recirculation circuit through the plate exchanger, to compensate its losses. In addittion, temperature signals will allow to evaluate if the HDW operation result is -or not- satisfactory.

5.5. EMS START-UP. START-UP TESTS.

In this section, the EMS start-up will be described from an operating point of view, once all the involved systems were completely activated and sampled. Besides the functioning tests and correct register of EMS signals, this includes fundamental analysis that have been already seen and that will be useful to check the facilities' functioning after their start-up, such as the EMST's operability as the characteriser and controller of the mentioned functioning.

5.5.1. VERIFICATION OF THE EMST AND PILOT PROJECT OPERABILITY.

As previously mentioned, the verification of the EMST is determined by the foundations of its establishment. Among them, it is underlined the analysis and control of energy flows involved in the energy systems, which must be efficient, representative and robust to become the vertebral axis of the EMS. The functional verification of the EMST, thus, performed in this way and directly on the infrastructure in which it is implemented, although it may be adapted to other systems or facilities.

5.5.1.1. THE EMS AS THE ENERGY GENERATION CHARACTERISER. OBSERVATIONS OF THE DIFFERENT VARIABLES<. ANALYSIS AND CONTROL.

This section will describe the first general test on the EMS and the functioning sytems to check that the tools and expected capacities from this control and analysis are functional and generate relevant results in the different areas of the project.

Under the paradigm described at the end of the section 5.4.2., the EMS capacities will be analised throguh the use of its monitoring and stored signal processing tool which will be applied to the functioning of every single element of the project (thermal generation- boilers and cogeneration y cogeneration-, energy storage , heating and HDW), as well as the control links to the services. In this way, during the mentioned checking process, the operating way of the facilities after the start -up of the optimization measures, as well as the functioning of the EMS itself (particularly the control/guidelines) and the general project will be showed.

a) Operational Application of the EMST to The Boiler Thermal Generation System

In this section, the functionality of the EMS and the systems with specific goals, such as the operational verification of the boiler ignition control loop on the one side, and the boilers efficiency on the other. To do it, the EMSTs will be used in order to find a suitable time interval to analyze the interesting variables in the following periods, after the implementation of measures. Later, the signals required by the analysis will be extracted from the chosen interval.

Focusing on the ignition control loop, it will be checked whether the boilers accomplish their task properly as well as the regulation of temperature.

The time interval selected for this goal, is that with shows the most unfavourable weather conditions (obtained from a temporary research on the outdoor temperatures) among those when boilers operate by themselves (weekends, what can be extracted from the schedules inserted in the EMST), in other words, from the 28 to 30 November 2015. The heating schedules for the different sectors in this time interval are:

- Student Residence: Sat. and Sun. from 7.00 to 9.00 and from 19.00 to 23.30
- Hemodonation Bank: Sat. and Sun. from 0.00 to 24.00
- Optics School: Sat. from 0.00 to 24.00, Sun. from 8.00 to 11.30 and from 14.40 to 18.00
- Physics Faculty: Sat. from 0.00 to 24.00, Sun. from 9.00 to 13.00 and from to 16.00 a 18.00

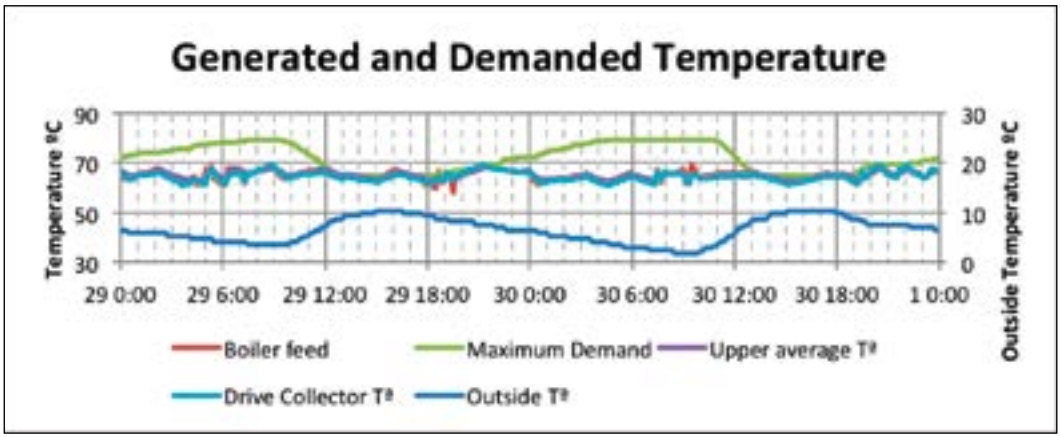


Figure 5.11. Generated and Demanded Temperature.

As seen, the EMST provides the option of extracting data related to convenient temperatures for consideration. In this particular case, indoor and outdoor temperatures, setting temperature, impeller manifold and average high temperature in the buffer tanks. The figure shows the existing modification in the setting temperature according the outdoor temperature, in the opposite direction, as expected, it is lower limited to 65 ºC for HDW, and, however, there is not any modification in the boiler impeller temperature or in the higher part of the tanks according to the same guideline. This means that the boiler performance is not suitable regarding this guideline. In the same way, the use of the tool and the corresponding calculations shows that the average of used power by boilers during that period is 13% with respect to the maximum, so it is proved that the observed problem is not related with the boilers capacity to generate the demanded energy at all.

The EMSTs allow an accurate and early detection of the problem, which would not be possible with the SCADA software. This problem will be considered in the following section.

As far as boiler efficiency is concerned, a period and time series-corresponding to the observation needs- are selected in the tool to be downloaded: relationship between natural gas extracted and used energy. The period corresponds to November 2015 and the calculations are directly performed from meter box signals from the consumed natural gas, its Lower Calorific Value (LCV) and the produced energy:

Complete November Month 2015	
Natural Gas Consumption	8590,2 m^3
Boiler Energy Meter Box	82,8 MWh
Other Data	
Natural Gas Lower Calorific Value (LCV)	10,83 kWh/m^3

Efficiency Calculation:

$$\eta = \frac{\text{consumo energía caldera}}{\text{PCI gas * consumo gas}} = \frac{82.8\ \text{MWh}}{10.83\text{KWh/m}^2 * 8590.2\text{m}^2} = 0.89 = 89.0\%$$

Including the error calculation from the energy meter box, the result is **η= (89.0±0.5)%**

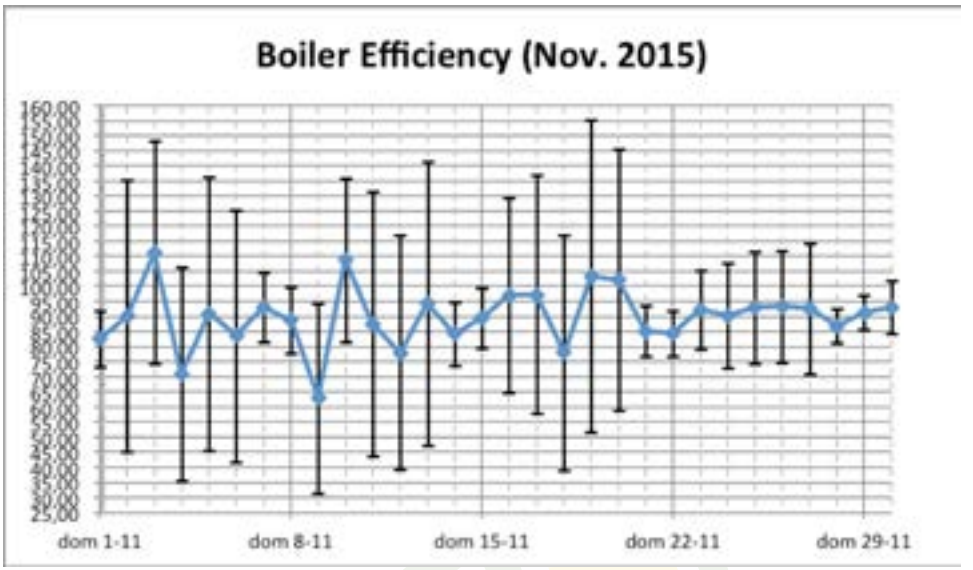


Figure 5.12. Boiler Efficiency (Nov. 2015)

In the diagram, the daily efficiency results are showed from total time series of de abovementioned month. A significant variability is observed in the results obtaining even an efficiency of 110% in some days, although there is not any data in this series being significantly different from other when errors are considered. The extent of such errors in calculation varies depending on the amount of power generated during the day, regarded being higher when this one is lower because of a bigger relative influence of the uncertainty in the energy counter values respect to the global measure of power in each case.

The same way in the other cases, the analysis supported by the EMS allows us to contrast the correlation of the results respect to the counter timetable of the cogeneration, which is not predictable beyond this effect misled by a higher thermal production during the weekends, when cogeneration remains inactive.

Again, implemented features in monitoring related to EMS, allow a suitable analysis and the detection of this situation. The analysis enable to set that the errors associated with the sensors in the system are too high for an accurate measure and therefore for a quick identification of this problem.

b) Tool Application to Verify Engine Thermal Production.

This section goes on with the verification of the EMS potential respect to the systems operating characterization and the current state of them. As already discussed, this is sequentially carried out for the various basic components in the actions implemented in the MdC, and in this case, the energy production made by the cogeneration thermal engine in our facilities during the month of November 2015.

As we mentioned before, the whole profitable thermal power of the engine is estimated in 285 kW. The EMS allows to extract from its Smart-grid signals of both the engine working times and the generated thermal power during these times. This, by definition, enables to calculate the engine average power during the period taken and compare it with the maximum value expected. Due to the uncertainty in the energy counter (500 kWh), calculation has been made in weekly periods apart from the ones in the whole month.

November			
Date	Generation time	Date	Generated power
02/11/2015 9:23	0 min.	02/11/2015 12:31	32,52 MWh
30/11/2015 16:54	16502 min.	30/11/2015 15:39	82,31 MWh
Power average 184 ± 1,4 kW			
Efficiency 65% ± 1%			

Week 1	Week 2
Power average 170 ± 7.8 kW	Power average 168 ± 7.0 kW
Efficiency 60% ± 2%	Efficiency 59 ± 2%
Week 3	**Week 4**
Power average 175 ± 7,2 kW	Power average 225 ± 7.7 kW
Efficiency 61% ± 2%	Efficiency 79 ± 3%

In the tables, it can be seen how the engine efficiency is a bit lower than the expected in maximum load. On the other hand, it is important to highlight that, during the fourth week there was a 24-hour hand power cut of the boilers that showed a weekly net efficiency increase.

c) Operative Characterization of the Buffer Tanks by EMS.

In this section, the EMS signal analysis is limited to the description of the buffer tanks. The way to approach this analysis in this particular case will be focused in valuing its capacity and the way the storage batteries work taking into account two points:

— Thermal uniformity testing among the different tanks in each one of the three defined height levels.

— A right settlement testing of the thermal stratification average in each one of the three levels.

At this point, it is important to remember that the expected temperature gradient in the buffer tanks saves, by design, its lower parts to be fulfilled with the cogeneration thermal contribution although all levels show useful power storage capacity in the tanks respect to the tanks conception, that is why both the behavior in these levels and the relation with the operation of the generators must be verified.

The required signals in the monitoring system for this analysis during the selected periods are temperatures in the three levels in each one of the five buffer tanks with a probe, although the operative states of the thermal

generators are also considered. The period for the first analysis (uniformity among tanks) is from November 9th to 15th, 2015.

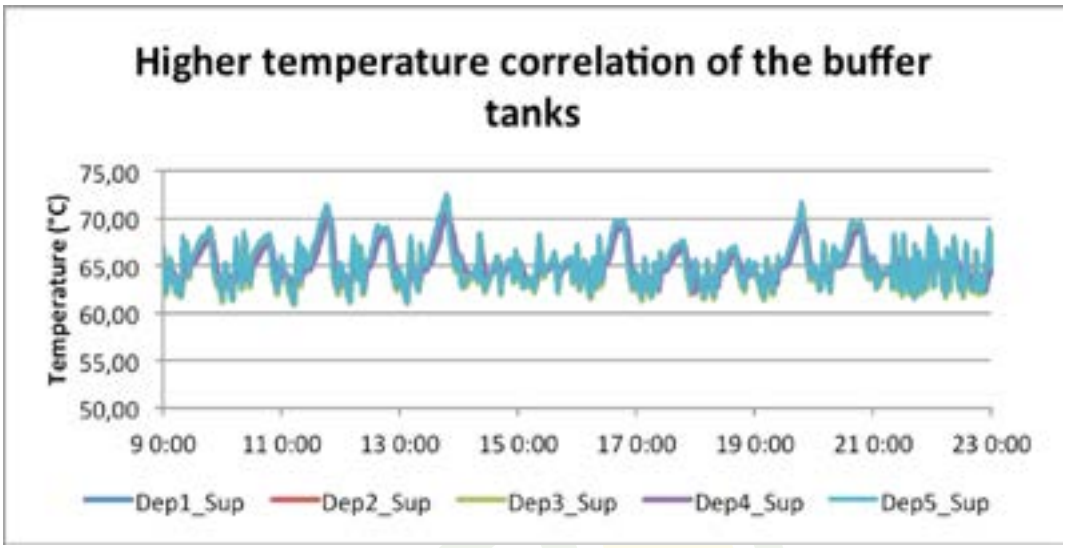


Figure 5.13. Higher temperature correlation of the buffer tanks.

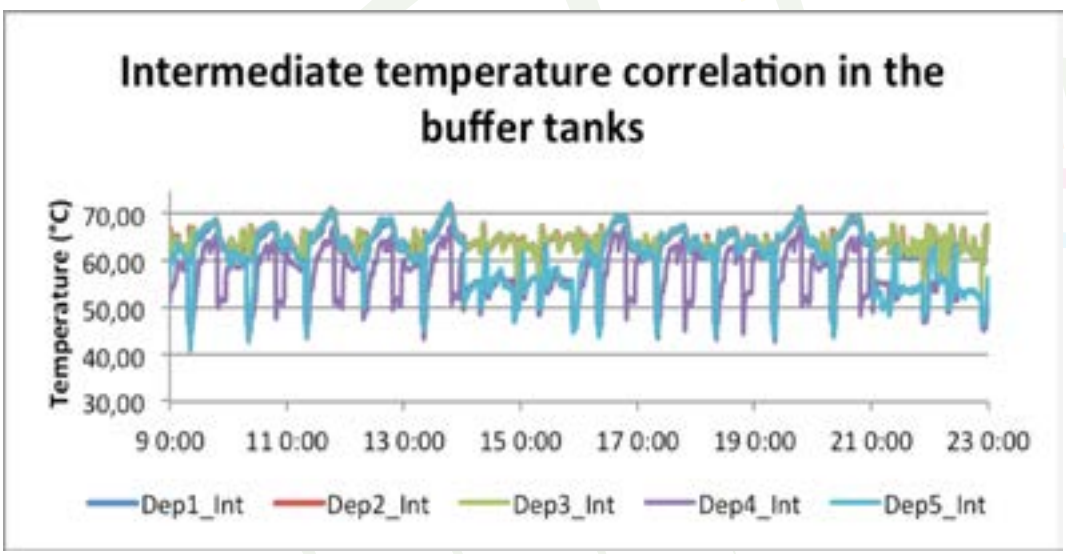


Figure 5.14. Intermediate temperature correlation in the buffer tanks.

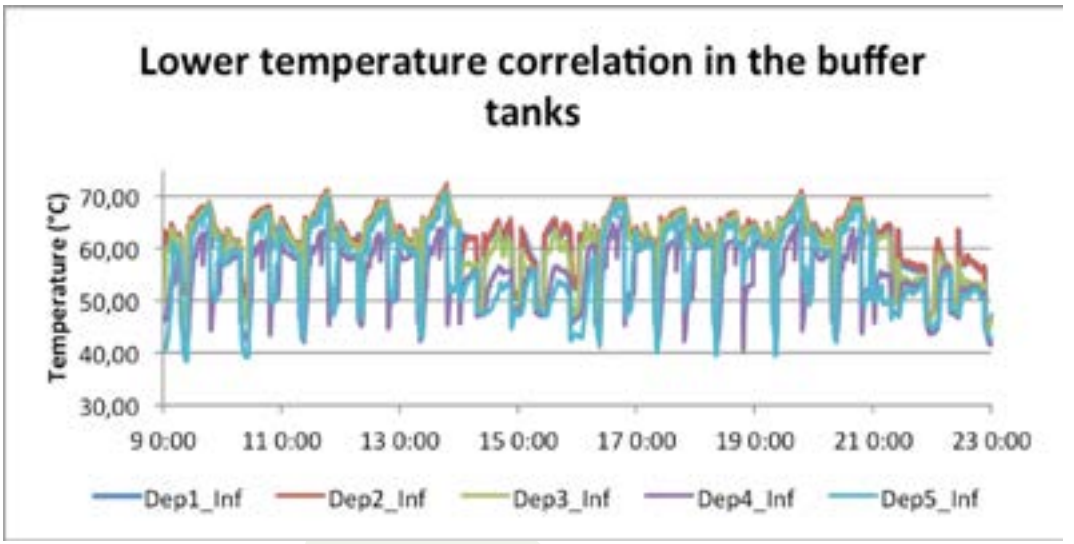


Figure 5.15. Lower temperature correlation in the buffer tanks

Again, The EMS analysis allows us to determine the state of the operation in the correspondent systems and the detection of the anomalous conditions to be solved. Among the last ones a significant inhomogeneity of the temperatures in the buffer tanks in their intermediate and lower parts is observed. Particularly, temperatures at these levels in tanks 4 and 5 obtain more reduced values than the ones in the rest of the tanks. This effect is the same during the weekends, without cogeneration. This asymmetrical behavior suggests a higher entrance of return water in these tanks, although it is not verified in the revisions with the fitter.

On the other hand, the sharp temperature rise observed in the lower part of the tanks, lowered when they reached 65 ºC, may show an unwanting excess of heat in the boilers at these levels, since, taking into account its creation, it is clear that cogeneration is the one who provides most of the energy to the tanks, particularly in its lower part. This was identified as one of the possible reasons for an unsuitable operation of a mixing valve as well as the constant working of pumps in the boilers, also registered and proved by the EMS as in the other cases. We will return to this point in section 5.5.2.

Respect to the use of tools to value the planned stratification of average temperatures in the tanks at different heights, the considered period is from 16th to 22th November. In this case, apart from the extract of signals given by de EMS, and the abovementioned average temperatures, the useful thermal energy stored in the tanks and the power on cumulative times in the boilers and the engine are added. With these wide ranging measures, it is possible to correlate temperatures, energies and thermal energy generators operability in the buffer tanks, which give us a characterization and control of them.

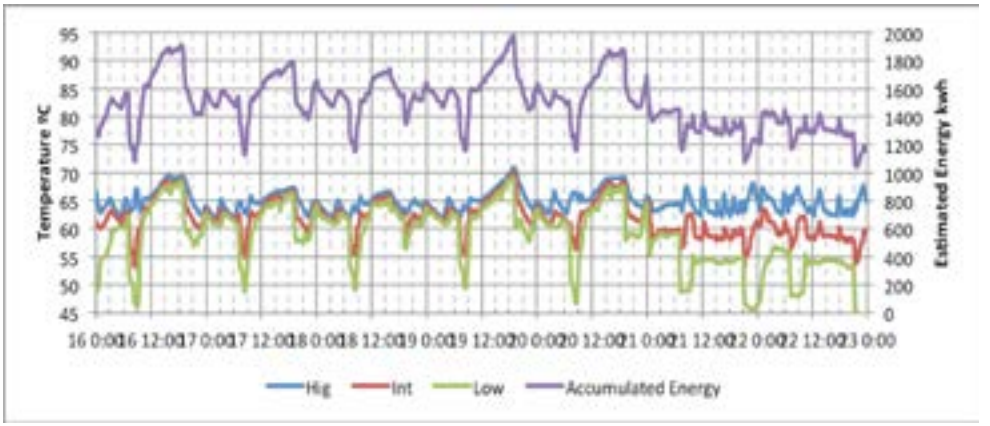


Figure 5.16. Average temperatures cumulated in the upper, middle and lower parts of the tanks and estimated energy.

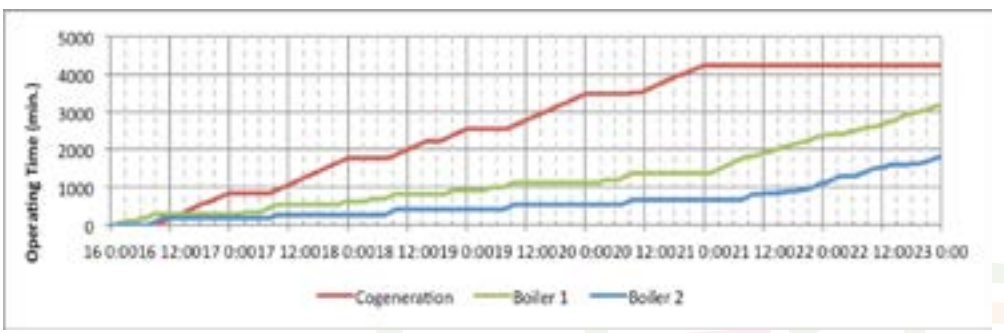
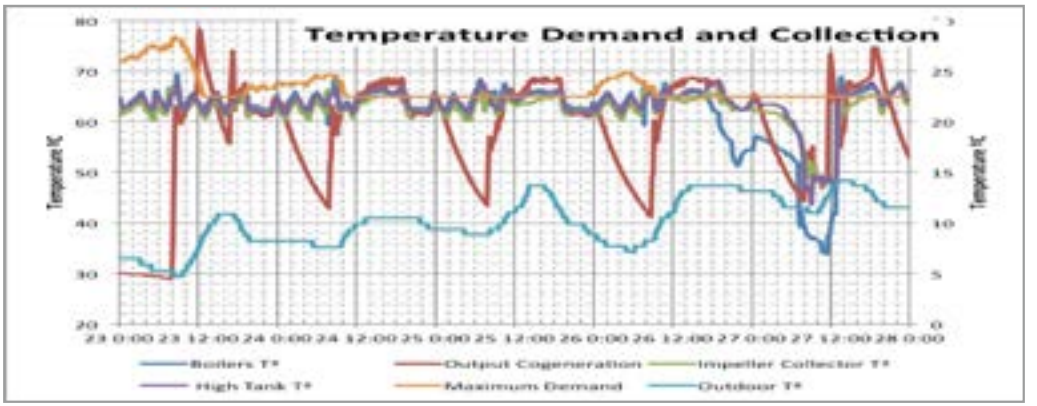


Figure 5.17.Boilers and cogeneration starting-up

Variables become solving to describe what is happening in the tanks, for instance the fact that during the morning period, when the engine starts working, the stratification is reduced, as it might be wished by its design. The same way, the power stored in the tanks is lower when only the boilers are working (week end), although is higher than expected, especially because of the excessive consumption in the lower parts of the tanks considered before. It is also observed that the storage energy decreases substantially when the heating is started in homes, making essential the use of boilers in the mornings, when the engine is switched off or in the start-up process.

d) EMST Application for the Joint Analysis of Thermal Power Generators and Control Loop.

In this section, the joint working and coordination of the heating boilers with the cogeneration system is considered. The EMST extracts the suitable data for this purpose as setting temperature, the boilers and cogeneration setting temperature, the impeller collector temperature, the average temperature in the upper part of the buffer tanks, the stored energy in the boilers and the engine and the operating times they have. .Likewise, it was possible to select quickly by monitoring the period of the lowest temperatures provided that both energy sources, boilers and cogeneration, where scheduled on November from 23th to 28th 2015.



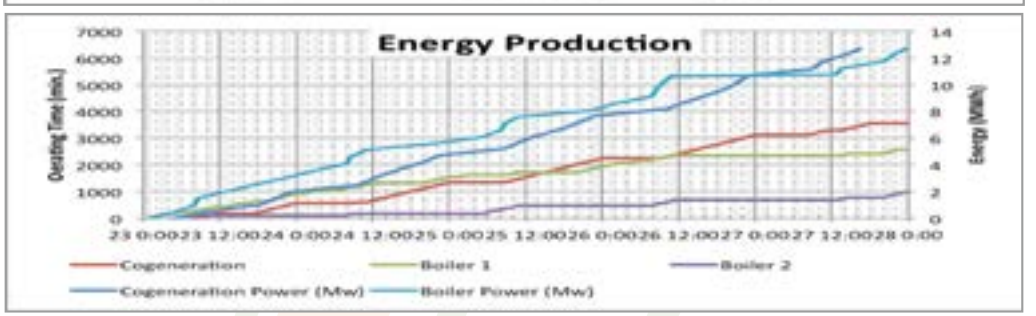


Figure 5.18. Graphic A: Temperature Demand and Collection. Figure B: Power production.

As it has been detected in the boilers efficiency analysis, an excessive discrepancy among the setting temperatures and the flowing ones was detected. Opposite to those ones, during the low heat demand times, cogeneration energy intake increases temperatures up to the criterion values, while the boilers remain off during this period with storage maintenance. .Although there is no graphic showed, it is important to highlight that stored power in the tanks during those periods is over 1700 kWh. It is also remarkable as we mentioned in paragraph b), during the week the boilers were switched off with the purpose of studying cogeneration behavior and the recovery once the systems are reactivated with the tanks empty (see the Figure where the boilers stay inoperative from 12:00 h November 26th to 24 hours later). Taking into account the temperature behavior during this period in the Figure, it is clear that the morning load is excessive due to engine switching off during de night (temperatures in the upper part of the tank low down 60 degrees after 6:00 h of 27th November, and as there is a high power demand during the morning, the engine is unable to recover its temperature), but it is possible to maintain temperature before the switching off..

Monitoring and associated time series enable to detect in (Figure B) that boilers and cogeneration work at the same time in several occasions, especially in times with high energy demand, as the heating activation timetable at home (7:00 h to 19:00 h). This is very harmful in the morning since cogeneration cannot achieve enough temperature after being powered up together with an increasing in the tanks temperature and its energy from the boilers, with the correspondent loss in the accumulation capability for the engine during the rest of the day.

In this case the EMST implementation proves to be operative and it gives us control and detection of interferences into the generation systems performance.

e) EMST Functionality for the HDW Characterization.

Across the entire spectrum of the EMS potential, HDW implemented actions were included. In this case, the solvency margin in characterization will be valued in two aspects: on one hand, HDW production and consumption and, on the other hand, the verification of the minimum temperature up to 50 ºC in the farthest terminal of the hydraulic HDW circuit (legal minimum to protect against Legionella).

Respect to the first point, signals extracted from the system show the next results.

- HDW produced: 891 m^3
- HDW consumed in the Residence : 4477.80 m^3
- HDW consumed in Hemodonation Bank: 0.02 m^3
- The values obtained by water meters are inconsistent, although its working method has been tested during the implementation and it is a design problem so that, the data taken must be solved.

Respect to minimum temperature verifying in the farthest point of the HDW circuit, suitable and necessary variables are drawn from the EMS that, in this case are the return setting temperatures of the Residence, the ones of the Hemodonation Bank and the ones in the return collector during the period November from 9th to 22th 2015.

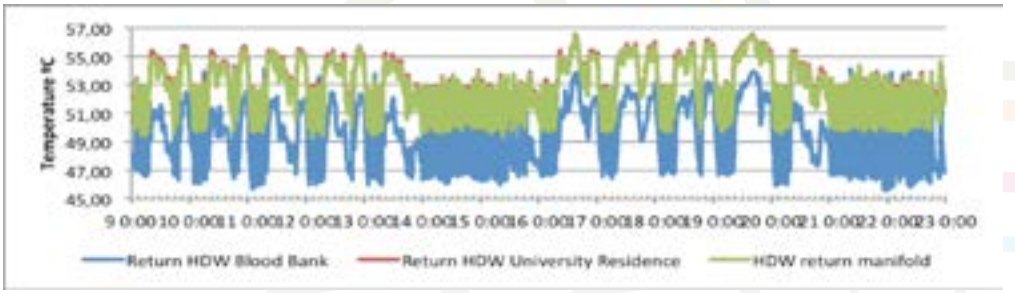


Figure 5.19. HDW return temperatures. Compliance with prevention Regulations: legionella.

The temperatures extract shows in the Figure that the conditions required in the residence are fulfilled while, in the hemodonation center, there is a number of measures below de threshold (under 50% of the data). This makes clear that temperatures in the residence and return collector are very similar due to the water input to the return by that one. Because of this, there is an imbalance in the case of the Blood bank, due to adjustment is made under the basis of the return collector temperature and this installation makes little effect over it. This can be solved modifying the control loop so that it works with the fewer return temperature.

In this case, the EMST allowed a characterization of the HDW, including the detection of some anomalies involving the adequate data intake

f) EMS and Comfort Control in the Installations

Finally, it will be verified if the implanted EMS versatility is enough to describe and set the comfort control in our installations. With this aim, stored data by the room temperature map system associated to different monitored areas, which are in different floors in the building, will be extracted. Outside temperature and the status of the pumping systems (on/off) for this sector will be added to the previous measures. Thermal comfort is established by convention over 21 ºC. In the chat, data are interpolated to see clearly from the square signals since they are registered by a value change.

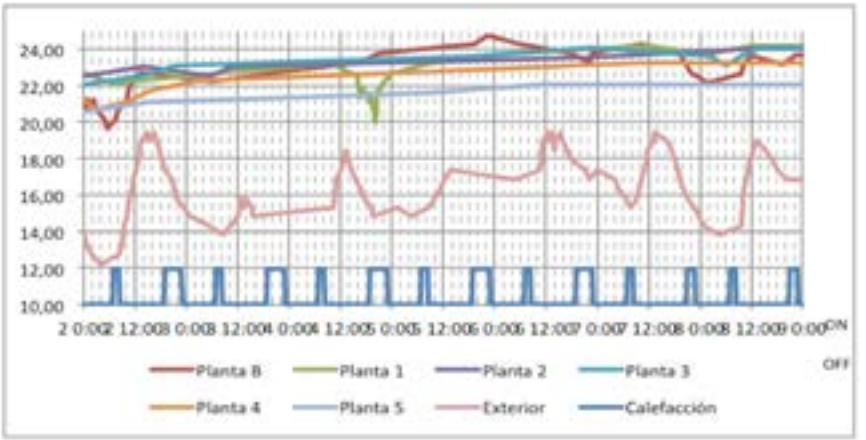


Figure 5.20. Room temperatures in the RUMC floors, outside temperatures and heating timetable

Daily and total temperature average in each floor:

Day	Groun F	1st fl	2nd fl	3rd fl	4th fl	5th fl	Exterior
2	21,75	22,28	22,73	22,35	21,19	20,79	15,52
3	22,45	22,53	22,93	23,11	22,21	21,10	14,81
4	23,00	22,48	23,03	23,11	22,27	21,10	15,61
5	23,92	23,02	23,03	23,21	22,55	21,43	16,28
6	24,29	23,70	23,03	23,66	22,77	21,88	17,75
7	23,86	23,97	23,54	24,13	23,05	22,12	17,21
8	23,01	24,00	23,78	23,80	23,28	22,12	16,19
All	23,18	23,14	23,15	23,34	22,47	21,51	16,20

For inspection, It can be seen that there is no a significant variability in temperatures in each floor, it is just a little higher in the ground floor (between 20 and 25 ºC when considering the total data). All floors, except the central floors, show certain measures in discomfort zone. In the case of the ground floor, there is also a correlation among them and temperature dropping in the outside ones, as it happened on the first floor in one occasion. These last measures can be caused by a fault in the use like opening windows since this circumstance

was not repeated again. In the case of the ground floor, it is not possible to evaluate if the temperature recovery after these decreases were due to the heating switching on or to the outside temperature increasing since both are interconnected, although-in the case of the first floor-it is clear the causal link with the heating The two upper floors show lower values in average and this fit with a higher global proximity to the outside part of the building and less thermal buffer.

At this point of the analysis, it is not possible to draw conclusive results respect to comfort in these floors due to temperatures are mild and correlations observed with the outside temperatures (the selected period by means of monitoring system, filtered the time intervals in which the lack of follow-up in heating production which leads to a thermal discomfort, happened independently of the data analised in this section. Anyway, the EMST enables to detect the deficiencies and, in future analysis, optimised the situation by adjustments as far as possible.

5.5.2. FIRST CONCLUSIONS AND SYSTEM IMPROVEMENTS

From the thorough review of the analysis discussed in the previous section, some related problems to our building have been identified.

The boilers starting tests show important programming defects that prevent the system to meet the point temperatures demanded for the heating.

On the other hand, stratification analysis of the tanks shows that this is rapidly broken in the moment the engine, and, therefore, its exchange pump, start working. This behavior, which is desirable when the engine supplies more power than the used in heating circuits, show, in a detailed study, that several negative effects are being produced:

Firstly, the big water flow moving in the pump exchanger, including at the lowest speed, leads to the power collection of the engine in the exchanger is made because of the water flow and not because of the thermal leap. As a consequence, in the output of the exchanger which takes the lowest temperatures in the tanks, the driven temperature, in the initial moment of the engine starting, is very low (including below 60 ºC which is the temperature needed to serve the HDW). This means that although the engine supplies the system, it does not do it at suitable temperatures.

On its behalf, the boilers, working with pumps at constant rate, try to maintain in the upper part of the tanks the maximum temperature required, which is rapidly driven forward to the lower part of the tanks by the pump in the exchanger connected to the cogeneration engine. At this point, what it was discussed in the first paragraph as a problem in boilers programming worked as a benefit since it prevented that more energy generated in the boilers was stored in the buffer tanks.

This way, as explained in previous paragraphs, the problem found in the system is not the breaking in its stratification but, fast temperature rising, the stored energy in the tanks is due to the boilers effect when they try to impose a criterion value in the upper part of the tanks and the exchanger pump drives this temperature downwards. Apart from this, as it can be seen, temperatures from the engine are clearly below the potential demand, leading the boilers to add even more energy.

Once identified the detected problems, a solution in the system during the trial period, which has gone through a infrastructure change and boilers programming, has been searched.

The infrastructure change abovementioned is showed in the following Figures where it is possible to appreciate that the pump and the engine exchanger are replaced with a three-way valve. This three-way valve is controlled respect to the motor shrouds temperature and the target is to introduce as much cold water in the engine as needed so that temperature remains at an ideal range. This way, when water is sent to the installation there will be always water at the highest temperature. this installation can provide, and the only thing the valve modifies is how much water flow there will be at this temperature. Doing this, when temperature from the engine is driven to the tanks, this one will always be at the maximum required by the installation. This is not a problem since temperature in the upper part of the tanks never goes directly to the installations because there are valves that buffer from it according to the demand for the service.

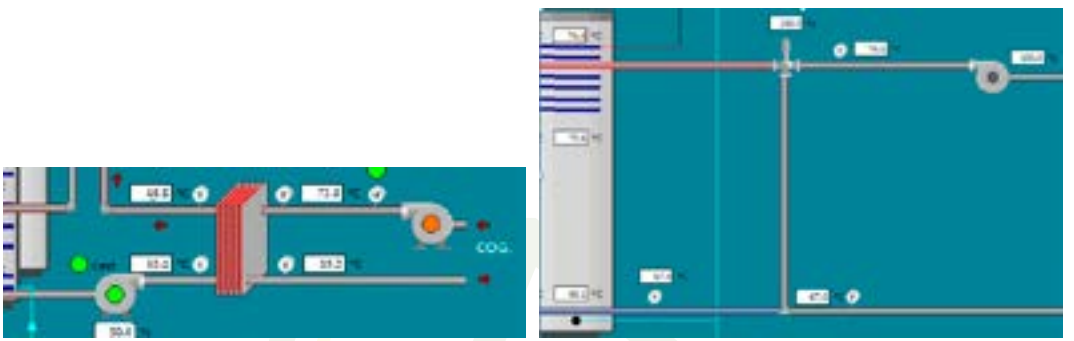


Figure 5.21. SCADA scheme sectors corresponding to the initial installation (left part “A”) and after the three-way valve replacement (“B”).

On the other hand, taking into account those things mentioned at the beginning of this section, there are also several changes in boilers programming. Firstly, to let them generate the required demanded temperatures, and, secondly, to avoid a continuous working of the pumps at a rated speed. This way, from the initial programming in which the boilers only switch on its own pumps, which means a constant flow work in a primary heating closed circuit in the upper part of the tanks, we turn to a program in which the boilers only switch on its pumps if temperature in the upper part of the tanks decreases under the setting value and. when they do so, it is reduced to the minimum the flow to ensure the maximum thermal leap between the middle and the upper part of the tanks. This way, if the maximum temperature in the tanks is injected downwards, the boilers tend to switch off quickly because high input temperatures, and the highest thermal leap possible, will rise sharply the temperature in the drives.

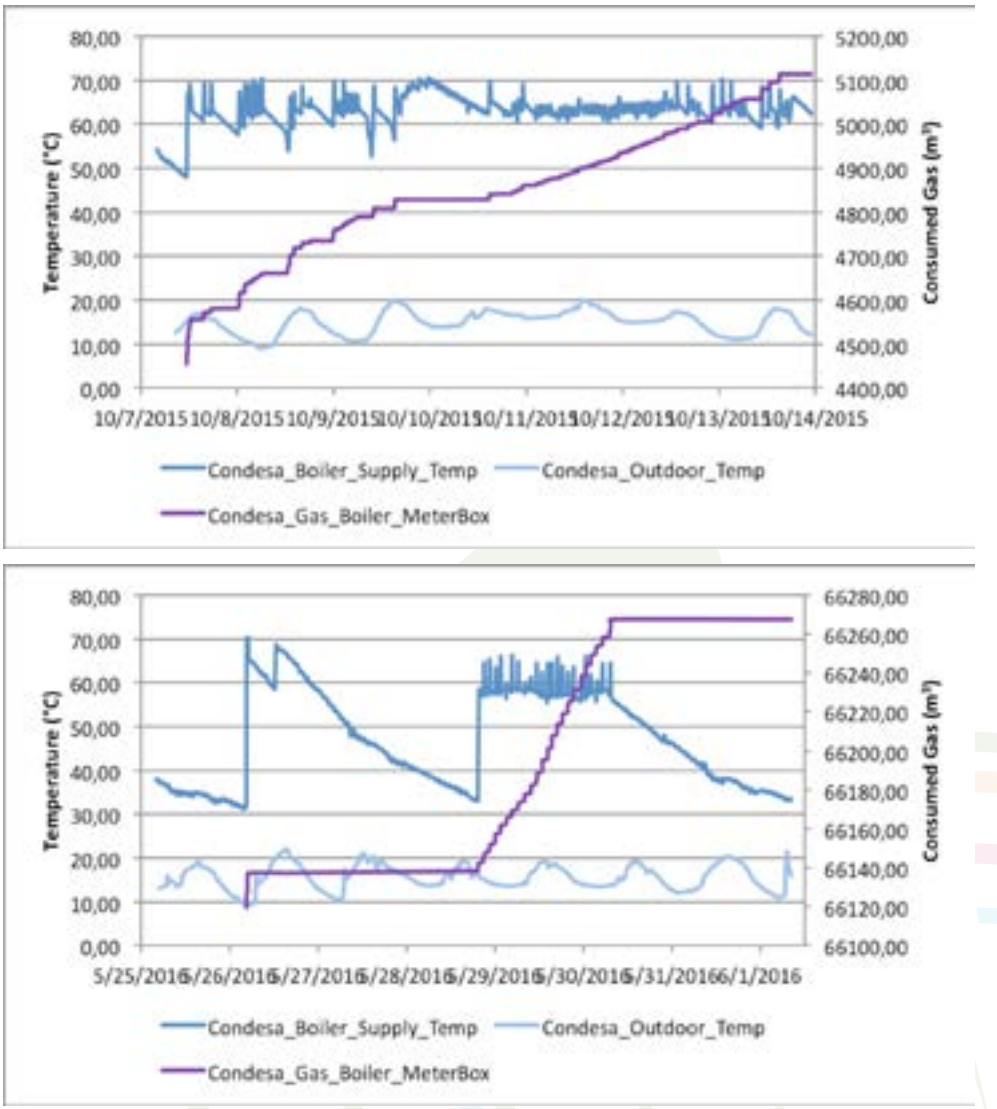


Figure 5.22. Setting temperatures behavior and gas consumption in the boilers before reprogramming (upper part "A") and after this (lower part "B"). In both cases outside temperature is represented in green and, the gas consumption, in red .

A first comparison between both behaviors suggests that these changes have been accurate. In the Figure, the impulsion behavior can be seen and the gas consumption is clearly different between two weeks, followed the pattern expected as it has just been explained respect to the programming. Before this reprogramming, boilers are permanently working and keep their fluid temperature steady and continuous gas consumption.

After the reprogramming, the boilers tend to remain off when the engine is able to maintain temperature at the higher part of the tanks. This means a lower net consumption and less sharp impulsion temperature rising in these ones, since the starting point temperatures comes from the cogenerator when the other one proved insufficient. In Figure B, it can be observed the quick temperature rising and the associated gas consumption during the weekends, due to the engine is off, and there is a decreasing in the starting-up on Mondays.

The next studies, discussed in the next section, also show clear signs that, all in all, the strategy proved to be suitable.

5.6. TEMPORARY VIEW OF THE INSTALLATIONS DURING THE DEMONSTRATIVE PERIOD

In this section, a panoramic view of the general working of basic components in our installations will be showed extended in time. Particularly, this sample will be focused on power generators during the Demonstrative Plan period, taking into account monthly measures mainly. Each one of the main electricity generators, boilers and cogeneration will be analised separately, and then conclusions will be showed as a whole.

5.6.1. BOILERS

In this section, an analysis of the energy performance in the boilers during the Demonstrative Period (October 2015 – October 2016) will be carried out. For this, as it happened in 5.5 section, thermal energy produced in the boilers and the energy correspondent to the natural gas consumption are considered. The first one is taken from the energy meter measures, while the second one is calculated from the measures taken from the consumption gas meter and the correspondent minimum heat power. Likewise, the outside monthly temperature average in each case was calculated. The results are plotted in this Figure.

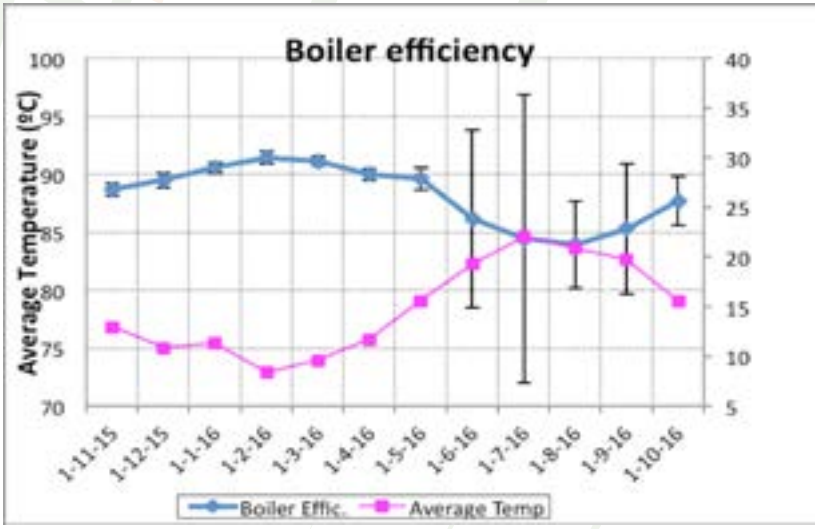


Figure 5.23. Condensation Boilers monthly energy performance through the Demonstrative Period

As it can be seen in the Figure, the boilers performance is clearly variable during the whole period, also considering the margins given by the calculation errors in the results, showing this is higher in cold periods. On the other hand, the performance values are just over the 91% that is below the performance expected according to the manufacturer's specifications. This may be due to a double circumstance: on one hand, before the reprograming in boilers, return temperatures were much higher which generated a lack of condensation during its running On the other hand, after the reprograming, boilers were submitted to a bigger quantity of short switch on and off in which they would not reach the optimum working mode with the corresponding performance decrease.

In Figure 5.22, correlation among performance values and outside temperatures is showed, adjusting most of the data inside the margin errors to the linear regression made.

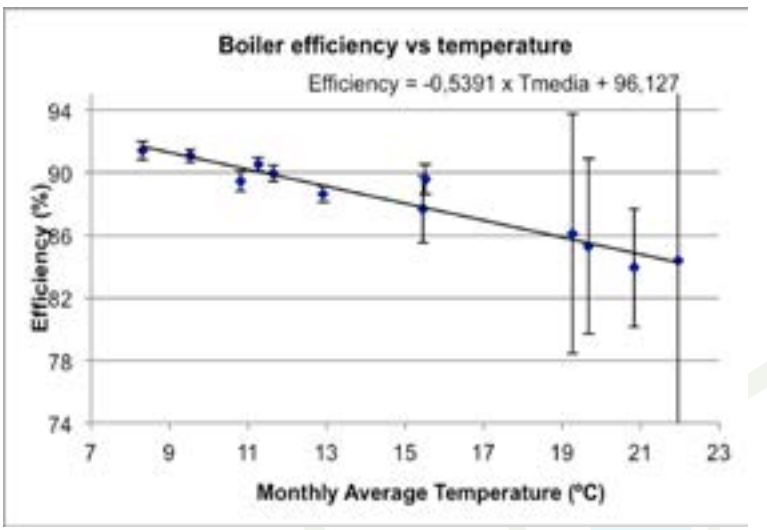


Figure 5.24. Monthly energy performance in condensation boilers respect to average temperature. The linear regression adjustment is showed.

5.6.2. COGENERATION

In this section, energy produced by the cogeneration engine during the Demonstrative Period, as the associated performances to the electric and thermal contribution exploited in the engine recovering, will be considered. In this case, the calculations were monthly again, from the consumption data in the natural gas tanks and the thermal energy added to the primary circuit. The electric power generated is taken from the measures from Sarpel since they are not monitored by EMST.

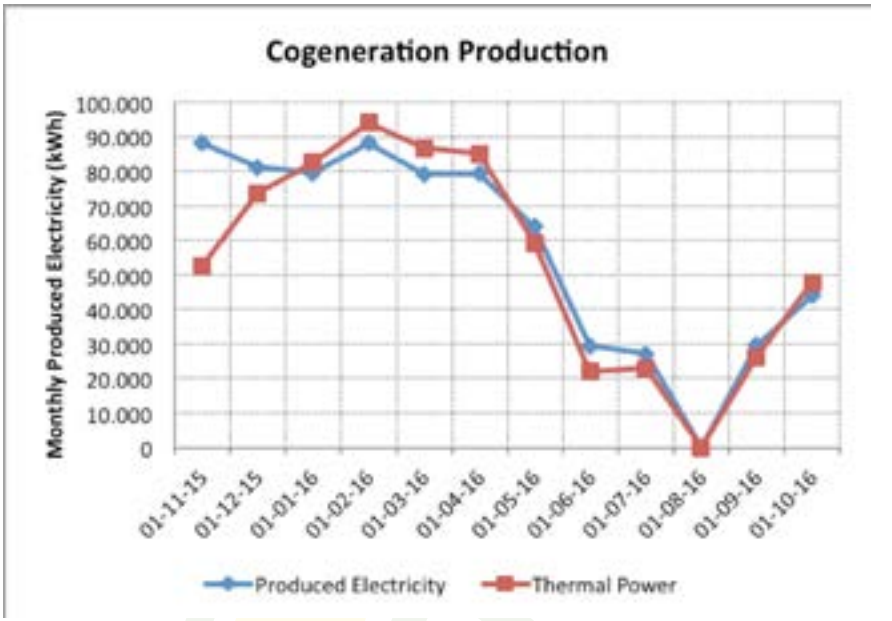


Figura 5.25. Energía eléctrica y térmica mensual producida por el motor de cogeneración.

In the Figure, thermal end electric production of the cogeneration engine through the Demonstrative Period is showed. In this, an appreciable variation in energy generation respect the time of the year considered is made manifest, being higher in winter months and lower during summer months. This is linked to the working times as well as to the fact that, when the engine overheats, this must be switched off. In the Figure, on the other hand, it is observed that the thermal and electric proportions vary during the year, being lower the thermal input at the beginning of the period than afterwards. It is noteworthy that, in colder months the thermal part goes over the electric production.

The next Figure gives us a balanced and broad view of this situation. In this one, cogeneration engine monthly average performance are showed in its two ways electric and thermal and the corresponding loss, associated to the remaining power in the primary production with is not effective in any of the two ways of energy. In this case, the electric engine performance is relatively stable during the period, while the thermal performance shows remarkable seasonal variations. This way, during the colder months the thermal performance goes over the electric one, having opposite behavior during the hotter months. There is particularly maximum peak over 70% from the global engine energy, related to the performance, in march. On the other hand, there is an imbalance respect the behavior during the initial part of the period and afterwards, being manifest an improvement in the engine thermal performance. This would consistent with the optimisedd implemented measures as the period moves further, especially during the installation of the three-way valve during boilers reprogramming.

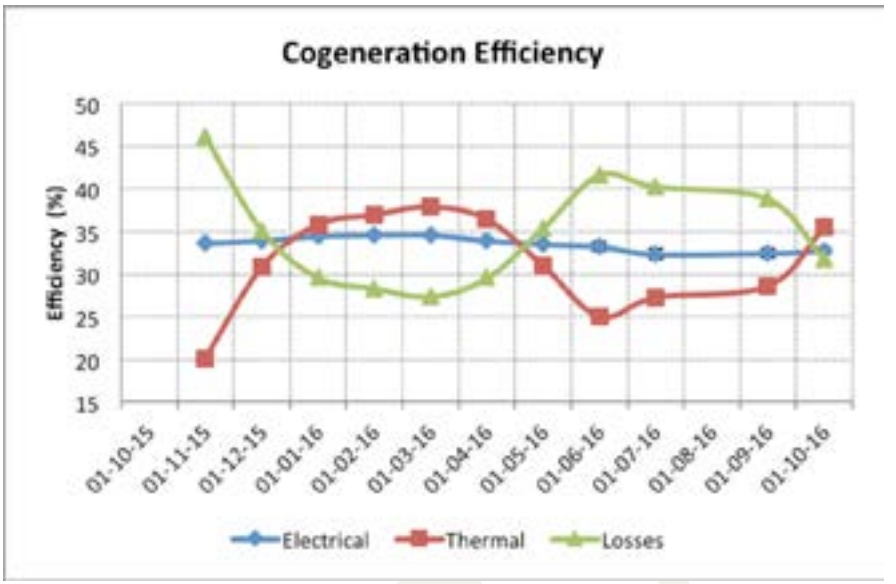


Figure 5.26. Monthly thermal and electric performances generated by the cogeneration engine..

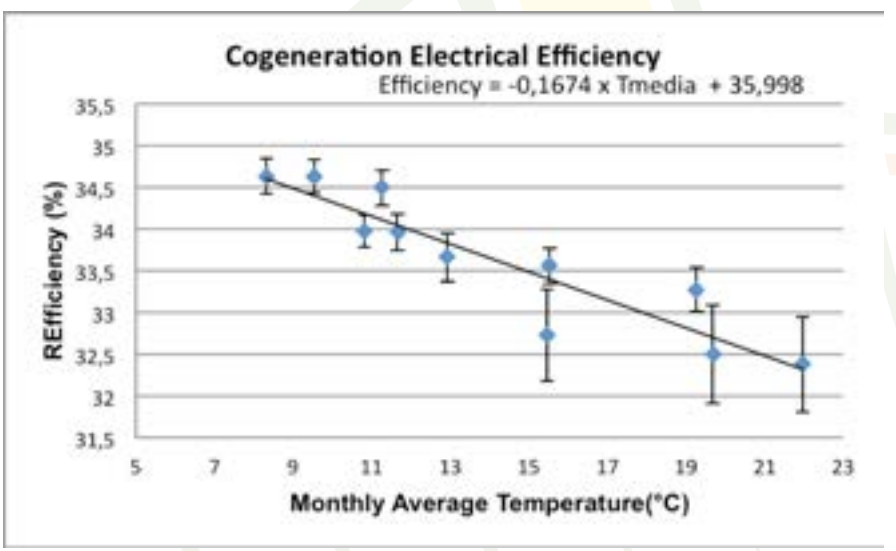


Figure 5.27. Monthy electric performance produced by the cogeneration engine faced to the outside temperature average.

On the other hand, in Figure 5.25,. it can be observed how, instead of being more stable, there is a correlation between the cogeneration engine electric performance and the outdoor temperature. This would fit the fact that, when temperature increases, the engine deviates from its optimal working temperature.

5.6.3. BOILERS AND COGENERATION

In this section, the contribution and behavior of the thermal section both in cogeneration engine and boilers are considered. Such results were taken from the boilers power meters and the secondary circuit in the engine as a direct way of direct heat contribution in the installations.

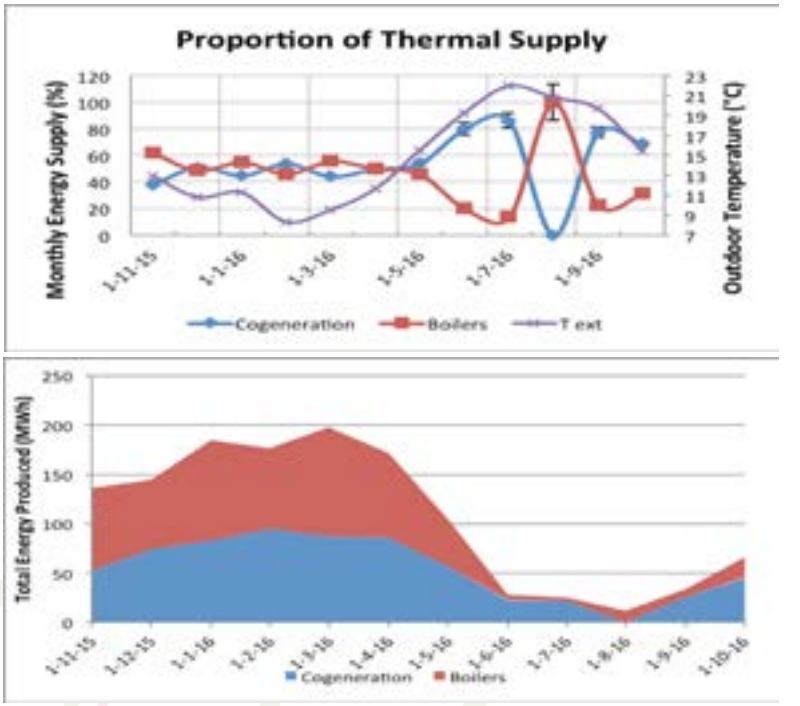


Figure 5.28. A) Average termal energy contribution from genetators to circuits (left) de energía térmica de los generadores a los circuitos (izquierda). B Total termal energy generated and distribution between generators (upper part, boileres en lower part cogeneration)

In the Figure, thermal energy proportions corresponding to generation units can be seen. As it is observed, during the first half of the period, all the contributions are in a proportion varying from 40% to 60% for both cases, being a bit higher in the case of boilers, due to the high thermal demand. As the period moves farther and especially when temperatures rise, the produced energy is greatly reduced, so the proportion of energy required by the boilers falls. In July, the engine contribution is more than the 86% of the total, while time proportion in which this was switched on during this month is 45% (since it was 5 weekends switched off, and the same all nights from 0:00h to 8:00h), this is an example of the proportion of energy saved this month in boilers thanks to the accumulation in the buffer tanks.

On the other hand, the last part of the period, (see Figure B specially), it is seen how the cogeneration contributing energy to the installations seems to be proportionately higher than the one at the beginning of the period after summer, although it will have to be further analised.

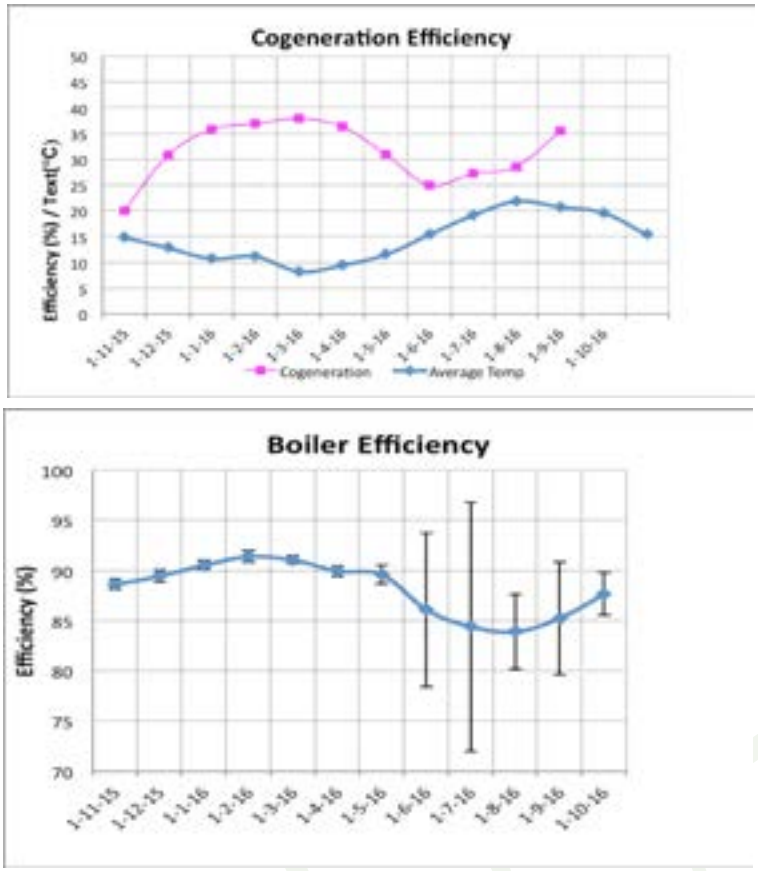


Figura 5.29. Monthly contribution comparison for generators (A) cogeneration engine (B)

Finally, in Figure 5.29, it is observed that, although the boiler performances and the ones in the thermal part of the cogeneration engine do not show symmetrical behavior provide they follow the same type of tendencies during the year, in the sense of increasing in inverted function respect temperature (with the exception in the case of cogeneration in May, in which there is an excessive drop because of the system stops when programming was carried out). Respect to the engine thermal performance, there is a paradigm shift between the initial and the final period, since, iniatially, the variations in the cogeneration engine performance were sharped in the final part while the boilers remained constant (in the estimation error). This circumstance can be linked to the stated in the precedent observations respect to the optimization measures made before. Anyway, the cogeneration performance Figure and the energy input by the engine, show that the heat which can be extracted from the engine is influenced both by the outdoor temperature and the quantity of energy the boilers are contributing.

5.7. CONCLUSIONS

In this chapter, Implementation process of the EMSTs in the process OPERE has been showed, as well as the implementation and its uses to obtain and analyze the system information in order to suggest optimization measures associated to this Project. These tools has been established in a structural frame with double basis: on one hand its own infrastructures in the installations associated to the energy efficiency reform Project in the MdC building complex, while, on the other hand, the TI supporting infrastructures required so that the tool, described in chapter 4 can implement its functions in a satisfactory way. In this sense ,several aspects and elements involving both infrastructures have been summarised in this chapter, both Project execution and tool appliance over the infraestructura, obtain satisfactory results.

On the other hand, the EMST operating fundamentals were established so that the control system and the signal acquisition in these systems (SCADA) which feeds the tool with data to be stored were described in one part, and on the other side, the relation between these accumulated signals and their use/management to extract high level information processed which is relevant and descriptive for the operational characterization of the energy systems in particular, and the optimization measures in general. In this way, an energy focus considering the flow and energy management from the primary sources to the consumption was used, taking into account the energy conversion made by the energy generation systems and the distribution of this one.

In the second part of this chapter, under this paradigm, initial trials in the installation of the EMS from its tools were showed. This way, EMST operability and potential have been checked simultaneously to characterise its functioning and to detect possible problems/lines to be improved in our installations, like the function state of the different elements associated to these systems once they are fully operative. This has been carried out for the different basic elements in the energy installation, generation systems, storing system, consumptions, control and fulfill of the needs/comfort in the complex. After the exposition of these verifications it can be concluded that the EMST is operative respect to what EMS demands in it, and this has allowed to verify that systems worked right in general during the implementation, although a series of problems were detected. Among these ones, it is the fact that the boilers performance is inferior to the expected, and the same happens, but in small extent, in the cogeneration engine. On the other hand, it was detected that the buffer tanks for the thermal energy accumulation in the cogeneration engine show certain inhomogeneities in medium and lower temperatures as well as some energy derivations produced by the boilers in them. This type of detections led to establish improvements in the period followed after the implementation. These were basically, on one part, the substitution of the interchanger and the pump associated to the second cogeneration circuit by a three via valve, while, on the other part, reprogramming of the boilers was made. The first case has as main purpose the production of higher temperatures in the cogeneration thermal contribution and the flow reduction generated by cogeneration in the buffer tanks. The second involves both consign temperature monitoring and the boilers work, which in this case will make the pumps off provided that temperatures in the higher part of the tanks do not decrease from the HDW consign/minimum values, reducing, this way, the energy boilers introduce in the buffer tanks..

Finally, the tool was used as means to establish a panoramic vision of the general functioning of the energy management systems extended along the demonstrative period. This way, it was proved that, thermal

performance of the cogeneration engine, were improved during this period while boilers remain more stable. A seasonal dependency in the generators performance was observed being the relation linear between boilers and monthly average temperatures, so that the first ones were higher while the second ones were reduced. This is the same in the electric performance of the cogeneration engine, sharper regarding to the thermal use although there is not a clear linearity with room temperatures, but sharper behaviors and the influence of the boilers energy implementation. It is remarkable that, during the coldest months, a performance of the cogeneration engine, over a 70% is observed, considering all in all thermal and electric parts.

On the other hand, since thermal demands decrease remarkably as the outdoor temperatures increase, the cogeneration engine implementation to thermal circuits is enough for the thermal demand in the correspondent periods. This way the boilers implementation is limited preferably to the weekends when the engine is not working and the energy stored in the tanks has been used up.

Finally, it was detected a growth trend in the proportional contribution of cogeneration as showed in the Demonstrative Period, as well as its thermal performance that, if confirmed, it would be associated to the improvement steps carried out. This would have a double effect: thermal recovery increase in the engine and boiler consumption reduction.

Chapter 6

Scalable modeling of thermal dynamics in buildings using fuzzy rules for regression

Pablo Rodríguez-Mier
Manuel Mucientes Molina
Alberto Bugarín Diz

Buildings account for 40% of the total energy consumption in the EU, according to European Directive 2010/31/EU on energy efficiency in buildings. Because of the expansion this sector is currently experiencing, a rise of that percentage will be inevitable. Therefore, it seems clear that the reduction of energy consumption and the use of energy from renewable sources in the building sector will play a key role in future measures to reduce emissions of greenhouse gases. One way to achieve energy savings in buildings is by reducing the total working hours of heating systems. However, a decrease in the total usage may lead to important decreases of indoor temperatures that can affect thermal comfort. In order to prevent this, automatic heating control systems must predict the future indoor temperature for a particular control policy in order to find the best strategy that minimizes power consumptions while keeping thermal comfort. Current methods for indoor temperature prediction [6] are mostly based on physical model simulations [20] and black-box machine learning methods [18], [9], [19], [21]. Physical models describe the building behavior by solving theoretical equations that describe to a certain precision the different dynamics and interactions between the variables. Although these methods are very powerful to simulate the different dynamics of a building, especially when there is no real data available, in general they are: 1) very time-consuming since they require many simulation hours, which prevents their application for predicting temperatures in small temporal windows; and 2) complex to formulate, since it is very difficult to produce a detailed model of a complex building, especially when there are many unknown factors that can affect the temperature dynamics. Machine learning models can overcome some of these limitations by learning the behavior from real data. However, current techniques, which are mostly black-box models based on neural networks, are hard to interpret and thus the interaction of the different variables of the building remains unknown. In this sense, the generation of accurate and interpretable models for thermal dynamics in smart buildings is fundamental 1) for modeling the thermal dynamics of the building to simulate the behavior of the system to find better control strategies to reduce the energy consumption; and 2) to allow experts to interpret how the different variables of the system interact.

In this sense, fuzzy rule-based systems are well suited to this kind of applications thanks to their interpretability. However, there are some challenges associated with the automatic generation of rule-bases. Particularly, in Genetic Fuzzy Systems (GFS), the size of the problem has a huge influence in the performance of the algorithm [4], [7]. The fuzzy rule bases learned suffer from exponential rule explosion as the number of variables increases and therefore the convergence time towards precise and simple models rises. Moreover, evolutionary algorithms are computationally expensive due to the large number of evaluations needed to reach convergence, and so the evaluation process to obtain the fitness may take a long time.

One way to cope with scalability issues from a Big Data perspective is to adopt the distributed computing paradigm for scaling GFS [12]. However, there is a lack of works --with only a few exceptions [5]-- that use Big Data frameworks, such as Spark [23] or Hadoop [22] to deal with the scalability issues for regression problems. Concretely, the use of Spark is closely related to the success of Hadoop, which enables the processing of vast amounts of data in parallel on large clusters, usually implemented using the Hadoop Distributed File System. Spark adds to the Hadoop ecosystem the capability to use advanced data-flow computations with an improvement of in-memory computing and high-level functions that facilitate to build parallel applications.

It was not until recently that the use of GFS for solving large scale regression problems has started to attract attention in the field [2], [3], [14], [15]. However, the size of the training data used in these works is not large enough to be considered Big Data. Among the different approaches, FRULER [15] obtains Takagi-Sugeno-Kang 1-order (TSK-1) fuzzy rule bases with high accuracy and the lowest number of rules. Although the runtime of this approach is acceptable for the most simple datasets, it does not scale properly when solving large scale problems and may not converge to a good solution in reasonable time.

These problems motivated the development S-FRULER, the distributed version of FRULER with scalability properties that allow its application to large scale problems. The main goal of our work is to address the problem of building accurate and interpretable models of thermal dynamics in buildings. One of the major issues is the large amount of data that will be generated in the following years, which will require the use of scalable learning algorithms --such as S-FRULER-- to be able to improve the models over time with a reasonable computational effort. To do so, we use both FRULER and S-FRULER to learn accurate and simple TSK rules [16], and we compare them using the available current data on two different cases: 1) generation of indoor temperature models for different floors of the building and 2) generation of models for predicting the evolution of the temperature in a set of buffer tanks that are used store hot water. These models will be used later in the EU LIFE-OPERE project [1] to predict the behavior of the building under different conditions in order to find new control strategies that lead to even further energy savings.

6.1. FRULER (FUZZY RULE LEARNING THROUGH EVOLUTION FOR REGRESSION)

FRULER (Fuzzy RUle Learning through Evolution for Regression is a novel GFS that obtains accurate and simple linguistic TSK-1 fuzzy rule base models for regression problems. FRULER (Fig. 1) is composed of a new instance selection method for regression, a novel multi-granularity fuzzy discretization of the input variables, and an evolutionary algorithm that uses a fast and scalable method with Elastic Net regularization to generate accurate and simple TSK-1 fuzzy rules.

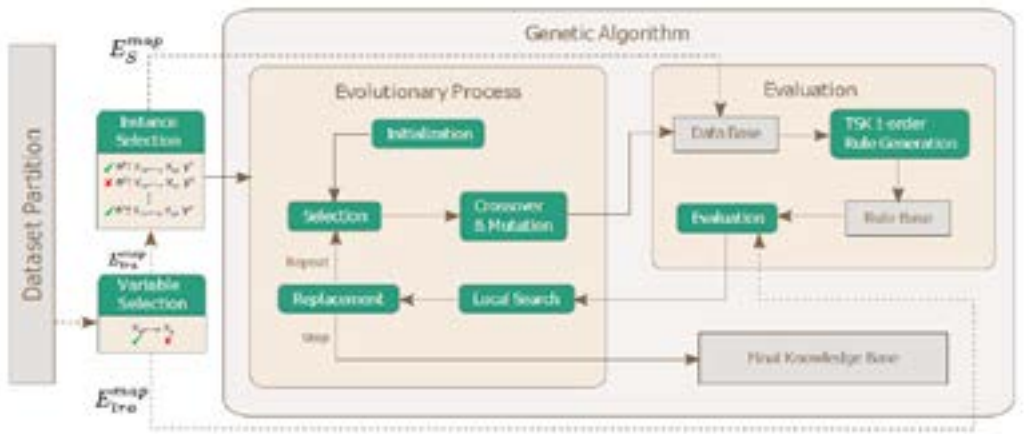


Figure 6.1. FRULER architecture. Dashed lines indicate flow of datasets, dotted lines multigranularity information and solid lines represent process flow.

6.2. S-FRULER

S-FRULER (Scalable Fuzzy Rule Learning through Evolution for Regression), is the distributed version of FRULER designed to improve the current scalability issues that hampers the use of FRULER with large-sized problems. To cope with these limitations, S-FRULER, instead of processing the entire dataset, divides the original problem into a set of smaller problems that are more tractable using a distributed approach (Map phase). Each of these divisions is then independently solved in the Map phase using the FRULER algorithm. Finally, the solutions obtained in each Map are combined in Aggregation phase in order to obtain a final solution for the original problem.

The algorithm structure is shown in Fig. 2. The first step consists of a multi-granularity fuzzy discretization process that is performed using the whole training dataset. Then, the training dataset is splitted into n partitions during the Map phase. Those partitions generated during the Map phase corresponds with the tasks that are distributed as independent sets of processes to be processed in the worker nodes using Apache Spark. For each partition, only a subset of randomly selected variables is taken into account. Each partition is solved using FRULER, considering each partition as an independent problem, where only the instance selection and the genetic algorithm are executed. Finally, each independent solution for each sub-problem is combined in the Aggregation phase, where the missing variables that were not selected in some of the partitions are combined with the information of the other partitions to produce the final knowledge base.

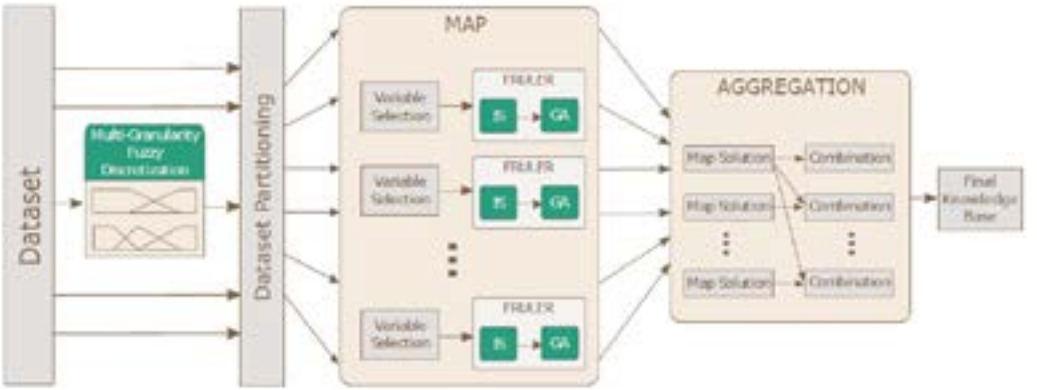


Figure 6.2. S-FRULER architecture.

6.3. MODELING THERMAL DYNAMICS IN BUILDINGS

Monte da Condesa comprises a set of centers that act as separate buildings, which nevertheless maintain thermal interaction through their conditioning circuits connected to a common cogeneration plant. The building is about 25,000 m^2 and reached in 2013 a total power consumption of 5,747 MWh. The set of all centers is supervised by a SCADA system that has 469 input and output variables that are associated with signals from the primary heating circuits and power consumption. Signals are collected in two different ways: synchronous (sync) and asynchronous (async). Synchronous signals are sequentially sampled at a fixed interval of 10 s, whereas asynchronous signals are registered by detecting a change of a value above a prefixed threshold. These signals include information about the indoor temperature of each floor, the outside temperature, the pumped water temperature of the heating systems, plus many other low level variables. All these signals can be used not only to monitor and control the building but also to predict the behavior of the system by observing its dynamics over time.

Predicting the dynamics of the building is useful to perform a smart adjustment of the heating systems based on the predicted state of the building. In this context, two goals have been set out in this project: 1) prediction of indoor temperatures for each floor, taking into account future weather predictions to improve the current heating control scheme; and 2) modeling of the thermal dynamics in the buffer tanks, which consist of a set of five hot water storage systems for Domestic Hot Water (DHW) that are directly affected by the operation of an electric generation system.

The implementation of the system also requires the update of the models over time, using the new collected data. This implies that, every year, the training set increases by 8,760 hours of new data, which makes it necessary to use scalable machine learning techniques to prevent the whole system suffering from scalability issues over time as the training set grows.

To achieve these goals, in this work we propose a method that automatically learns scalable, accurate and interpretable non-linear models using S-FRULER.

6.3.1. MODELS FOR INDOOR TEMPERATURE

In order to predict the indoor temperatures of each floor, we focus on the variables that may directly affect the temperature dynamics. These variables are represented in Fig. 3, which shows a high-level representation of the building. T^n_{in}, where n=[0,...,5], corresponds with the indoor temperature sensors of the building. Thus, there are 6 different sensors (T^0_{in},...,T^5_{in}), one for each floor, which are the response variables we aim to predict. Each floor is heated with hot water pumped from one of the two hot water pumps (Pump1 and Pump2). Pump1 corresponds with the status of the pump of the heating system that feeds both floors 0 and 1, whereas Pump2 corresponds with the status of the second pump that feeds the remaining floors. Note that, for the sake of clarity, in the following we will refer to Pump instead of Pump1 and Pump2, where Pump=Pump1 for floors 0 and 1 and Pump=Pump2 for floors from 2 to 5.

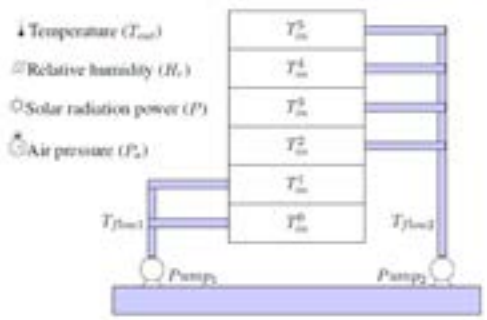


Figure 6.3. Schema of the Monte da Condesa residential college with the related variables.

In addition to these SCADA variables installed in the building, we also obtained the humidity (Hr), solar radiation power (P), and pressure (Pa) from Santiago-EOAS, a Meteogalicia [10] weather station situated approximately 100 meters from the building. These features give relevant information about weather conditions that may directly affect the indoor temperatures.

Moreover, the temperature (TMSout), relative humidity (HMSr) and pressure (PMSa) predictions are obtained from MeteoSIX [11], a Galician numerical weather prediction service that provides hourly predictions from the current day to four days in ahead. MeteoSIX predictions provide information about future weather conditions at a given instant of time.

Synchronous measures were downsampled to 1 h bins and asynchronous measures were converted into time series by applying linear interpolation and 1 h resampling. To summarize, the selected signals, sampled at 1 h interval (t) are:

- $T^n_{in}(t)$: indoor temperature at t of floor n (ºC, async.)
- $T_{out}(t)$: outside temperature at t (ºC, async.)
- Pump(t): binary status (1-on, 0-off) of the water heating pump at t (sync.)
- $H_r(t)$: relative humidity (%, sync., Meteogalicia)
- $P_a(t)$: global solar radiation power (W/m^2, sync., Meteogalicia)
- $P_a(t)$: air pressure (hPa, sync., Meteogalicia).

— $T^{MS}_{out}(t)$: outdoor temperature prediction (ºC, MeteoSIX).

— H^{MS}_{r} (t): relative humidity prediction (%, MeteoSIX).

— P^{MS}_{a} (t): air pressure prediction (hPa, MeteoSIX).

The variable Pump is one of the most important features of the model, since pumping hot water to the building has a direct impact on both the indoor temperature and the energy consumption.

Thus, this variable can be controlled to simulate different heating control schemes to maximize energy savings while keeping thermal comfort. For this purpose, we use the information of the previous 24 hours, but instead of using 24 binary features (1-Pump ON, 0-Pump OFF for each hour), we generate 4 features grouping the last 24 hours into 4 groups of 6 hours:

— $Pump^{0}(t)$: total ON hours from t to t-6.

— $Pump^{1}(t)$: total ON hours from t-6 to t-12.

— $Pump^{2}(t)$: total ON hours from t-12 to t-18.

— $Pump^{3}(t)$: total ON hours from t-18 to t-24.

We constructed a rule-based regression model with S-FRULER to predict each variable response Tnin(t,k), where n=[0,…,5] for different values of k (period lags).

6.3.2. BUFFER TANKS TEMPERATURE PREDICTION

In addition to the gas-fired boilers installed in the building that are used for heating water, the heating system also has a cogeneration system that provides thermal energy to the buffer tanks and produces electricity. The residual heat produced by the engine is transferred to a set of five buffer tanks. These tanks are used to store the hot water not used during periods where the electrical engine is working, so that it can be used later during periods of high demand (basically, heating and Domestic Hot Water (DHW) consumption). Predicting the thermal dynamics in the buffer tanks is important in order to draw a better schedule of the cogeneration operation.

Figure Fig. 4 shows the five buffer tanks. Each tank has three thermal sensors to monitor the water temperature at three different levels (lower, middle and upper positions). For this problem, only the upper and lower temperature is taken into account, since it is a reliable indicator of the available thermal energy in the tanks. Besides, the temperature in all tanks has a similar behaviour, so that we can consider Tuptank as the average upper temperature and Tlowtank as the average lower temperature.

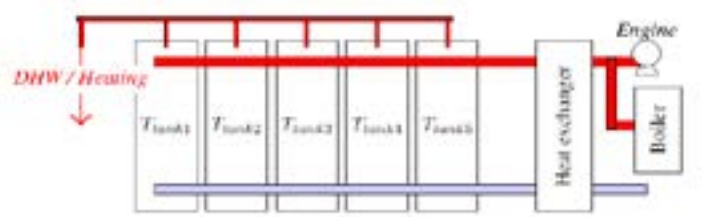


Figure 6.4. Buffer tanks and cogeneration engine schema.

In addition to the weather features used for predicting the indoor temperature, we selected the following features to be included in the final model:

— $T^{(up \mid low)}_{tank}(t)$: average upper or lower temperature at t (ºC, sync).

— DHW(t): estimated 24 hours of domestic hot water consumption, using the values of the previous week as an estimation (m3, async).

— Cog(t): cogeneration system status (1-ON, 0-OFF), (binary, async).

Cog(t), as in the case of the Pump(t) variable used in the indoor temperature models, is the control variable that can be used to optimize the cogeneration scheme. Cog(t) is also grouped into 4 groups of 6 hours:

— $Cog^0(t)$: total ON hours from t to t-6.

— $Cog^1(t)$: total ON hours from t to t-6 to t-12.

— $Cog^2(t)$: total ON hours from t to t-12 to t-18.

— $Cog^3(t)$: total ON hours from t to t-18 to t-24.

We constructed a rule-based regression model with S-FRULER using the features described above to predict the average T^{up} y T^{down}.

6.4.RESULTS

In this section we compare the performance of FRULER vs S-FRULER. We collected a total of 8,760 hours of training data from 2016-02-01 to 2017-01-31 for the indoor temperature models, and a total of 6,161 hours from 2016-05-19 to 2017-01-31 for the buffer tank models. For each run, the dataset was randomly divided into training (80%) and test (20%). Both FRULER and S-FRULER have been used with the default settings. In the case of S-FRULER, models were generated using the multithread mode with 8 threads.

6.4.1. INDOOR TEMPERATURE MODELS

We generated a total of 36 models, one for each k = [2,4,8,16,32,64]h and for each floor of the building, with 12 input variables, using both FRULER and S-FRULER. Table 1 and Table 2 show the RMSE, number of rules, and total time for each approach for the models of the floor 0 and 1 respectively.

As can be seen, FRULER always generates models with lower errors (~20% lower RMSE) but at expenses of a higher computational cost and complexity. In the worst case, FRULER takes 7h to generate a model of the floor 1 for k=8h (Table 2), using a total of 86 rules, which clearly goes against the interpretability goal. On contrast, S-FRULER is on average 12 times faster than FRULER using the same computer (all models were generated in less than 15 min) with rule bases that are 6 times smaller on average.

	FRULER			S-FRULER		
k	RMSE	#Rules	Time (s)	RMSE	#Rules	Time (s)
2h	0.27	53	4781	0.32	6	687
4h	0.41	25	9074	0.45	11	708
8h	0.54	21	8247	0.69	5	581
16h	0.60	24	8681	0.78	4	699
32h	0.70	21	9408	0.85	2	698
64h	0.75	15	2159	0.96	6	724

Table 6.1. Indoor temperature models for floor 0.

	FRULER			S-FRULER		
k	RMSE	#Rules	Time (s)	RMSE	#Rules	Time (s)
2h	0.26	39	8432	0.33	6	913
4h	0.42	33	9122	0.49	9	810
8h	0.55	86	25212	0.72	6	786
16h	0.71	13	4552	0.78	4	826
32h	0.77	54	6234	0.87	6	800
64h	0.84	37	11967	1.01	16	839

Table 6.2. Indoor temperature models for floor 1.

6.4.2. BUFFER TANK PREDICTION MODELS

In this case, we generated two types of models: one for the average temperature of the upper part of the tanks (Table 3) and the other for the lower part (Table 4), using in total 13 input variables. Again, we observe a similar behavior as in the case of the indoor temperatures. Errors are again larger for the models generated with S-FRULER (~25% larger), but using much smaller rule bases (4x smaller on average) and much faster (7x faster on average). Fig. 5 shows an example of the predictions for the upper and lower temperatures, using up to 64h of simulations, starting at different times.

	FRULER			S-FRULER		
k	RMSE	#Rules	Time (s)	RMSE	#Rules	Time (s)
2h	2.36	3	1259	2.45	2	480
4h	2.72	6	2693	3.78	4	560
8h	3.69	16	3376	4.45	6	535
16h	3.89	16	2285	4.61	12	506
32h	4.72	23	2430	6.10	12	505
64h	4.96	48	3423	6.08	4	532

Table 6.3. Lower tank temperature models.

	FRULER			S-FRULER		
k	RMSE	#Rules	Time (s)	RMSE	#Rules	Time (s)
2h	2.23	8	2333	2.27	6	448
4h	2.45	12	2450	3.16	6	464
8h	2.83	30	5704	4.31	4	456
16h	3.69	24	2721	4.57	6	440
32h	3.91	19	5974	5.32	3	430
64h	3.77	21	5174	4.98	6	485

Table 6.4. Upper tank temperature models.

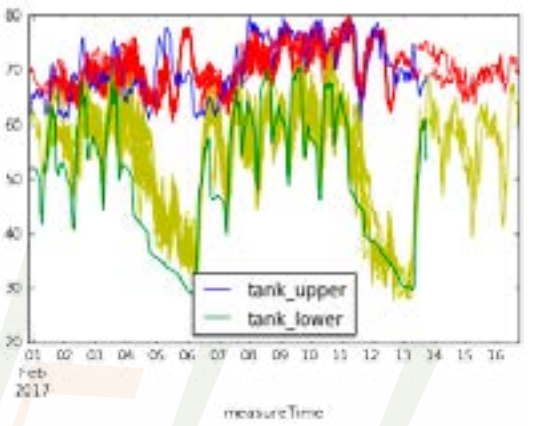


Figure 6.5. Multiple predictions of 64h (red, yellow) over a period of 16 days for upper/lower temperatures in tanks.

6.5. CONCLUSIONS

We developed a novel approach for modeling the thermal dynamics of buildings using the information of different sensors to automatically generate a knowledge base of fuzzy rules for regression. To do so, we focus on Monte da Condesa, with 469 sensors that provide information of the different parts of the system. One of the main issues is the generation of interpretable and accurate fuzzy models in reasonable time, given the large amount of data generated in the building, a problem that is going to grow year after year as more information is available. This requires the use of scalable techniques to be able to cope with the increase in complexity. For this purpose, we used S-FRULER, a distributed algorithm for learning fuzzy rules that can scale with the size of the problem, and we compare its performance against FRULER, the original non-distributed version of the algorithm. Results proved that S-FRULER clearly improves FRULER in terms of number of rules and runtime, obtaining rule bases 6 times smaller on average and an average speed-up of 11.7, with only a 21% increase of the average RMSE

Chapter 7

Monitoring of The Environmental and Economic Impacts

Gerardo Rodríguez Vázquez
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Iago Rodríguez Cabo
José A. Taboada González

This chapter aim is to explain the procedure and the methods used to monitor the environmental and economic impacts of the OPERE, to check the final achievement of the initial proposed goals.

The IPMVP protocol has been used to calculate the savings. It establishes a base reference and performs the necessary actions to estimate the savings after the implementation of energy efficiency improvements.

7.1 AIM OF THE MONITORING OF ENERGY, ENVIRONMENTAL AND ECONOMIC IMPACTS OF THE MANAGEMENT SYSTEM IMPACTS

The aim of the monitoring of the energy, environmental and economic impacts is to provide information about the energy and economic parameters of a facility, building or industry to optimise the energy consumption management.

— The provided information is the base of the energy efficiency and also used to accomplish studies and reports related to it, as well as to make decisions linked to energy improvements in the facilities.

It must be underlined that the results obtained from the monitoring of an environmental impact also allow:

- Improving the way of consuming energy the location and breakdown of consumption help to know the energy demand: who are the main energy consumptions, so it allows to use energy demand management systems in an individual way.
- Consumption sectorisation and performance of comparative studies between the different buildings of the Monte da Condesa and between this and other buildings of the USC.
- Adjusting the contracted power and the period of use to get the maximum savings in the bill.
- The detection of inefficiencies in the consumption system such as unintended latent consumptions, after setting hours consumption, incorrect functioning of the system, detection of deviations in the expected energy performances.
- The improvement of the maintenance system through a quick detection of problems and also of the implementation of corrective measures.
- The accomplishment of energy audits, as well as the implementation of measures to manage the demand.

In the particular case of the OPERE project, monitoring has a clear goal: setting the base of energy consumption and costs to calculate the obtained savings after the implementation of energy efficiency actions.

7.2 SELECTION OF MONITORING INDICATORS

The aims of the OPERE project, include the implementation of methods and rationalization of energy expenses, the reduction of combustible consumption, and reduction of greenhouse gases. However, in order to check the efficiency of the used methods, it was necessary to define a system of indicators to determine the degree of coverage of the set goals. In this case, it was determined that the system of indicators must fulfill five of the requirements for the “SMART” indicators.

Figure 7.1. “SMART” Indicators.

— Specific: they must concretise exactly what is intended to be achieved, without ambiguities.

— Measurable: they can be quantified to determine if they are performing properly.

— Achievable: they must be reachable (by specific resources and capacities)

— Relevant: they must be suitable to measure a particular goal.

— Time bound: they must specify a deadline to get the goal.

According to these premises, the OPERE Project defined the system of indicators described in the Figure 7.2

Figure 7.2 OPERE Indicators System

The monitoring consists of a set of environmental indicators which provide information related to the achievement of the goals set for the Project. All this information is linked to energy consumption, and reduction of CO_2 emissions and economic indicators, which provide information about the achievement of the set economic savings.

7.1.1 MONITORING INDICATOR UNITS

Regardless of the units in which different indicators are registered, it is necessary to perform some conversions to unify the indicators with the units used to calculate the impacts of the Project, which are:

— Final Energy (kWh)

— CO_2 (tons): tCO_2.

To express the combustible consumption (diesel C, natural gas) in kWh of final energy, the following conversion factors (published by the IDAE guide, a public Spanish institution depending on de Ministry of Industry, Tourism and Trade) have been used:

	Calorific Power	
Combustible	Low (PCI)	Superior (PCS)
Diesel	10,28 kWh/L	10,89 kWh/L
Natural Gas	10,83 kWh/Nm^3	11,98 KWh/Nm^3

Table 7.1.Calorific power (low and superior) of the combustible used in the Project.

The following coeffiecients have been used or calculate the CO_2 emissions from energy consumption, as showed in the table:

Coefficient to Transform Final Energy into CO_2 Emissions		
Natural Gas	252	gr CO_2/kWh
Diesel C	311	gr CO_2/kWh
Conventional Electric Power	357	gr CO_2/kwh

Table 7.2. Coefficient to Transform Final Energy into CO2 Emissions (with the Project's Combustible).

7.3 MONITORING OF INDICATORS

7.1.2 MEASURING PERIODS

The monitoring process of the indicators must be performed in specific time perdiods in order to analyse the impact of the implementation of Energy Management Measures (EMMs). In this way, the measuring periods are fixed like that:

- Reference or Base Period → Before the implementation of EMM.
- Optimised or Demonstrative Period → After the implementation of EMM.

In the case of the OPERE project, considering that the implementation of the measures took place between July and October 2015, these are the set measuring periods:

- Base Period: July 2014 – June 2015
- Demonstrative Period: November 2015 – October 2016

The base period has been set in the dates immediately preceding the implementation of the energy management measures (EMM). As far as the demonstrative period is concerned, this starts once the start-up and setting of the new systems is performed.

Every selected period lasts 12 months. This selection is due to the demand variations experienced by the building because of internal (occupancy, schedules, holidays…) and external (temperatures…) variations. In this way, the complete building operating cycle is being taken.

The registraton of indicators has been monthly performed during the complete project.

7.1.3 ENVIRONMENTAL AND MONITORING INDICATORS IN REFERENCE PERIOD

During the reference period, the data and indicators corresponding to the monitoring of the environmental and economic impact are obtained from physical meter boxes in the energy systems and are registered and treated to be later analysed.

It must be underlined that even though the Universidad of Santiago de Compostela already had a SCADA system during this period, this only provided instant data of the collected variables. It did not allow to add results, so they cannot be used to obtain indicators with a monthly frequency, as the Project requires.

The indicator related to the total energy consumption is obtained from the sum of the eight analogue meter boxes of every single sector or centres (Optics, residence, dining room, common services, Hemodonation, Physics-Archeology and Pottery).

The data linked to diesel consumption are collected by the five meter boxes in the boilers: those from the Hemodonation Centre (heating and HDW), Optics-Physics School and University Residence 2. It must be highlighted that the data related to the Hemodonation building are not included as it is not included in the OPERE Project.

Figure 7.3. Optics/Physics Diesel Meter Boxes

Figure 7.4. Diesel Meter Boxes Residence 1 and 2

The natural gas and electric/thermal power consumption indicators are monthly provided by the company in charge of the system maintenance.

The economic indicators during the base period are obtained from energy billing data of the USC. The following considerations have been taken in to account in every indicator:

- If there are more than one energy price for a same period (electricity), the energy consumption and the Price for every pricing period has been averaged for the same periods.
- If there are a fixed and a variable concept in the energy bill (natural gas and diesel), the only element considered is that linked to consumption.
- The special tax on hydrocarbons (natural gas and diesel) and electricity while VAT was excluded..

On the other hand, the CO_2 emission indicator is obtained from the implementation of the coefficients mentioned in the section 7.1.1. The CO_2 emissions include those related to thermal (boilers) and electricity (cogeneration) generation.

As a result of the monitoring of the different analysed variables, it is obtained a set of data linked to environmental and economic indicators in the reference period:

	Natural Gas Consumption (cogeneration)	Diesel C Consumption (boilers)	Electricity Consumption	Generated Electricity	Generated Thermal Energy	CO_2 Emissions
Month	m^3	litros	kWh	kWh	kWh	tCO_2
Jul.-14	23.417	4.146	33.150	82.924	20.300	70,95
Aug.-14	0	6.141	28.560	0	0	18,41
Sep.-14	22.722	4.185	34.510	78.927	18.200	75,59
Oct.-14	24.120	7.003	41.720	84.780	37.500	87,05
Nov.-14	23.981	13.616	41.650	85.171	62.200	103,12
Dec.-14	20.628	16.190	36.590	74.859	63.200	104,51
Jan.-15	15.327	20.889	36.090	56.388	45.900	112,09
Feb.-15	23.062	18.838	37.730	84.782	67.800	124,97
Mar.-15	24.141	17.766	40.700	89.598	69.500	116,31
Apr.-15	21.834	10.252	36.560	80.289	42.400	86,81
May.-15	23.114	6.995	37.880	84.912	35.600	83,07
Jun.-15	22.524	3.322	31.910	79.768	24.800	75,45

Table 7.3. Environmental Indicators in The Reference Period.

It must be underlined that -in August- the building's generation system is not operating, this is why the data related to gas consumption and thermal and electric energy generation are 0.

The total amount of monitoring data collected during the reference or base period are showed in the following table:

	Electricity Price	Natural Gas Price	Diesel C Price
Months	€/kWh	€/kWh	€/litro
Jul.-14	0,131	0,046	0,697
Aug.-14	0,072	0,075	0,697
Sep.-14	0,096	0,046	0,719
Oct.-14	0,081	0,041	0,719
Nov.-14	0,085	0,041	0,719
Dec.-14	0,102	0,041	0,589
Jan.-15	0,106	0,041	0,589
Feb.-15	0,109	0,041	0,566
Mar.-15	0,085	0,041	0,543
Apr.-15	0,081	0,041	0,547
May.-15	0,080	0,041	0,547
Jun.-15	0,104	0,042	0,547

Table 7.4. Economic Indicators in The Reference Periods

7.1.4 ENVIRONMENTAL AND ECONOMIC MONITORING INDICATORS IN THE DEMOSNTRATIVE PERIOD

During the demonstrative period, the data were collecting following the same guidelines set in the reference period, although the reform accomplished in the MdC building facilities and the implementation of the monitoring system allow to get a set of improvements, which are later detailed.

Figure 7.5. Energy Meter Boxes

After the reform, the diesel consumption indicator is not considered anymore while the natural gas consumption indicator of the boilers (m3) is included. It must be underlined that, in regard to this last indicator, that besides the on-site data collection, the database developed in the Project is also checked as it registers and stores 303 real-time variables. The new monitoring allows a lower uncertainty in its values, as it covers the whole real month, from 0.00 h of the first day to the 24.00 h of the last one. This is why data will be collected from the data base to get higher accuracy.

Other important aspect to be mentioned, as seen in the Chapter 5, is the installation of seven thermal energy meter boxes, one in the boiler room and the others in the tanks room, one for every section of the complex (Residence, Blood bank, Physics Faculty B4, Physics Faculty B5 and Optics Faculty) together with a hot domestic water recirculation meter box that allows to control the real of the HDW system. These are one of the most favourable novelties added to the new facilities as, although their results are not included as monitoring system results, they are monthly collected in order to -according to what was explained in the Chapter 5-get a better knowledge of the complex sectorised performance.

As far as the cogeneration system is concerned, it must be highlighted that the implementation of EMM has allowed to install thermal energy meter boxes to control the cogeneration heat recovery in order to check the total heat which is actually being used with the engine heat dissipation and the cogeneration engine recovery. Data are also being obtained from the monitoring system of the Project. However, it is still using the operation set in the base period.

The environmental and economic indicators collected during the demonstrative period are showed in the following tables:

	Natural Gas Consumption (cogeneration)	Electricity Consumption	Electricity Consumption	Generated Electricity	Generated Thermal Energy	CO_2 Emissions
Date	m^3	m^3	kWh	kWh	kWh	tCO_2
Nov.-15	22.626	8.810,50	39.170,00	82.650	49.600	85,80
Dec.-15	22.203	8.402,50	37.085,00	81.780	74.100	82,79
Jan.-16	19.474	8.573,20	37.316,67	72.780	78.000	75,79
Feb.-16	23.463	8.686,20	36.947,50	88.062	94.300	88,56
Mar.-16	19.967	11.195,40	37.236,00	74.732	81.600	84,06

Apr.-16	19.146	9.482,90	37.405,00	70.309	75.200	25,88
May.-16	17.573	4.222,20	37.840,00	63.868	59.000	59,11
Jun.-16	8.475	602,9	38.718,00	30.511	23.100	24,78
Jul.-16	7.387	342,5	38.826,67	25.893	21.800	21,06
Aug.-16	0	1.272,60	37.816,50	0	0	3,36
Sep.-16	8.386	720,6	38.705,91	29.515	26.000	24,85
Oct.-16	11.742	1.823,40	39.700,42	41.589	44.400	37,02

Table 7.5. Environmental Indicators of the Demonstrative Project

	Electricity Price	Natural Gas Price	Diesel C Price
Month	€/kWh	€/kWh	€/litro
Nov.-15	0,089	0,04	0,493
Dec.-15	0,109	0,04	0,433
Jan.-16	0,109	0,04	0,376
Feb.-16	0,112	0,04	0,363
Mar.-16	0,091	0,04	0,421
Apr.-16	0,084	0,04	0,431
May.-16	0,084	0,04	0,441
Jun.-16	0,11	0,04	0,485
Jul.-16	0,122	0,04	0,458
Aug.-16	0,076	0,04	0,458
Sep.-16	0,068	0,02	0,461
Oct.-16	0,061	0,022	0,48

Table 7.6. Economic Indicators of The Demonstrative Period

7.4 ANALYSIS OF THE ENVIRONMENTAL AND ECONOMIC INDICATORS EVOLUTION

The graphs showed below are the result of the different pilot building's indicators evolution, both in the reference and in the demonstrative period. In this way, the evolution of consumptions can be observed, as well as the production of the cogeneration system.

The chronological framework of the Project will enable a better analysis. Therefore, the data on the left are corresponded to the implementation of the EMM. From July to October 2015, the EMM implementation is performed and, finally, the demonstrative period is also represented.

As far as the evolution of the electricity consumption is concerned, it must be mentioned that there are not any important change in the consumption pattern, as the OPERE Project has not the goal of influencing this variable.

Figure 7.6. Evolution of Electricity Consumption

In everything linked to the combustible consumption during the Project, there are two different sides: the combustible used by boilers and the combustible used by cogeneration:

- It is observed that the boiler consumption is considerably reduced after the implementation of improvements in the boiler room.
- As far as the natural gas consumed by the engine is concerned, it follows a similar trend, as the system demands are not determined by the energy needs of the pilot building but by the energy demands of the Campus Vida. Thus, the activities developed by the OPERE Project do not affect this parameter. However, the total cogeneration hours during the demonstrative period were lower than the base period, what justifies the slight reduction in natural gas consumption for cogeneration.

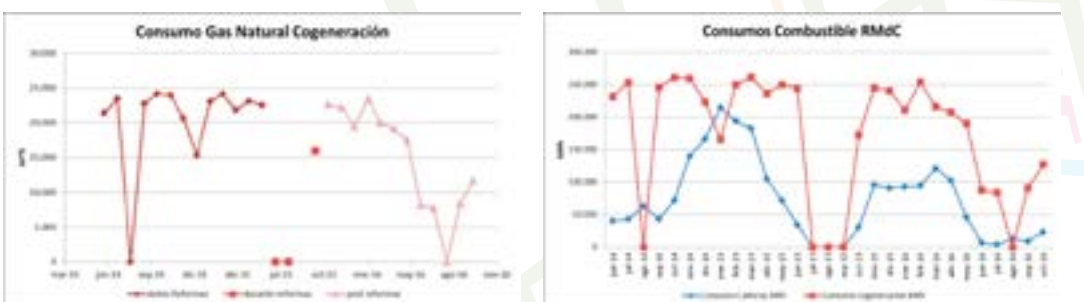

Figure 7.7. Evolution of natural gas cogeneration (left) and evolution of combustible consumption (right)

Regarding CO_2 polluting emissions, it can be appreciated the evolution registered along the Project's useful lifetime, a monthly important reduction of the registered values as a result of the implemented measures to reduce emissions, as it is showed in the following table:

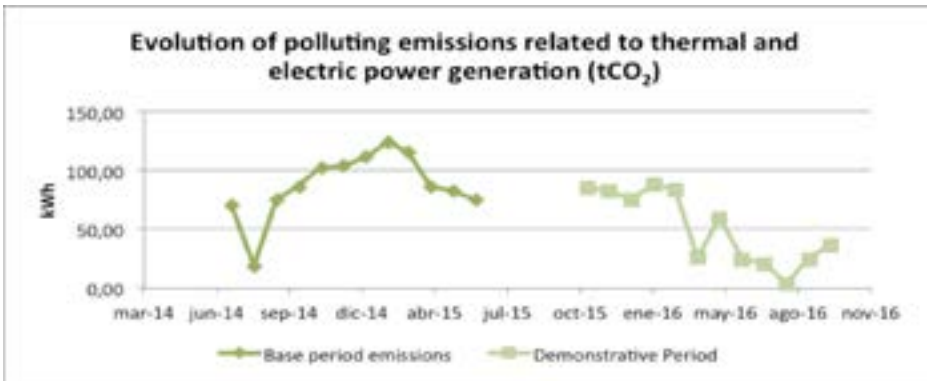

Figure 7.8. Evolution of polluting emissions related to thermal and electric power generation

Finally, Figure 7.9 summarizes the evolution of prices of electricity, natural gas and diesel, so that while the former have remained stable over time, the evolution of diesel prices have been affected by a significant fall Throughout the analyzed period of time.

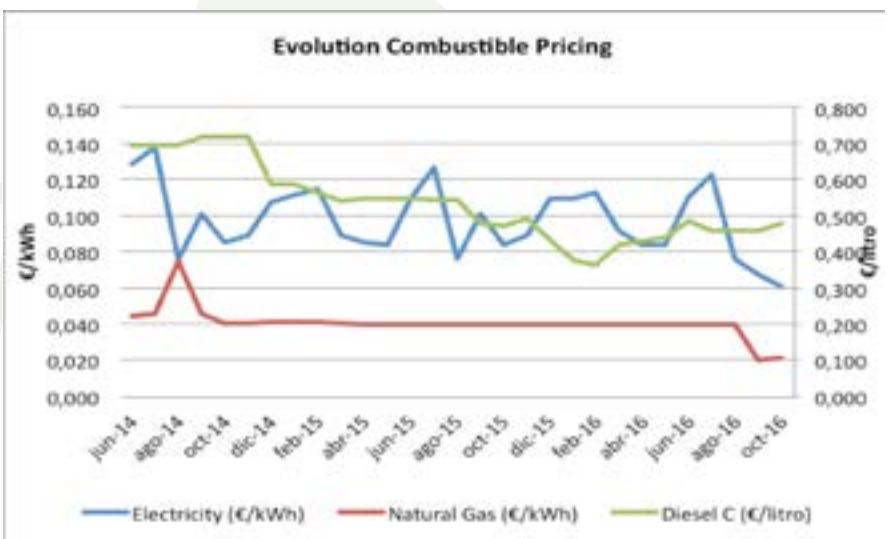

Figure 7.9. Evolution Combustible Pricing

7.5 SAVINGS MEASUREMENT AND VERIFICATION

Energy saving cannot be measured in a direct way, as it represents the absence of consumption, so it has to be estimated by comparing the consumption before and after the implementation of the energy efficiency project.

To do it, it is necessary to set a reference or base period that allows to establish a reference on the energy consumption, a demonstrative period, with the same length. It will represent the obtained savings after the implementation of the energy efficiency improvements and, with some settings, it will also allow to update the new values collected during the demonstrative period (reference line setting).

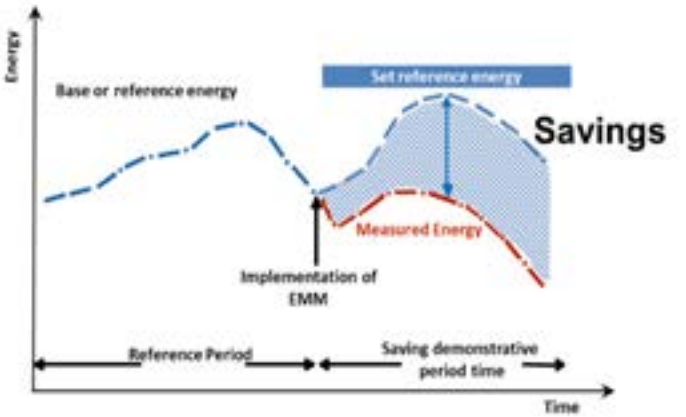

Figure 7.10. Process to determine energy saving or avoided consumption in an energy system before and after the implementation of an energy efficiency improvement. Source: EnergyLab.

The previous figure, shows the above-mentioned procedure, it can be seen how the reference power and the reference period measuring are adapted to the conditions required by the demonstrative period in order to get an accurate reference line from which energy savings can be estimated.

The part of a project which explains the procedure and results of calculation of the savings in an energy efficiency project is characterized by the implementation of a savings measuring and verification plan. There exist different protocols to measure and verify. In this case, the chosen option is the International Performance Measurement & Verification Protocol (IPMVP), created by Efficiency Evaluation Organization (EVO).

The IPMVP presents a set of common principles and terms that are accepted as a base for the correct process of measuring and verification. It relies on international credibility and t has been adopted by numerous public and private institutions to ease the management of their energy and environmental efficiency programmes, as it guarantees veracious results.

In the case of OPERE Project, the implemented alternative is the Option C of the IPMVP Volume I, EVO 10000 – 1:2007 to determine savings. This option is the most suitable when the energy consumption of the whole system during the reference and demonstrative periods, as in the case of the OPERE Project.

In this way, and, as previously mentioned, the calculation of savings in the OPERE Project is performed according to the IPMVP, Option C, by the application of the following formula:

Energy Savings= (Reference Period Energy – Demonstrative Period Energy) ± Settings

Through this equation and the application of the settings, which will be explained later, the consumption in the reference and demonstrative period are analysed under similar conditions.

7.1.5 INDEPENDENT VARIABLES

The independent variables considered to explain the variation in the energy consumption (dependent variable) will be climatic variables.

As obtaining data is difficult, the option of including the occupancy in the university residence has been discarded.

In the case of university offices, the occupancy of the building cannot be included as an independent variable, as it is difficult to get reliable data and given that the goodness of the proposed fit has been proved.

The consideration of the average monthly temperature (registered by the nearest meteorological station, in the USC facilities) as an independent variable is a great alternative in the use of a climatic variable.

These climatic data, the source of information will be the website of meteorological service provided by the local government, Xunta de Galicia (www.meteogalicia.es).

7.1.6 BASE REFERENCE LINE

The energy base will be the quantitative reference that provides the energy consumption basis of comparison, using it to calculate the energy savings as a reference after anfd before the improvement actions on energy efficiency.

— Reference Period:
  - As the established in the Coincide Section 7.1.1.Measuring Periods
  - Compilation of the average monthly temperatures.
  - Obtaining the energy base line from the monthly diesel consumption and the average monthly temperatures. The result will be a mathematical equation which establishes a relationship between the building consumption and the average monthly outdoor temperature.

— Savings Demosntrative Period:
  - As the established in the Chapter 7.1.1. Measuring Periods.
  - Compilation of average monthly temperatures.
  - Calculation of the diesel consumption values that would have been obtained without the implementation of energy efficiency improvements related to the OPERE Project.

— The indicator monitoring methods performed by the USC is explained in the sections 7.1.2 and 7.1.3.

7.1.7 CALCULATION OF ENERGY SAVINGS

As mentioned in the previous section, the calculation of energy savings will be performed by the comparison before and after the implementation of measures related to the energy management Project. The steps to do it are described below:

— The energy base line for boiler consumption can be obtained from the building consumption and the average outdoor temperatures history,using a calculation sheet (Microsoft Excel, in this case):

	Average Temp.	Diesel Boiler Consumption
Month	ºC	L
Jul.-14	18,6	4.146,29
Aug.-14	17,9	6.141,46
Sep.-14	18,8	4.184,67
Oct.-14	16,6	7.002,53
Nov.-14	11,2	13.616,40
Dec.-14	8,6	16.189,55
Jan.-15	8,0	20.889,10
Feb.-15	7,3	18.838,45
Mar.-15	10,1	17.766,42
Apr.-15	13,6	10.252,17
May.-15	14,7	6.994,58
Jun.-15	18,5	3.322,41
Total	13,7	129.344,02

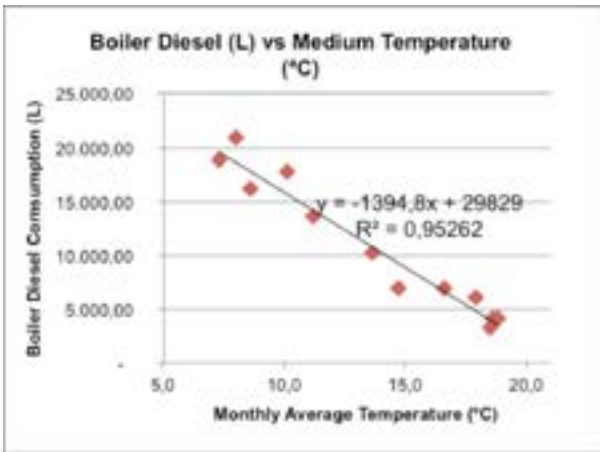

Table 7.7. Getting the consumption base from diesel monthly consumption (L) and average monthly outdoor temperature (ºC)

— The goodness of the performed fit is proved through the determination coefficient R2: This statistical parameter shows the degree of relationship between the dependent variable (energy consumption) and the independent one (average monthly outdoor temperature in the studied location).

— Its value is between 0 and 1 (0 shows that there is no relationship between the variables and 1 shows that their relationship is perfect), so variables $R^2 > 0,75$ will be acceptable.

— If the miniminum values were not reached, it would mean that the energy consumption does not totally depend on the weather conditions but on other variables such as occupancy, random equipment management, malfunctions and another variable which cannot be simply quantified.

— As the performed fit is suitable, the average monthly temperature is the only variable chosen so other variables are discarded, in spite of being interesting, as they would increase the M&V costs without showing any improvement in the results. E.g.: degrees/day in heating, university residence occupancy, etc.

— From the data related to the average monthly temperatures, after the implementation of the energy efficiency measures of the OPERE Project and mathematical equation that defines the energy base line, the reference consumption (that would had existed without the mentioned energy efficiency measures) can be obtained:

	Average Temp.	Boiler consumption adjusted
mes	ºC	L
Nov.-15	12,8	11.975,56
Dec.-15	11,7	13.509,84
Jan.-16	9,8	16.159,96
Feb.-16	8,8	17.554,76
Mar.-16	9,1	17.136,32
Apr.-16	10,4	15.323,08
May.-16	13,8	10.580,76
Jun.-16	17,0	6.117,40
Jul.-16	20,2	1.654,04
Aug.-16	20,4	1.375,08
Sep.-16	18,0	4.722,60
Oct.-16	15,1	8.767,52
Total	13,9	124.876,92

Y =-1394,8x+29829

Tabla 7.8. Consumption of diesel adjusted for the demonstration period

— Through the mentioned procedure and using the fuel conversion factors specified at the end of the section 7.2 Selection of Monitoring Indicators, it is possible to adapt the boiler consumption in the reference period to the savings demonstrative period. The results are showed in the following graph:

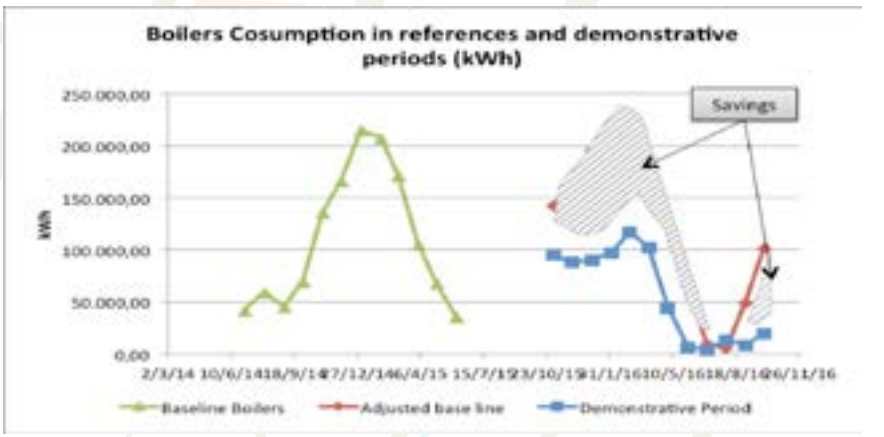

Figure 7.11. Energy savings linked to thermal generation

7.6 SUMMARY OF THE ENVIRONMENTAL AND IMPACTS ON THE OPERE PROJECT

The Chapter 1 showed the main results expected form the OPERE project, that, from a economic and environmental point of view, are summarised in the same way:

— Reduction of 30% in energy consumption linked to thermal generation.

— Reduction of 35% of polluting emissions associated with electricity and thermal generation and consumption.

— 35% of economic savings that allow to accomplish an analysis on the profitability of the implementation of energy management systems in other centres with huge cconsumptions, different to this project.

According to the impact indicators monitoring methods and the savings verification methodology, presented in the previous chapters, the following impacts of the project, which fullfill project's aims, both in relative and absolute values, appeared as a result:

7.1.8 REDUCTION IN ENERGY CONSUMPTION

The calculation of the following indicator includes the final energy consumption in kWh associated with the thermal generation of heating and HDW in the OPERE complex, before and after the implemented improvements.

Thus, the previous calculation on considers the boiler consumption before and after being renovated.

The resulting savings are showed in the following table:

Indicator	Objective	Result	Fulfillment (%)
Reduction of Consumption Associated with Thermal Generation	30%	53%	177%
Reduction of Consumption Associated with Thermal Generation (kWh)	200.000 kWh	785.345 kWh	393%

Tabla 7.9. Summary of energy indicators in the OPERE project.

The achieved saving is very significant and can be justified with the improvements in the thermal generation room of the Monte da Condesa building.

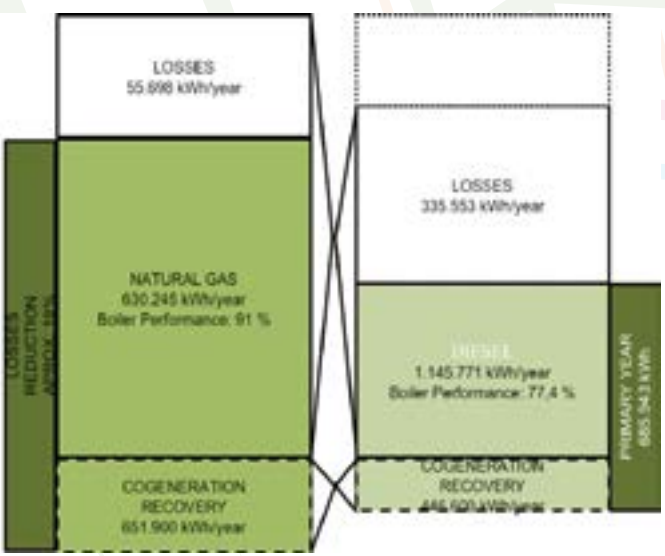

Figura 7.12. Ahorro energético proyecto OPERE.

The following conclusions can be obtained from the Figure:

- The reduction of 53% in energy consumption linked to thermal generation (boilers) is explained, mainl, because of the improvement of the seasonal performance of the new natural gas condensation boilers, which improve from values next to 77% to around 91%.
- The installation of buffer tanks as well as the rest of improvements performed on sectorisation, pumping and control, allow an increasement in thermal use of cogeneration (46%), from 446,600 kWh to 651,900 kWh, even with less cogeneration functioning hours in the demonstrative year
- The improvement in the system's performance as well as the better control and management obtained from the new energy management system, justify the additional reduction of 19% in final energy consumption. This includes the reduction of losses related to the system's performance, getting a thermal generation adapted to the final demand in the OPERE complex.

The previous graph is the result of the settings improved during the saving measuring and verification phase, adapting energy consumption in the reference period to the weather conditions in the demonstrative period.

7.1.9 REDUCTION OF POLLUTING EMISSIONS

In regard to polluting emissions linked to thermal generation, the project's impact are showed in the following table:

Indicator	Goal	Result	Fulfillment (%)
Reduction of Polluting Emissions Linked to Electricity and Thermal Generation (%)	35%	35%	101%
Reduction of Polluting Emissions Linked to Electricity and Thermal Generation (tCO_2)	150 tCO_2	337 tCO_2	224%

Table 7.10. Impact of OPERE project on polluting emissions.

The impacts linked to polluting emissions include those associated with thermal and energy generation, so they are also linked to boiler and cogeneration fuel.

The goals fulfillments related to the reduction of polluting emissions is due to the improvement of the emissions coefficient generated by the boiler's fuel replacement and also to the reduction in the energy consumption in the boiler thermal generation (see previous section).

7.1.10 PROJECT'S ECONOMIC SAVINGS

Finally, the economic impacts of the improvement measures implemented in the OPERE Project are also analysed.

The study about economic savings includes the reduction in hand operating cost regarding the initial solution. The considered cost elements are the following:

— Fuel costs of thermal and power generation: boiler consumption and cogeneration engine.

— Electricity supply costs according to the building's demand.

— Cogeneration maintenance costs.

— Electricity generated by cogeneration, which are considered as negative cost, as cogeneration injects this power into the USC ring network, otherwise, it would be supplied by distributing company, at market price.

So the equation to calculate operational costs, both for reference and demonstrative periods, in a yearly calculation is the following:

Operational Cost (€) = Cogeneration Combustible (€) + Boiler Combustible (€) +Electricity Demand (€) - Cogenerated Energy (€) + Maintenance Costs (€)

As a consequence, and after the application of the previous equation on the indicators collected by the Project, we get the following table, which summarises economic savings obtained from the implementation of energy efficiency improvements and the installation of the energy management system accomplished in the OPERE Project:

Indicator	Goal	Result	Fulfillment (%)
Operational Costs Savings Regarding The Initial Situation	35%	21,0%	60%
Economic Savings €/year	15.000,00 €	26.264,40 €	175%

Table 7.11. Impact on the operative costs of OPERE Project.

It is proved that, although economic savings are under the initial expectations, regarding savings percentage values; the reduction of operational costs in the USC is higher than expected, if savings are considered in total values

The main obstacle to get the goal value related to cost saving is the experienced reduction of heating diesel prices, as it is mentioned in the section 7.4 Analysis of The Environmental and Economic Indicators Evolution. In this way, the price of diesel changes -during the reference period- from an average price of 0.623 €/l, to an average price of 0.442 €/l in the demonstrative period. This price reduction of 29 % in the diesel prices is much more significant than the one suffered by electricity and natural gas (6% and 17%), respectively. Therefore, and given that the costs saving is calculated with demonstrative the prices of the demonstrative price, savings are quite lower than the one obtained if the prices would not have been reduced after the reference period.

— If savings are calculated with the prices of the reference period, economic savings would reach 29 %.

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